Biosorption of Cr (III) from Aqueous Solutions Using Bacterium Biomass *Streptomyces rimosus*

Sahmoune, M.N.[1*], Louhab, K.[1] and Boukhiar, A.[2]

[1]Laboratoire Matériaux, revêtement et environnement (LMRE), Faculty of Science of the engineer, University of Boumerdes, 35000- Boumerdes, Algeria

[2]Département technologie alimentaire, Faculty of Science of the engineer, University of Boumerdes, 35000- Boumerdes, Algeria

ABSTRACT: In the present investigation, dead bacterium biomass *Streptomyces rimosus* was used as an inexpensive and efficient biosorbent for Cr (III) removal from aqueous solution. The bacterial biomass was treated with 0.1 M NaOH. Sorption level of 65 mg/g was observed at pH 4.8 while precipitation effect augmented this value at higher pH range. Chromium desorption increased with decreasing desorption agents pH (including HCl and H_2SO_4) to a maximum value of 95% at approximately zero pH. Langmuir, Freundlich and Temkin models were applied to describe the biosorption isotherm of the metal ions by *Streptomyces rimosus* biomass. Langmuir model fitted the equilibrium data better than the Freundlich isotherm. Maximum metal uptake q_{max} was observed as 83.33 mg g^{-1} indicate good biosorbents than other biomass. Experimental data were also tested in terms of biosorption kinetics using fractional power, Elovich, pseudo-first order and pseudo-second order rate expressions. The results showed that the biosorption processes followed well pseudo-second-order kinetics and the intra-particle diffusion is not the rate-limiting step for the whole reaction.

Key words: Biosorption, Chromium (III), Isotherms, Kinetics, *Streptomyces rimosus*

INTRODUCTION

Trivalent chromium is evacuated to the environment by the effluents of a large number of industries such as mining, iron sheet cleaning, chrome plating, leather tanning and wood preservation (Krishna & Philip, 2005). The maximum levels permitted in wastewater are 5 mg/l for trivalent and 0.05 mg/L for hexavalent chromium (Richard and Bourg, 1991). Although chromium (III) is an essential element, it can be toxic at elevated concentrations in the environment. Cr (III) is selected instead of Cr (VI) because of following facts Cr (III) is toxic if excess quantity is taken and cause abnormalities in organisms. Chromium (III) sulphate salts are mainly used in tanning (Mant *et al.,* 2005).

The removal of chromium employing conventional methodologies (Tiranvanti *et al.,* 1997) like ion exchange, chemical precipitation or reverse osmosis suffer from limitations like high operating cost, incomplete precipitation, sludge generation, etc. On the other hand biosorption is receiving increasing attention as an emerging technology for the removal of heavy metals from contaminated effluents (Kumari *et al.,* 2006). The process is based on the adsorption behaviour of certain biological materials towards organic or inorganic substances from their solution.

Fungal biomass and seaweed biomass have been found to be excellent biosorbents for sequestering heavy metals (Lewis and Kiff 1988, Holan and Volesky 1994, Volesky and Holan 1995).

*Corresponding author E-mail:sahmoune63@yahoo.fr

Fungal biomass has been used to sequester copper, lead, zinc, nickel, cadmium, gold, silver and various actinide elements, such as thorium, uranium and plutonium (Tsezos and Volesky 1981, Gadd and White 1989, Luef *et al.,* 1991, Kapoor and Viraraghavan 1995, Meyer and Wallis 1997, Kapoor and Virraghavan 1998).

Streptomyces rimosus, mycelial bacterium is classified Gram-positive. In general, Gram-positive bacteria have a greater sorptive capacity due to their thicker layer of peptidoglycan which contains numerous sorptive sites (Van Hullebusch *et al.,* 2003).Metal removal treatment systems using micro-organisms is a cheap and practical alternative to conventional processes, since low cost sorbent materials are used. Micro-organisms based technologies must compete with both operational and economical terms in existing metal removal treatment systems. Non-living biomass appears to present specific advantages in comparison to the use of living micro-organisms (Öztürk *et al.,* 2004).

The objective of the present work is to investigate the biosorption potential of *Streptomyces rimosus* biomass in the removal of Cr (III) ions from aqueous solution. An optimum biosorption condition was determined as a function of pH. The Langmuir, Freundlich and Temkin models were used to describe equilibrium isotherms. Various kinetic models were tested to describe the sorption data and desorption processes were also investigated to facilitate metal recovery.The study of adsorption dynamics describes the solute uptake rate. This rate controls the residence time of adsorbate uptake at the solid solution interface. The kinetics of chromium biosorption on dead biomass were analyzed using Fractional power (Basha, and Murthy, 2007), pseudo-first-order (Ho, 2004). , Elovich (Ho, 2006), pseudo-second-order (Ho, 2006), and intra-particle diffusion (Weber and Morris, 1963) kinetics models.The sorption kinetics is described by power function model as follows:

$$q_t = kt^\nu \qquad (1)$$

Where q_t is the amount of chromium mg/g sorbed at time t and ν the rate constant of power function (min^{-1}). k is constant of power function model (mg/g).Equation (1) can be rearranged to obtain equation (2), which has a linear form:

$$\ln q_t = \ln k + \nu \ln t \qquad (2)$$

The plot $\ln q_t$ and $\ln t$ should give linear relationship from which ν and k can be determined from the slope and intercept of the plot, respectively.The pseudo-first order kinetic rate equation is expressed as:

$$\frac{dq_t}{dt} = k_1 \left(q_e - q_t \right) \qquad (3)$$

Where k_1 is the rate constant of pseudo first order adsorption (min^{-1}), q_e is the amount of chromium sorbed at equilibrium (mg/g) and q_t the amount of chromium sorbed at time t (mg/g). Integrating Equation (3) for the boundary conditions $t=0$ to $t=t$ and $q_t=0$ to $q_t=q_e$ and rearranging yields the linear time-dependent function.

$$\log\left(q_e - q_t \right) = \log q_e - \frac{k_1 t}{2.303} \qquad (4)$$

The intercept of the straight-line plots of $\log\left(q_e - q_t \right)$ against t should equal $\log q_e$. However, if the intercept does not equal q_e, then the reaction is not likely to be first-order, irrespective of the magnitude of the correlation coefficient.The pseudo-second- order kinetic rate equation is expressed as:

$$\frac{dq_t}{dt} = k_2 \left(q_e - q_t \right)^2 \qquad (5)$$

Where k_2 is the rate constant of pseudo second order adsorption (g.mg^{-1}.min^{-1}). Taking into account, the boundary conditions t=0 to t=t and q$_t$=0 to $q_t = q_t$. The integrated form of equation (5) can be rearranged to obtain equation 6.

$$\frac{t}{q_t} = \frac{1}{k_2 q_e^2} + \frac{t}{q_e} \qquad (6)$$

The initial adsorption rate h (mg.g^{-1}.min^{-1}) is expressed as:

$$h = k_2 q_e^2 \qquad (7)$$

The plot of (t/q_t) and t of equation (6) should give a linear relation ship from which q_e and k_2 can be determined from the slope and intercept of the plot, respectively. The Elovich model equation is generally expressed as:

$$\frac{dq_t}{dt} = a_E \exp\left(-\beta_E q_t\right) \qquad (8)$$

Where a_E is the initial adsorption rate (mg/g .min⁻¹). β_E is the desorption constant (g.mg⁻¹) during any one experiment. To simplify the Elovich equation the authors (Chien and. Clayton, 1980) assumed $a_E \beta_E \gg 1$ and by applying the boundary condition $q_t = 0$ at t=0 and $q_t = q_t$ at t=t. Equation (8) becomes:

$$q_t = \frac{\ln a_E \beta_E}{\beta_E} + \frac{1}{\beta_E} \ln t \qquad (9)$$

If Chromium biosorption fits the Elovich model, a plot of q_t versus $\ln t$ should yield a linear relationship with a slope of $1/\beta_E$ and an intercept of $\ln a_E \beta_E / \beta_E$. The intra-particle diffusion model presented here refers to the theory proposed by the authors (Weber and Morris, 1963), who concluded that the uptake is proportional to the square root of contact time during the course of adsorption. Accordingly:

$$q_t = K_p t^{0.5} \qquad (10)$$

Where K_p is the intra-particle diffusion rate constant (mg/g .min$^{0.5}$)

Equilibrium data, commonly known as adsorption isotherms, are the basic requirement for the design of adsorption systems. Classical adsorption models, such Langmuir (1916), Freundlich (1906) and Temkin (1940) models were used to describe the equilibrium between adsorbed chromium on the biomass and chromium in solution (C_e) at constant temperature. The Freundlich isotherm is a non linear sorption model. This model proposes a monolayer sorption with a

heterogeneous energetic distribution of active sites, accompanied by interaction between adsorbed molecules. The general form of this model is:

$$q_e = K_F C_e^{\frac{1}{n}} \qquad (11)$$

Where K_F is the extent of the adsorption and n the degree of non-linearity between chromium concentration and adsorptionEquation (11) can be linearized in logarithmic form and the Freundlich constants can then be determined:

$$\ln q_e = \ln K_F + \frac{1}{n} \ln C_e \qquad (12)$$

The Langmuir equation which is valid for monolayer sorption on a surface with a finite number of identical sites, is given by:

$$\frac{C_e}{q_e} = \frac{1}{bq_{max}} + \frac{C_e}{q_{max}} \qquad (13)$$

q_{max} is attributable to the maximum metal uptake upon complete saturation of the sorbent, and b is a coefficient attributed to the affinity between the sorbent and sorbate. q_{max} and b can be determined from the linear plot C_e / q_e versus C_e. The essential characteristic of the Langmuir isotherm can be expressed in terms of dimension less constant separation factor for equilibrium parameter R_L (Hall and. Vermeylem, 1966), which is defined by:

$$R_L = \frac{1}{b + C_0} \qquad (14)$$

Hall and Vermeylem (1966) show, using mathematical calculation, that the parameter R_L indicates the shape of isotherm as follows (Table 1).

Table 1. Constant parameter R_L

R_L Value	Type of isotherm
$R_L > 1$	unfavourable
$R_L = 1$	linear
$R_L = 0$	Irreversible
$0 < R_L < 1$	favourable

Temkin (1940) model was also used. This isotherm was first developed by Temkin and Pyzhev, and it is based on the assumption that the heat of adsorption would decrease linearly with the increase of coverage of adsorbent [30].

$$q_e = \frac{RT}{b_t}\ln(a_t C_e) \qquad (15)$$

Where R is the gas constant, T the absolute temperature in Kelvin, b_t the constant related to the heat of adsorption and a_t is the Temkin isotherm constant. Equation (15) can be rearranged to obtain equation (16):

$$q_e = \frac{RT\ln a_t}{b_t} + \frac{RT}{b_t}\ln C_e \qquad (16)$$

MATERIALS & METHODS

The dead *Streptomyces rimosus* biomass was obtained from the SAIDAL-complex manufacturing unit of antibiotics Medea-Algeria The biomass was washed with deionised water, dried at 50°C for 24 h in a drying oven, then the activated biomass was prepared by treating the raw biomass with 0.1 N NaOH solution for 30 min at ambient temperature, at once again washed, dried and then screened through a set of sieves to get geometrical size 50-160 µm. The effluent used in the experiment was the deep blue colour characteristic of Cr (III) and had a pH of 4. Chromium content, as determined by atomic absorption spectroscopy, was found to be 2.4 g/L. No Cr(VI) was present in the effluent as indicated by phenylcarbazide testing. Sodium concentration was 30 g/L. Control experiments confirmed that no signal interference occurred between the two metals.

Chromium uptake serial dilutions of the tanning effluent were prepared using deionised distilled water to give solution ranging in concentration from full strength to 1 in 40 dilutions. Aliquots of 100 ml were contacted with 0.3 g quantities of *Streptomyces rimosus* biomass. Samples were filtered (0.45 µm filters) and the filtrates were analysed for remaining metals using a Perkin Elmer 2380 atomic absorption spectrometer. The amount of Chromium accumulated by biomass was calculated as the difference between the amount present in the initial solution and that in the final solution after equilibration with biomass using the following formula (Holan and Volesky, 1994).

$$q_e = \frac{V(C_0 - C_e)}{m} \qquad (17)$$

All experiments were conducted at a constant temperature of 20 ± 1 °C to be representative of environmentally relevant conditions. Kinetic experiments were conducted on a rotary shaker with constant agitation speed of 300 rpm; using conical flasks (250 ml) containing 100 ml of solution and 0.3 g of biomass and an initial pH 4.8 with initial concentration of 2400 mg l^{-1} for 80 min. To avoid shifts in pH due to biomass addition, the pH was adjusted with 0.1N HCl or 1N NaOH after the solution had been in contact with the biosorbent. For sorption isotherm experiments, flasks were agitated on a rotary shaker (300 rpm) until no additional metal was removed (5 h). The samples were filtered through 0.45 µm millipore filters and were taken periodically to analyse the chromium concentration. To make the biosorption process more economical, it would be necessary to regenerate the spent biosorbent. To evaluate the desorption efficiency the Chromium loaded biomass was dried at 60°C for 24 h after equilibrium sorption at pH 4.8. The dried biomass was contacted with 1 M H$_2$SO$_4$ or 1 M HCl for 4 h to allow chromium to be released from the biomass, there after, the desorbed chromium was analysed and desorption efficiency was calculated as follows (Choi. and Yun, 2004):

Desorption efficiency (%) =

$$\frac{\text{released chromium (mg)}}{\textit{initially} \text{ sorbed chromium (mg)}} *100 \qquad (18)$$

All the model parameters were evaluated by non-linear regression using Excel 2007® software. The optimization procedure requires an error function to be defined in order to be able to evaluate the fit of the equation to the experimental data (Ho *et al.,* 2002, Kundu, and Gupta, 2006). Apart from the correlation coefficient (R^2), the residual root mean square error (RMSE) and the chi-square test were also used to measure the goodness-of-fit. RMSE can be defined as:

$$RMSE = \sqrt{\frac{1}{m-2}\sum_{i=1}^{m}(q_i - q_{ie})^2} \qquad (19)$$

Where the observation from the batch experiment is q_i, q_{ie} is the estimate from the isotherm for corresponding q_i and m is the number of observations in the experimental isotherm. The

smaller RMSE value indicates the better curve fitting Tsai and Juang, 2000). The chi-square test can be defined as:

$$\chi^2 = \sum_{i=1}^{m} \frac{(q_i - q_{ie})^2}{q_{ie}} \qquad (20)$$

If data from model are similar to the experimental data, χ^2 will be a small number (Ho *et al.,* 2005).

RESULTS & DISCUSSION

The pH of the metal solution usually plays an important role in the biosorption of metals (Vijayaraghavan *et al.,* 2005). As can be seen in (Fig. 1). the uptake of Cr^{3+} by *Streptomyces rimosus* biomass was obtained by varying the initial concentration of chromium. When the pH value was raised from 1 to 4.8, the adsorption capacity was enhanced significantly from 27 to 64 mg/g biomass. Uptake was enhanced, probably because of proton competition to Cr^{3+} binding (Yun and Volesky, 2003),Adsorption at pH 5.5 marked precipitation effects augmented the biosorption removal of chromium, from solution resulting in apparent sequestration levels of in excess of 93 mg/g as illustrated in fig. 1. As can be seen in the figure, when the precipitation component is subtracted the net biosorption values are in good agreement with each other and those observed at pH 4.8 (Tobin and Roux, 1998). If the biosorption takes place under conditions that chromium may precipitate, a chemical sludge is generated which should be treated via appropriate solid waste management methods. From a practical point of view, therefore, chromium biosorption process is better operated at pH 4.8.
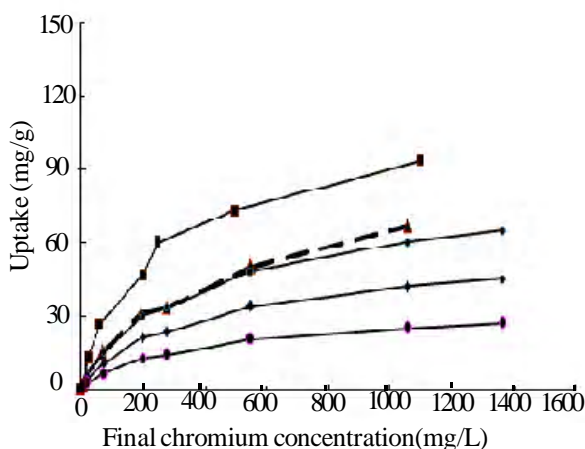

Fig. 1. Effect of pH and influence of precipitation on uptake (* indicate where precipitation effects have been subtracted)

The batch experimental data, shown in (Figs. 2 & 3) on kinetic and equilibrium studies for the biosorption of Cr (III) on *Streptomyces rimosus* were tested to fit the various kinetic and equilibrium models, respectively As shown in (Fig. 2). the removal of chromium increases rapidly in the beginning (first 30 min) and than more slowly until the equilibrium.
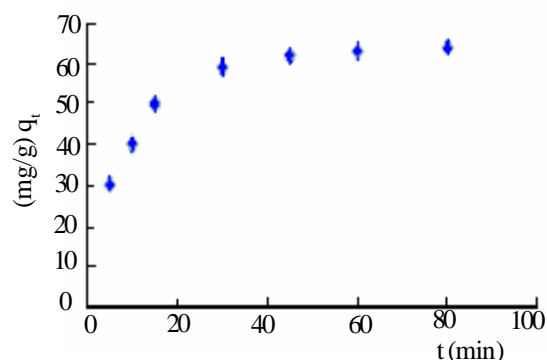

Fig. 2. Kinetic (biosorption capacity vs. time) of Cr (III) on *Streptomyces rimosus*
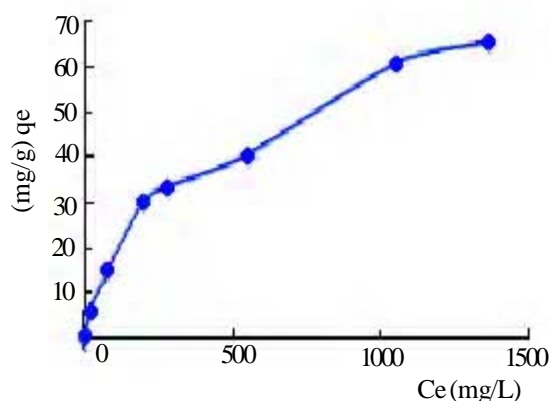

Fig. 3. Biosorption isotherm for Cr (III) on *Streptomyces rimosus*

As seen in (fig.3). it readily appears that, isotherm is somewhat curved and the equilibrium is established between chromium ions and the biomass The metal-binding properties of Gram-positive bacteria are largely due to the existence of specific anionic polymers in the cell wall structure, consisting mainly of peptidoglycan, teichoic acids (Hancock, 1986, Hughes and Poole, 1989, Remacle *et al.,* 1992). Due to this high fixed anionic content of the cell forms which are obviously present in *Streptomyces rimosus*, they may exhibit high sorption capacities that would be very important aspect in future because of its industrial application as biosorbent for the metal

cations. A simple kinetic analysis of biosorption of Cr (III) on Streptomyces *rimosus* has been tested according to fractional power model (Basha, and Murthy, 2007) and Table 2 shows the estimated parameters of the model. The results indicate that the power function model described the time-dependent Cr (III) on sorbent as the value of constant *v* was less than 1(Basha, and Murthy, 2007). The chromium biosorption data do not correlate well with fractional power model and this confirmed by high RMSE and chi-square values (Table 2).

The kinetic constant, k_1, of the pseudo-first-order equation (Ho, 2004) for the biosorption of Cr (III) on to biomass is given in (Table 2). The results demonstrated that Lagergren model (Ho, 2004) is not applicable in the present case as high RMSE and chi-square values were observed. The kinetic constants obtained from the Elovich equation (Ho, 2006) are listed in (Table 2). The results demonstrate a significant relationship between Cr (III) sorbed, q_t and *t* in this study with acceptable regression coefficient 0.95 and low values of RMSE and chi-square. The low values of standard error reflect agreement between the sets of data studied. In other words, the data also show satisfactory compliance with the Elovich equation. The results in (Table 2) show the biosorption rate constant, k_2, initial biosorption rate, *h*, and equilibrium biosorption capacity, q_e, of the pseudo-second-order model (Ho, 2006). These results show a very good compliance with the pseudo-second-order equation with high regression coefficients (>0.99). The rate of a biosorption reaction nonlinearly decreased with time. For example, the instantaneous rates at 50 and 90% of Cr (III) biosorption (SR$_{50}$ and SR$_{90}$, respectively) can be calculated from pseudo-second order rate equation as follows:

$$SR_{50} = k_2 \left[q_e - (0.5q_e) \right]^2 = \frac{k_2 q_e^2}{4} = \frac{h}{4} \qquad (21)$$

$$SR_{90} = k_2 \left[q_e - (0.9q_e) \right]^2 = \frac{k_2 q_e^2}{100} = \frac{h}{100} \qquad (22)$$

Therefore, SR$_{50}$ and SR$_{90}$ values are one-fourth and one-hundredth of initial biosorption rate, *h*, respectively (see Table5), and comparisons reported here based on h values can be extended

to the entire experiment duration. Based on the pseudo-second-order kinetic model the half-life of Cr (III) biosorption (the time at which half of the biosorption process is completed) directly depends on the biosorption capacity of the biosorbent and inversely relates to the initial biosorption rate:

$$t_{\frac{1}{2}} = \frac{1}{k_2 q_e} = \frac{q_e}{h} \qquad (23)$$

Biosorption capacity of the biosorbent determined from the fitted pseudo-second-order kinetic model was comparable to the maximum biosorption capacity calculated from the Langmuir isotherm as can be seen later.

Table 2. Kinetic model parameters for Cr (III) biosorption on *Streptomyces rimosus*

Models	Parameters	
Fractionalp ower	v (min^{-1})	0.271
	k (mg.g^{-1})	21.434
	R^2	0.916
	RMSE	4.7284
	χ^2	2.109
pseudo-first-order	k_1 (min^{-1})	0.064
	q$_e$ ($mg.g^{-1}$)	41.512
	R^2	0.989
	RMSE	27.083
	χ^2	116
Elovich	a_E ($mg.g^{-1}$min^{-1})	33.212
	β_E (g.mg^{-1})	0.079
	R^2	0.950
	RMSE	3.224
	χ^2	1.026
pseudo-second-order	k_2 (g.mg^{-1} min^{-1})	2.2 10^{-3}
	q$_e$ (mg.g^{-1})	71.43
	h (mg.g^{-1})	11.11
	SR$_{50}$ (mg.g^{-1})	2.778
	SR$_{90}$ (mg.g^{-1})	0.111
	t$_{\frac{1}{2}}$ (min)	6.43
	R^2	0.999
	RMSE	2.035
	χ^2	0.436

The intraparticle diffusion coefficient for the biosorption of Cr (III) was calculated from the slope of the plot (Fig.4). between the amounts of Cr (III) sorbed, q_t (mg/g) vs. $t^{1/2}$ (min$^{1/2}$). Based on this plot, the biosorption process of the Cr (III) is comprised by two phases, suggesting that the intraparticle diffusion is not the rate-limiting step for the whole reaction (Ho and Ofomaja, , 2005), the initial portion of the plot indicated an external mass transfer whereas the second linear portion is due to intraparticle or pore diffusion. Similar results were reported by the authors (Aguilar-Carrillo *et al.,* 2006). The intercept of the plot provides an estimation of the thickness of the boundary layer (Oubagaranadin *et al.,* 2007).The slope of the second linear portion of the plot has been identified as the intra-particle diffusion rate constant (K_p = 12,90 mg/g min$^{-1/2}$). The high value of K_p corresponded to low value of pseudo-second order rate constant, k_2 (Table 2), indicating that the intra-particle diffusion retards the biosorption process. This also indicates, the biosorption process is rather complex and involves more than one diffusive mechanism.
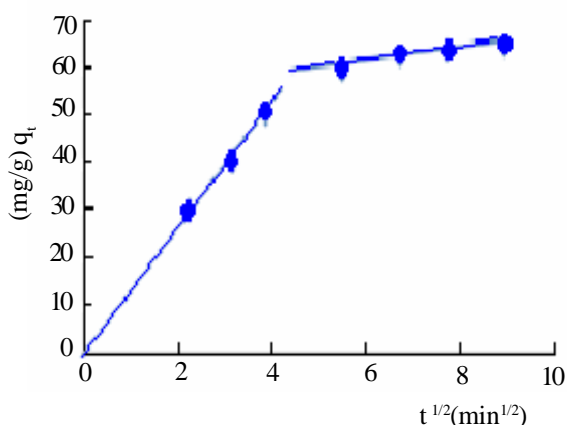
Fig. 4. Intra-particle diffusion plots for the biosorption of Cr (III) on *Streptomyces rimosu*s

Analysis of equilibrium data is important for developing an equation that can be used to design and optimize an operating procedure. To examine the relationship between biosorption and aqueous concentration at equilibrium, various biosorption isotherm models are widely employed for fitting the data.The Temkin model parameters are compared with value for the Langmuir and Freundlich model in (Table 3).

The Freundlich isotherm is originally empirical in nature (Freundlich ,1906), but was later interpreted as biosorption to heterogeneous surfaces or surfaces supporting sites of varied affinities and has been used widely to fit experimental data (Aksu and Kutsal, 1991) . The value of *n*, of this model, falling in the range of 1–10 indicates favourable biosorption (Aksu, 2002). The numerical value of 1/n < 1 indicates that adsorption capacity is only slightly suppressed at lower equilibrium concentrations. This isotherm does not predict any saturation of the adsorbent by the adsorbate. Thus infinite surface coverage is predicted mathematically, indicating multilayer adsorption on the surface (Hasany *et al.,* 2002) .The present study results indicate that the Freundlich model does not fit the experimental data well. It is not the suitable model for describing these biosorption processes, as RMSE and χ^2 values are higher than 10.

Temkin model is unable to describe the data, as low correlation coefficients and high RMSE and chi-square values were observed.The adsorption data provided an excellent fit to the Langmuir isotherm with high values of the R^2 (see Table3). The separation factor (R_L) value indicates that Cr (III) biosorption of biosorbent in this study is favourable.Comparisons of maximum experimental biosorption capacities of Cr (III) for some biomasses were also given in (Table 4). It can be seen from the table, *Streptomyces rimosus* used in this study has high biosorption capacity.

To make the adsorption process more economical it is necessary to regenerate the spent adsorbent**.** In this study, the chromium bearing biomass was contacted with hydrochloric acid or sulphuric acid (Fig. 5).When a low pH was used the desorption efficiency was 95 %. At pH values of 0.5 and 1.0 only 66 and 51 % chromium was recovered respectively.Chromium desorption increased with decreasing desorption agents pH (including HCl and H_2SO_4) to a maximum value of Cr 95% at approximately zero pH.Variation of the hydrochloric acid or Sulphuric acid caused non-difference in desorption over the experimental range investigated as shown in (fig.5).

Table 3. Isotherm constants for Cr (III) biosorption on *Streptomyces rimosus*

Equilibrium models	Parameters		
Freundlich	K_F (lg^{-1})		1.724
	n		1.443
	R^2		0.957
	RMSE		10.659
	χ^2		11.69
Temkin	a_T (lg^{-1})		0.086
	b_T $(jmol^{-1})$		197.27
	R^2		0.933
	RMSE		6.607
	χ^2		15.97
Langmuir	$q_{max}(mg.g^{-1})$		83.33
	b $(l.mg^{-1})$		0.0028
	R_L		0.13
	R^2		0.992
	RMSE		2.009
	χ^2		1.067

Table 4. Comparison of biosorption capacity of *Streptomyces rimosus* biomass with that of different biomasses

Biosorbent	q_{max}	pH	Reference
Chlorella miniata	41.18	4.5	Han et al., (2006)
Carrot residues	45.10	4	Nasernejada et al., (2005)
Parmelina tiliaceae	52.10	5	Uluozlu et al., (2008)
Spheroidal cellulose	89.90	5	Liu et al., (2001)
spirogyra species	30.21	5	Bishnoi et al., (2007)
Sargassum SP	68.12	3.5	Cossich et al., (2004)
Streptomyces rimosus	83.33	4.8	the present study
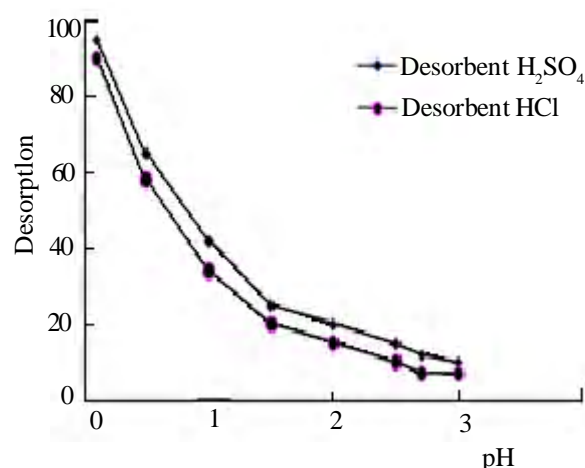
Fig. 5. Effect of desorption agents (H_2SO_4, HCl) pH on desorption efficiency

CONCLUSIONS

The present study showed that *Streptomyces rimosus* a biological sorbent of mycelial bacteria origin can find an application as a biological sorbent of Cr (III) ions from aqueous solution. The process kinetics was found to follows the pseudo-second order rate equation. Langmuir model presents good fits of the experimental data. The application of this model to complex biological system may not to explain the biosorption behaviour. Hence, conclusion derived only from good fit of the model should be avoided. The metal ion could be stripped by addition of HCl or H_2SO_4 at low pH, making the adsorbent regeneration and its reutilization possible.

REFERENCES

Aguilar-Carrillo, J., Garrido, F., Barrios, L.and Garcýa-Gonzalez, M.T. (2006). Biosorption of As, Cd and Tl as influenced by industrial by-products applied to an acidic soil: equilibrium and kinetic experiments, *Chemosphere,* **65,** 2377–2387.

Aksu, Z. (2002). Determination of the equilibrium, kinetic and thermodynamic parameters of the batch biosorption of nickel (II) ions onto *Chlorella vulgaris* Proc. Bio., 89-99.

Aksu, Z.and Kutsal, T. (1991).A bioseparation process for removing lead(II) ions from waste water by using *C. vulgaris, J. Chem. Technol. Biotechnol.,* **52,** 109–118.

Basha, S. and Murthy, Z.V.P. (2007).Kinetic and Equilibrium models for biosorption of Cr (VI) on chemically modified seaweed cystoseir indica. Proc.bio., **42(11)**,1521-1529.

Bishnoi N.R, Kumar R, Kumar S and Rani S, (2007). Biosorption of Cr(III) from aqueous solution using algal biomass *spirogyra* spp. *J. Hazard Mater.,* **145**,142-147.

Chien, S.H. and. Clayton, W.R. (1980). Application of Elovich equation to kinetics of phosphate release and sorption in soil. J. Am. Soil Sci. Soc., **44,** 265-268.

Choi, S.B. and Yun, Y.S. (2004). Lead biosorption by waste biomass of *Corynebacterium glutamicum* generated from lysine fermentation process. *Biotechnology Letters,* **26,** 331–336.

Cossich E.S. , Da silva E.A., Tavares C.R.G. and Filho L.C. (2004).Biosorption of Chromium(III) by Biomass of Seaweed *Sargassum* sp.in a Fixed-Bed Column. *Adsorption,* **10**, 129–138.

Freundlich, H. M. F. (1906). Uber die adsorption in losungen, Zeitschrift furPhysikalische Chemie (Leipzig) 57A 385–470.

Gadd, G.M. and White, C. (1989). Removal of thorium from simulated acid process streams by fungal biomass. Biotech Bioeng, **33,** 592–597.

Hall, K.R. and Vermeylem, T. (1966). Pore-and solid-diffusion kinetics in fixed bed adsorption under constant-pattern condition. Ind, Eng, Chem Fundam, **5(2)**, 212-223.

Han X, Shan S, Wong Y. and Yee N.F. (2006). Surface complexation mechanism and modeling in Cr(III) biosorption by a microalgal isolate, *Chlorella miniata. J.Colloid Interf. Sci,.* **303,** 365–371.

Hancock, I.C. (1986). The use of Gram-positive bacteria for the removal of metals from aqueous solution. In: R. Thompson, Editor: *Trace Metal removal from Aqueous Solution*, Royal Soc. Chem., London , Spec. Publ. **61,** 25-28.

Hasany, S.M., Saeed, M.M. and Ahmed, M. (2002). Sorption and thermodynamic behavior of Zn(II)-thiocyanate complexes onto polyurethane foam from acidic solutions. J. Radioanal. Nucl. Chem., **252(3),** 477–484.

Ho, Y.S. (2004). Citation review of Lagergren kinetic rate equation on adsorption reactions. *Scientometrics,* **59,**171–177.

Ho, Y. S. (2006).Review of second-order models for adsorption systems. *J. Hazard Mater.,* **136,** 681–689.

Ho, Y.S. Porter, J.F. and McKay, G. (2002). Equilibrium isotherm studies for the biosorption of divalent metal ions onto peat: copper, nickel and lead single component systems. *Water Air Soil Pollut.,* **141,** 1–33.

Ho, Y.S. and Ofomaja, A.E., (2005).Kinetics and thermodynamics of lead ion biosorption on palm kernel fibre from aqueous solution. *Process Biochem.,* **40**, 3455–3461.

Ho, Y.S., Chiu, W.T. and Wang, C.C. (2005). Regression analysis for the sorption isotherms of basic dyes on sugarcane dust. *Bioresour. Technol.,* **96**, 1285–1291.

Holan, ZR. and Volesky, B., (1994). Biosorption of Pb and Ni by biomass of marine algae. Biotechnol Bioeng., **43,** 1001–1009.

Hughes, M.N. and. Poole, R.K. (1989). Removal or recovery of metal ions and compounds from solution by microbiological methods. *Metals and Microorganisms*, Chapman and Hall, London, 328-332.

Kapoor, A. and Viraraghavan, T. (1998). Application of immobilized *Aspergillus niger* biomass in the removal of heavy metals from an indusrial wastewater. J. Environ. Sci. Health. Pt. A. Toxic Hazard —Subst Environ Eng., **A33(7),** 1507–1514.

Kapoor, A. and Viraraghavan, T. (1995). Fungal biosorption. An alternative treatment option for heavy metal bearing wastewaters: a review. Bioresource Technol., **53**, 195–206.

Krishna, K.R. and Philip, L. (2005). Bioremediation of Cr (VI) in contaminated soils. *J. Hazar. Mater.,* **121**, 109–117.

Kundu, S. and Gupta, A.K. (2006). Arsenic adsorption onto iron oxide-coated cement (IOCC): Regression analysis of equilibrium data with several isotherm models and their optimisation. *Chem. Eng. J.,* **122,** 93–106.

Kumari, P., Sharma, P., Srivastava, S. and Srivastava, M.M. (2006). Biosorption studies on shelled Moringa oleifera Lamarck seed powder: removal and recovery of arsenic from aqueous system. *Int. J. Miner. Process.,* **78**,131–139.

Langmuir, I. (1916). The constitution and fundamental properties of solids and liquids, *J Am Chem Soc* **38,** 2221–2295.

Lewis, D. and Kiff, R. G. (1988). The removal of heavy metals from aqueous effluents by immobilized fungal biomass. Environmental Technology Letters, **9,** 991–998.

Liu, M.H., Zhang, H., Zhang, X.S., Deng, Y., Liu, W.G. and Zhan, H. Y. (2001). Removal and recovery of chromium(III) from aqueous solutions by a spheroidal cellulose adsorbent. Water Environ. Res., **73**, 322–328.

Luef, E., Prey, T. and Hubicek, CP. (1991). Biosorption of zinc by fungal mycelial wastes. Appl. Microbial. Biotechnol., **34,** 688–692.

Mant, C., Costa, S., Williams J. and Tambourgi, E. (2005). Studies of removal of chromium by model constructed wetland. *Brazil. J. Chem. Eng., 22,* 381–387.

Meyer, A. and Wallis, F. M. (1997). The use of *Aspergillus niger* (strain 4) biomass for lead uptake from aqueous systems. Water SA., **23,** 187–192.

Nasernejada, B., Zadehb, T. E., Poura, B. B., Bygia, M. E. and Zamani, A. (2005). A Comparison for biosorption modeling of heavy metals (Cr(III), Cu(II), Zn(II)) adsorption from wastewater by carrot residues. *Process. Biochem., 40,* 1319–1322.

Oubagaranadin, J.U.K., Sathyamurthy, N. and Murthy, Z.V.P. (2007). Evaluation of Fuller's earth for the adsorption of mercury from aqueous solutions: a comparative study with activated carbon. *J. Hazard Mater., 142,* 165–174.

Öztürk, A., Artan, T. and Ayar, A (*2004*). Biosorption of nickel(II) and copper(II) ions from aqueous solution by *Streptomyces coelicolor* A3(2). *Colloids and Surfaces B: Biointerfaces*, **34(2),** 105-111.

Remacle, J., Hambuckers-Berhin, F. and Infantino-Masuy, B. (1992). Metal fixation by Gram negative and Gram positive bacterial walls. In: J.P. Vernet, Editor, *Proceedings of 5th International Conference on Environmental Contamination* Morges, Switzerland, 116-121.

Richard, F.C. and Bourg, A.C.M. (1991). Aqueous geochemistry of chromium: a review. *Water Res.*, 807–816.

Temkin, M.J.and Pyzhev, V. (1940). Recent modifications to Langmuir isotherms. *Acta Physiochim USSR., 12,* 217–225.

Tiranvanti, G., Petruzzelli, D. and Passino, R. (1997). Pretreatment of tannery wastewaters by an ion exchange process for Cr(III) removal and recovery. *Water Sci. Technol.,* **36,** 197-207.

Tobin, J.M. and Roux, J.C , (1998). Mucor biosorbent for chromium removal from tanning effluent. Water Res., **32,**1402-1416.

Tsai, S.C. and Juang, K.W, (2000).Comparison of linear and non-linear forms of isotherm models for strontium sorption on a sodium bentonite. *J. Radioanal. Nucl. Chem.,***243,** 741–746.

Tsezos, M. and Volesky, B. (1981). Biosorption of uranium and thorium. Biotech Bioen., **23,** 583–604.

Uluozlu, O.D, Sari, A., Tuzen, M. and Soylak M.(2008).Biosorption of Pb(II) and Cr(III) from aqueous solution by lichen (Pamelina tiliaceae) biomass. *Biortech.,***99(8),** 2972-2980.

Van Hullebusch, E.D., Zandvoort, M.H. and Lens, P.N.L. (2003). Metal immobilization by biofilms: mechanisms and analytical tools.*Rev. Environ. Sci. Bio. Technol., 2,* 9–33.

Vijayaraghavan, K., Jegan, J., Palanivelu, K. and Velan, M. (2005).Biosorption of cobalt (II) and nickel (II) by seaweeds: batch and column studies, *Sep. Purif. Technol., 44,* 53–59.

Volesky, B. and Holan, ZR., (1995). Biosorption of heavy metals. Biotechnol. Prog., **11,** 235–250.

Weber, W.J. and Morris, J.C. (1963).Kinetics of adsorption on carbon from solution. *J. Sanitary Eng. Div. Am. Soc.Civil Eng.,* **89(SA2),** 31–39.

Yun, Y.S. and Volesky, B. (2003). Modelling of Lithium interference in cadmium biosorption. Environ. Sci. Technol., **37,** 3601-3608.