Separation Science and Technology
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713708471

Biosorption of Chromium from Effluent Generated in Chrome-Electroplating Unit using *Saccharomyces cerevisiae*

K. Parvathi[a]; R. Nagendran[a]
[a] Centre for Environmental Studies, Anna University, Chennai, Tamilnadu, India

To cite this Article Parvathi, K. and Nagendran, R.(2007) 'Biosorption of Chromium from Effluent Generated in Chrome-Electroplating Unit using *Saccharomyces cerevisiae*', Separation Science and Technology, 42: 3, 625 — 638
To link to this Article: DOI: 10.1080/01496390601070158
URL: http://dx.doi.org/10.1080/01496390601070158

Separation Science and Technology, 42: 625–638, 2007

ISSN 0149-6395 print/1520-5754 online
DOI: 10.1080/01496390601070158

Biosorption of Chromium from Effluent Generated in Chrome-Electroplating Unit using *Saccharomyces cerevisiae*

K. Parvathi and R. Nagendran
Centre for Environmental Studies, Anna University, Chennai, Tamilnadu, India

Abstract: Biosorption of chromium from effluent generated in chrome-electroplating unit using waste yeast biomass *Saccharomyces cerevisiae* was carried out. Chromium concentration in the effluent was 204 mg/L. Chromium biosorption equilibration time was found to be 2 hours, with uptake of 6.607 mg/g. Biosorption increased with rise in pH and chromium concentration. Equilibrium biomass concentration and agitation speed were 2% and 150 rpm, respectively. The biosorption equilibrium data fit with Freundlich and Langmuir isotherm models revealed K_f and Q_{max} values of 0.3727 and 384.61 mg/g, respectively.

Keywords: Biosorption, chromium, chrome-electroplating effluent, *Saccharomyces cerevisiae*, Freundlich isotherm, Langmuir isotherm

INTRODUCTION

Pollution of water by chromium and its compounds used in leather tanning, electroplating, metal finishing, and chromate preparation processes is of serious environmental concern as the metal is highly reactive (1). It is a highly toxic non-essential metal for living systems (2) and is a known carcinogen and mutagen (3). Its removal from effluents prior to their disposal is essential from environmental health, management, and the economics points of view. Conventionally, the following methods are employed for the

Received 14 May 2006, Accepted 18 September 2006
Address correspondence to R. Nagendran, Centre for Environmental Studies, Anna University, Chennai 600 025, Tamilnadu, India. Tel.: +91-44-22301283; Fax: +91-44-22354717; E-mail: nag.np@hotmail.com

removal of heavy metals from effluents: oxidation and reduction, precipitation, filtration, electrochemical treatment, and evaporation (4). Search for newer methods of removal of toxic metals from wastewaters has directed attention to biosorption, based on metal binding capacities of various biological materials (5).

The term "biosorption" refers to the passive non-metabolically—mediated process of metal binding by biomass (6). Bacteria, yeasts, fungi, and algae have been used as biosorbents of heavy metals. Among these, yeasts are known to be selective metal biosorbents as compared to fungi, actinomycetes, and bacteria (7).

The yeast *Saccharomyces cerevisiae* is readily available as a by-product of established fermentation processes and can be easily obtained in considerably substantial quantities at low costs (8). Often, the economics of the treatment process is improved by using waste biomass instead of cultured biomass (9). The application of *S. cerevisiae* as a biosorbent not only removes metals from wastewaters but also eases the burden of disposal costs associated with waste biomass (6). *S. cerevisiae* has been used to remove Cr^{6+}, Fe^{3+} (10), Pb^{2+} (11), Cu^{2+} (12), zinc and nickel (13) from synthetic aqueous solutions. *S. carlsbergensis* has been reported to be effective in removing metals such as copper, zinc, and nickel from synthetic aqueous solutions (7, 13). However, studies on biosorption of chromium from real effluents are scarce (14). The present study investigates the efficiency of biosorption of chromium from effluent generated in a chrome-electroplating unit using *S. cerevisiae*.

MATERIALS AND METHODS

Biosorbent

Spent yeast biomass *Saccharomyces cerevisiae* was collected from the fermentor at a brewery located near Chennai, India and transported to the laboratory in plastic containers. The yeast cells were washed thrice with double distilled water. After each wash, the biomass was separated by filtration using Whatmann No. 42 filter paper. The biomass was dried in a hot air oven at 80ºC for 8 hours and stored for further use.

Collection and Characterization of Effluent

Raw effluent was collected from an electroplating unit and transported to the laboratory in plastic cans. pH of effluent was measured using a pH probe (Elico pH meter). The effluent was characterized for its physicochemical parameters employing Standard Methods (15). Heavy metal analysis was done using Atomic Absorption Spectrophotometer (Vario-6, Analytik Jena, Germany).

Biosorption Experiments

2 g of biomass was suspended in 100 mL of effluent taken in 250 mL Erlenmeyer flasks and maintained at 150 rpm on a rotary shaker (IKA-501, Germany). Samples were withdrawn periodically during the 2-hour biosorption experiment and filtered using Whatmann No. 1 filter paper. The concentration of total chromium remaining in the filtrate was determined using an Atomic Absorption Spectrophotometer.

Time-Dependence Studies

Samples were withdrawn at fifteen-minute intervals during the biosorption experiments and analyzed for chromium. The results were recorded and the time profile of manganese biosorption sketched.

Effect of Biomass Concentration

Dry biomass was added to the effluent to yield concentrations (w/v) of 0.5, 1, 1.5, 2, 2.5, 3, 3.5, 4% and biosorption experiments were carried out.

Effect of pH

The pH of the effluent was adjusted and maintained at 1, 2, 3, 4, 5, and 6 using 1 N H_2SO_4 and 1 N NaOH and biosorption experiments were carried out.

Effect of Chromium Concentration

The effluent was diluted with double distilled water to yield solutions containing 25, 50, 75, 100, 125, 150, 175, and 200 mg/L of chromium. They were subjected to biosorption, maintaining the biomass concentration constant at 2%.

Effect of Agitation Speed

Experiments were carried out by varying the agitation speed of the biosorption mixtures from 0 (no agitation; control), 50, 100, 150, to 200 rpm and biosorption experiments were carried out.

Calculation of Chromium Uptake

Chromium uptake by biomass was calculated using the following mass balance equation for the biosorbents (16):

$$q = [V(C_i - C_f)]/S \quad (1)$$

where,

q = chromium uptake (mg metal / g cell dry weight)
V = volume of metal-bearing solution contacted (batch) with the biosorbent (L)
C_i = initial concentration of metal in solution (mg/L)
C_f = final concentration of metal in solution (mg/L)
S = dry weight of biosorbent added (g)

Biosorption Isotherms

Freundlich and Langmuir isotherms were used for interpreting the chromium biosorption equilibrium.

The Freundlich equation is given below:

$$q = K_f C_e^{1/n} \tag{2}$$

where,

q = heavy metal adsorbed on the biomass (mg/g dry weight)
C_e = final concentration of metal (mg/L) in the solution
K_f = an empirical constant that provides an indication of the adsorption capacity of biomass
n = an empirical constant that provides an indication of the intensity of adsorption

The Freundlich adsorption constants (K_f and $1/n$) were obtained by plotting log Q_e as a function of log C_e.

The Langmuir equation is given below:

$$q = (Q_{max} b\ C_e)/(1 + b\ C_e) \tag{3}$$

where,

q = heavy metal adsorbed on the biomass (mg/g dry weight)
C_e = final concentration of metal (mg/L) in the solution
Q_{max} = maximum possible amount of metallic ion adsorbed per unit weight of adsorbent
b = equilibrium constant related to the affinity of the binding sites for the metals

The Langmuir adsorption constants (Q_{max} and b) were obtained by plotting $1/Q_e$ as a function of $1/C_e$.

RESULTS AND DISCUSSION

Effluent Characteristics

The physicochemical characteristics of the effluent from a chrome-electroplating unit are given in Table 1. The permissible levels for various heavy metals in effluent generated in electroplating units have been specified by The Central Pollution Control Board of India (17). From the table, it is evident that chromium with a concentration of 204 mg/L exceeds the permissible level of 2 mg/L. In comparison with chromium, the concentrations of all other metals were not only very less, but also within specified limits. Hence, the metal of focus in this study is chromium.

Time-Dependence Studies

Time profiles of chromium biosorption by *Saccharomyces cerevisiae* are shown in Fig. 1. Biosorption of chromium increased with time. The equilibration time for biosorption of chromium from the effluent by *S. cerevisiae* was 2 hours. In contrast to this, Ferraz et al. (18) have reported an equilibration time of 30 minutes during chromium biosorption from its synthetic aqueous solutions by *S. cerevisiae*. The longer equilibrium time recorded in the present study may be attributed to the presence of other ions in the effluent (Table 1) and their interference with chromium biosorption. Investigating the biosorption of chromium from its synthetic aqueous solutions by *S. cerevisiae* in the presence of lead, Ferraz and Teixeira (19) have reported slower metal uptake from multi-metal solutions, suggesting a competition between the ions for binding sites in yeast cellular walls.

Table 1. Physicochemical parameters of effluent generated in chrome-electroplating unit

Sl. No.	Parameter	Concentration[a]	Permissible level for effluent generated in electroplating industry (EPA, 1987)
1.	pH	3.6	6.0–9.0
2.	TSS	120	100
3.	COD	30	250
4.	Cu	0.29	3
5.	Ni	0.05	3
6.	Fe	0.26	3
7.	Zn	0.10	5
8.	Cr	204	2

[a]All values are in mg/L except pH.

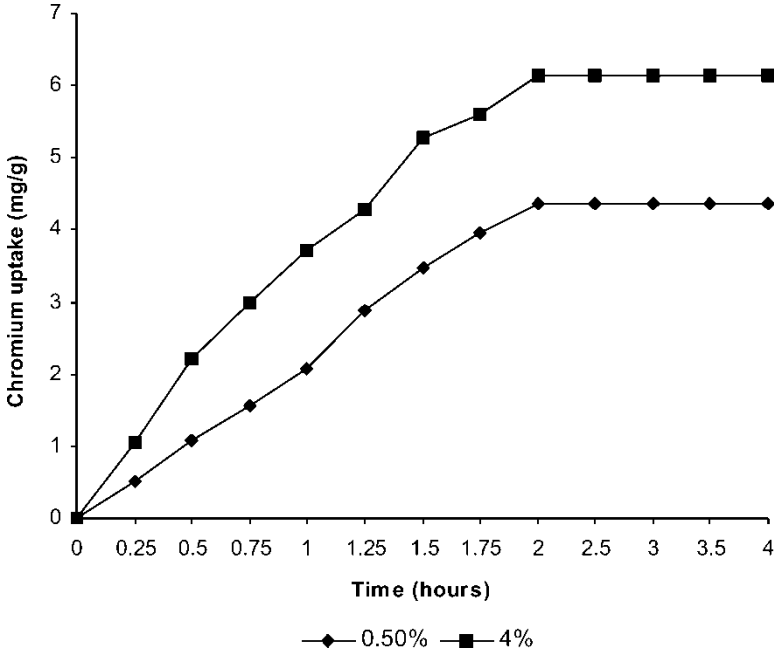

Figure 1. Time profile of chromium biosorption by *Saccharomyces cerevisiae* from effluent generated in chrome-electroplating unit.

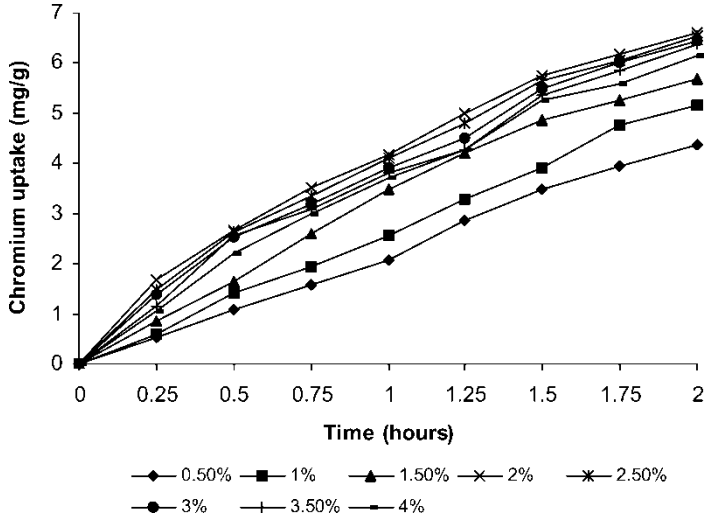

Figure 2. Effect of biomass concentration on chromium biosorption by *Saccharomyces cerevisiae* from effluent generated in chrome-electroplating unit.

Effect of Biomass Concentration

Biosorption of chromium with varying biomass concentration is shown in Fig. 2. Chromium uptake rose from 4.356 mg/g to 6.607 mg/g with increase in biomass concentration from 0.5% to 2%. Chromium uptake decreased slightly when the biomass concentration reached 4% (6.148 mg/g). A similar trend in metal uptake with variations in biomass concentration has been reported for chromium biosorption from its synthetic aqueous solutions by *Aspergillus niger* and *Saccharomyces cerevisiae* by Chandrasekhar et al. (20) and Ferraz and Teixeira (19), respectively. High biomass concentrations are known to cause cell agglomeration and consequent reduction in inter-cellular distance (21). This is reported to produce a "screen effect" among the dense layer of cells, leading to "protection" of the binding sites from metal ions (22). In other words, the metal uptake is higher when the inter-cellular distance is greater, as this condition ensures optimal electrostatic interaction between cells, a significant factor for biosorption (21). Decrease in biomass concentration in the suspension at any given metal concentration is known to enhance the metal/biosorbent ratio and thus increase the specific metal uptake (22).

Effect of pH

Uptake of total chromium was highest at pH 2 (16.75 mg/g), as evident from Fig. 3. The uptake decreased to 9.536 mg/g at pH 6. It is also clear from the

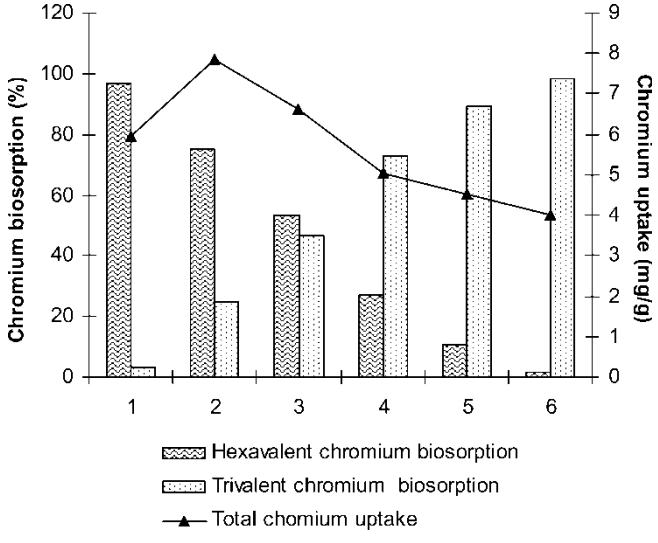

Figure 3. Effect of pH on chromium biosorption by *Saccharomyces cerevisiae* from effluent generated in chrome-electroplating unit.

figure that biosorption of hexavalent chromium decreased sharply with pH, from 94.5% at pH 1 to 1.99% at pH 6. Maximum biosorption of trivalent chromium was observed at pH 6, the value being 98.01%, whereas, the minimum removal of 5.43% was recorded at pH 1.

The different biosorption profiles of Cr (III) and Cr (VI) may be attributed to the solution chemistry of the chromium ion (23) at different pH and its nature of interaction with the biosorbent (24).

In the case of biosorption of trivalent chromium, as the pH is lowered, the overall surface charge on the biosorbent becomes positive due to increased number of H^+ ions; these ions compete with chromium ions for the binding sites on the biosorbent (24). Hence, the low biosorption of Cr (III) at low pH may be due to the competition between protons and Cr (III) ions for the binding sites of the biosorbent. However, with increasing pH, the number of H^+ ions decreases and hence Cr (III) is effectively biosorbed (25).

Cr (VI) showed an opposite trend because it is an anionic species in solution. The dominant hexavalent chromium species at acidic pH are $HCrO_4-$ and CrO_4^{2-} (26). At acidic pH, due to increased H^+ ion concentration, the biosorbent becomes protonated. The increase in Cr (VI) biosorption at acidic pH may be attributed to the electrostatic attraction between positively charged groups of the protonated biosorbent and anionic species of chromium. Moreover, the fall in biosorption with increasing pH could be due to two reasons: one is the decrease of the electrostatic attraction and the

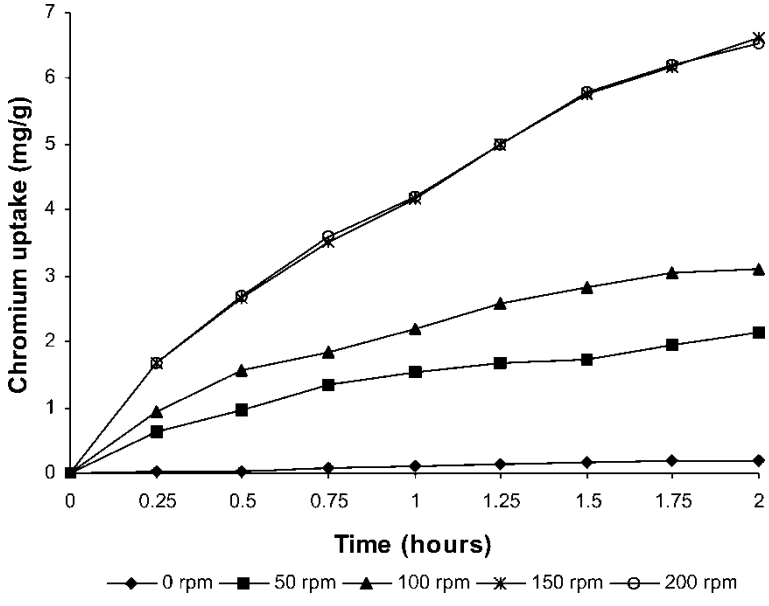

Figure 4. Effect of agitation speed on chromium biosorption by *Saccharomyces cerevisiae* from effluent generated in chrome-electroplating unit.

second is the competition between the chromium anionic species and OH^- ions for adsorption onto the binding sites of the biosorbent. Such a phenomenon for Cr (VI) biosorption has also been observed by Bingol et al. (27).

Effect of Agitation Speed

Figure 4 presents the effect of agitation speed on chromium biosorption by *Saccharomyces cerevisiae*. Control units at 0 rpm (no agitation) exhibited very low chromium uptake (0.2 mg/g). Chromium uptake increased 3-fold from 2.14 mg/g to 6.607 mg/g with a rise in agitation speed from 50 to 150 rpm, beyond which there was no further increase. Similar trends in biosorption of cadmium and lead by *Sargassum sp*. have been reported by Cruz et al. (28) and Martins et al. (29), respectively. Lower metal uptake at higher agitation speeds beyond a point is attributed to non-homogeneity of the biosorption mixtures (30) caused by vortex phenomenon (31). The highest uptake of chromium at an agitation speed of 150 rpm observed presently indicates least mass transfer resistance experienced by the system. Thus, it appears prudent to carry out biosorption at this speed and no further enhancement is needed to make the binding sites readily available for chromium uptake. It is known that external mass transfer resistance is directly proportional to the thickness of the stationary fluid layer surrounding the biomass particles. The film thickness in turn is controlled by the agitation speed of the bulk solution. A higher agitation speed decreases the film thickness and eventually eliminates film resistance (31).

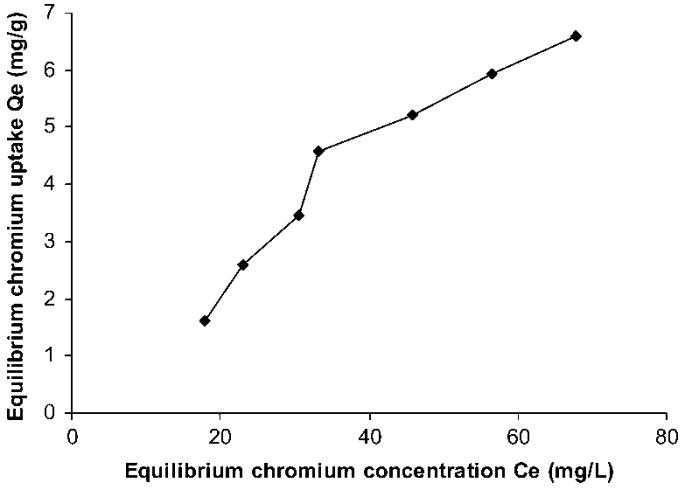

Figure 5. Effect of metal ion concentration on chromium biosorption by *Saccharomyces cerevisiae* from effluent generated in chrome-electroplating unit.

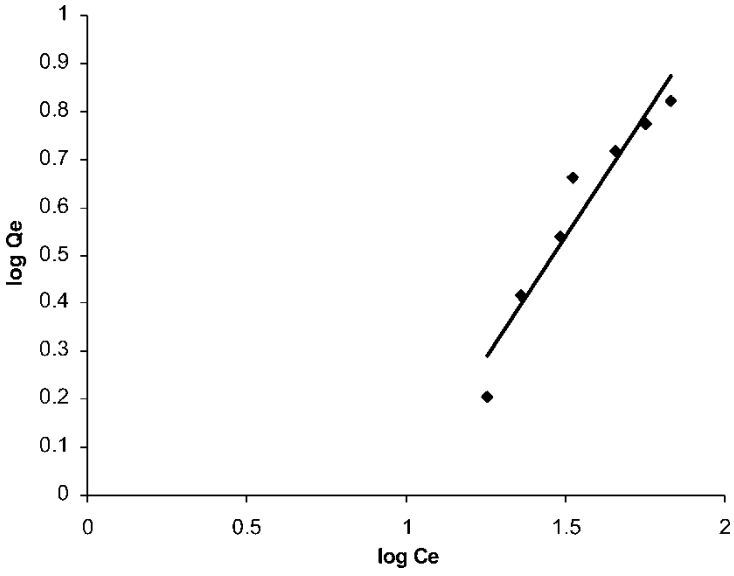

Figure 6. Freundlich isotherm for chromium biosorption by *Saccharomyces cerevisiae* from effluent generated in chrome-electroplating unit.

Effect of Chromium Concentration

Biosorption increased with rise in chromium concentration in the effluent (Fig. 5). A rise in chromium concentration from 25 to 200 mg/L resulted in an increase in its uptake by *Saccharomyces cerevisiae* from 0.85 to 6.607 mg/g (more than 7-fold), respectively. Similar performance by *S. cerevisiae* during studies on chromium biosorption from its synthetic aqueous solutions has been reported by Goyal et al. (10).

Table 2. Isotherm constants for chromium biosorption by *Saccharomyces cerevisiae* from effluent generated in chrome-electroplating unit

Sl. No.	Isotherm constants
1. Freundlich	
R^2	0.9241
K_f	0.3727
1/n	1.016
2. Langmuir	
R^2	0.9376
Q_{max} (mg/g)	384.61
b (L/mg)	0.1259

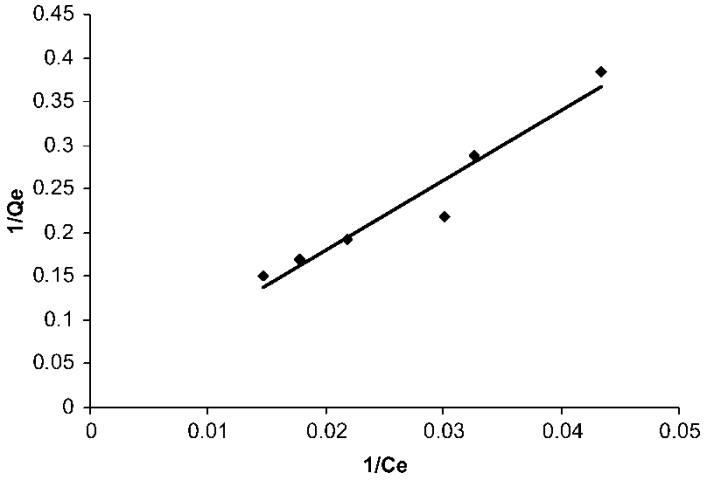

Figure 7. Langmuir isotherm for chromium biosorption by *Saccharomyces cerevisiae* from effluent generated in chrome-electroplating unit.

Biosorption Isotherms

The Freundlich adsorption isotherm for chromium biosorption by *Saccharomyces cerevisiae* is given in Fig. 6. Values of K_f and $1/n$ obtained from the isotherm are compared in Table 2. The magnitude of K_f and $1/n$ illustrate the separation of metal ions from wastewater and the adsorption capacity of the yeast ($K_f = 0.3727$). The Freundlich adsorption equation thus arrived at is: $q = 0.3727C_e^{1.016}$. The Langmuir adsorption isotherm for chromium biosorption by *S. cerevisiae* is plotted in Fig. 7. Values of Q_{max} and b obtained

Table 3. Comparison of isotherm constants for chromium biosorption available in literature

Sl. No.	Type of biomass	Freundlich constant K_f	Langmuir constant Q_{max} (mg/g)	Maximum concentration used (mg/L)	Reference
1.	*Saccharomyces cerevisiae*	0.3727	384.61	200	Present study
2.	*Sargassum sp.*	10.782	68.94	300	(32)
3.	*Pantoea sp.*	1.80	204.1	250	(25)
4.	*Aeromonas caviae*	11.76	181.48	250	(33)
5.	*Rhizopus nigricans*	12.06	43.47	400	(34)
6.	*Pseudomonas sp.*	0.112	111.11	325	(35)
7.	Bacterial consortium	2.63	38.17	100	(36)

from the isotherm are compared in Table 2. Q_{max} value of 384.61 mg/g for *S. cerevisiae* indicates high metal uptake by the biomass. The Langmuir adsorption equation thus arrived at is: $q = [384.61 \times 0.1259 \times Ce]/[1 + (0.1259 \times Ce)]$.

Table 3 gives a comparison of the Freundlich and Langmuir isotherm constants available in literature for chromium biosorption by various biosorbents. Comparatively lower K_f value (0.3727) was observed in the present study. This may be due to the presence of ions other than chromium in the effluent which decrease the specificity of *Saccharomyces cerevisiae* for chromium. However, the Q_{max} value of 384.61 mg/g is indicative of high biosorption potential of the biomass.

CONCLUSION

Chromium biosorption efficiency of *Saccharomyces cerevisiae* from effluent generated in a chrome-electroplating unit was evaluated under laboratory conditions. The chromium biosorption equilibration time was 2 hours with an uptake of 6.607 mg/g. In the biosorption system where the biomass concentration was varied, chromium uptake was highest at 2%. An increasing trend in biosorption was observed with rise in pH and chromium concentration. In experiments where agitation speed was varied, the chromium uptake increased gradually from 50 to 150 rpm. The Freundlich and Langmuir constants determined from the respective adsorption isotherms revealed K_f and Q_{max} values of 0.3727 and 384.61 mg/g, respectively. These constants are indicative of high biosorption potential of the *S. cerevisiae*. The findings of the study indicate that biosorption is a promising technology for removal of chromium from effluent generated in chrome-electroplating unit. However, further studies with respect to metal-biomass specificity and applicability to various other metal-laden effluents will help fine-tune this process for large-scale application.

REFERENCES

1. Gupta, V.K., Mohan, D., Sharma, S., and Park, K.T. (1999) Removal of chromium(VI) from electroplating industry wastewater using bagasse fly ash-a sugar industry waste material. *Environmentalist.*, 19: 129–136.
2. Cervantes, C., Garcia, J.C., Devars, S., Corona, F.G., Tavera, H.L., Guzan, J.C.T., and Sanchez, R.M. (2001) Interactions of chromium with microorganisms and plants. *FEMS Microbiol Rev.*, 25: 335–347.
3. Carson, B.L., Ellis, H.V., and McCann, J.L. (1986) *Toxicology and Biological Monitoring of Metals in Humans*; Lewis Publishers: Chelsea, USA.
4. Baik, W.Y., Bae, J.H., Cho, K.M., and Hartmeier, W. (2002) Biosorption of heavy metals using whole mold mycelia and parts thereof. *Biores Technol.*, 81: 167–170.

5. Veglio, F. and Beolchini, F. (1997) Removal of metals by biosorption, a review. *Hydrometallurgy*, 44: 301–316.
6. Ting, Y. and Sun, G. (2000) Use of polyvinyl alcohol as a cell immobilization matrix for copper biosorption by yeast cells. *J. Chem. Technol. Biotechnol.*, 75: 541–546.
7. Zouboulis, A.I., Rousou, E.G., Matis, K.A., and Hancock, I.C. (1999) Removal of toxic metals from aqueous mixtures. Part 1: Biosorption. *J. Chem. Technol. Biotechnol.*, 74: 429–436.
8. Goksungur, Y., Uren, S., and Guvenc, U. (2005) Biosorption of cadmium and lead ions by ethanol treated waste baker's yeast biomass. *Biores. Technol.*, 96: 103–109.
9. Marques, P.A.S.S., Rosa, M.F., and Pinheiro, H.M. (2000) pH effects on the removal of Cu^{2+}, Cd^{2+}, and Pb^{2+} from aqueous solution by waste brewery biomass. *Bioprocess Eng.*, 23: 135–141.
10. Goyal, N., Jain, S.C., and Banerjee, U.C. (2003) Comparative studies on the microbial adsorption of heavy metals. *Adv. Environ. Res.*, 7: 311–319.
11. Suh, J.H., Kim, D.S., Yun, J.W., and Song, S.K. (1998) Process of Pb^{2+} accumulation in *Saccharomyces cerevisiae*. *Biotechnol. Lett.*, 20: 153–156.
12. Jianlong, W. (2002) Biosorption of copper (II) by chemically modified biomass of *Saccharomyces cerevisiae*. *Process Biochem.*, 37: 847–850.
13. Zouboulis, A.I., Matis, K.A., and Lazaridis, N.K. (2001) Removal of metal ions from simulated wastewater by *Saccharomyces* yeast biomass: combining biosorption and flotation processes. *Separ. Sci. Technol.*, 36: 349–365.
14. Brower, J.B., Ryan, R.L., and Pazirandeh, M. (1997) Comparison of ion-exchange resins and biosorbents for the removal of heavy metals from plating factory waste. *Water Sci. Technol.*, 31: 2910–2914.
15. American Public Health Association (APHA). (1998) *Standard Methods for the Examination of Water and Wastewater*, 20th ed.; American Public Health Association Publications: Washington, DC, USA.
16. Vieira, R.H.S.F. and Volesky, B. (2000) Biosorption: a solution to pollution? *Int. Microbiol.*, 3: 17–24.
17. Environment (Protection) Act. (1987) *Electroplating Industry: Wastewater Discharge Standards*; Ministry of Environment and Forests, Government of India: New Delhi, India.
18. Ferraz, A.I., Tavares, T., and Teixeira, J.A. (2004) Cr(III) removal and recovery from *Saccharomyces cerevisiae*. *Chem. Eng. J.*, 105: 11–20.
19. Ferraz, A.I. and Teixeira, J.A. (1999) The use of flocculating brewer's yeast for Cr(III) and Pb(II) removal from residual wastewaters. *Bioprocess Eng.*, 21: 431–437.
20. Chandra Sekhar, K., Subramanian, S., Modak, J.M., and Natarajan, K.A. (1998) Removal of metals using an industrial biomass with reference to environmental control. *Int. J. Miner. Process.*, 53: 107–120.
21. Itoh, M., Yuasa, M., and Kobayashi, T. (1975) Adsorption of metal ions on yeast cells at various cell concentrations. *Plant Cell Physiol.*, 16: 1167–1169.
22. Pons, M.P. and Fuste, C.M. (1993) Uranium uptake by immobilized cells of *Pseudomonas* strain EPS 5028. *Appl. Microbiol. Biot.*, 39: 661–665.
23. Seki, H., Suzuki, A., and Maruyama, H. (2005) Biosorption of chromium (VI) and arsenic (V) onto methylated yeast biomass. *J. Colloid Interf. Sci.*, 281: 261–266.
24. Oliveira, E.A., Montanher, S.F., Andrade, A.D., Nobrega, J.A., and Rollemberg, M.C. (2005) Equilibrium studies for the sorption of chromium and

nickel from aqueous solution using raw rice bran. *Process Biochem.*, 40: 3485–3490.
25. Cossich, E.S., Tavares, C.R.G., and Ravagnani, T.M.K. (2002) Biosorption of chromium (III) by *Sargassum sp.* biomass. *Electron. J. Biotechno.*, 5: 133–140.
26. Fiol, N., Villaescusa, I., Martinez, M., Miralles, N., Poch, J., and Serarols, J. (2003) Biosorption of Cr(VI) using low cost biosorbents. *Environ. Chem. Lett.*, 1: 135–139.
27. Bingol, A., Ucun, H., Bayhan, Y.K., Karagunduz, A., Cakici, A., and Keskinler, B. (2004) Removal of chromate anions from aqueous stream by a cationic surfactant-modified yeast. *Biores. Technol.*, 94: 245–249.
28. Cruz, C.C.V., da Costa, A.C.A., Henriques, C.A., and Luna, A.S. (2004) Kinetic modeling and equilibrium studies during cadmium biosorption by dead *Sargassum sp*. *Biomass. Biores. Technol.*, 91: 249–257.
29. Martins, B.L., Cruz, C.C.V., Luna, A.S., and Henriques, C.A. (2006) Sorption and desorption of Pb^{2+} ions by dead *Sargassum sp.* biomass. *Biochem. Eng. J.*, 27: 310–314.
30. Selatnia, A., Kechid, B.N., Bakhti, M.Z., Chergui, A., and Kerchich, Y. (2004) Biosorption of lead (II) from aqueous solution by a bacterial dead *Streptomyces rimosus* biomass. *Biochem. Eng. J.*, 19: 127–135.
31. Vilar, V.J.P., Sebesta, F., Botelho, C.M.S., and Boaventura, R.A.R. (2005) Equilibrium and kinetic modelling of Pb^{2+} biosorption by granulated agar extraction algal waste. *Process Biochem.*, 40: 3276–3284.
32. Ozdemir, G., Ceyhan, N., Ozturk, T., Akirmak, F., and Cosar, T. (2004) Biosorption of chromium (VI), cadmium (II), and copper (II) by *Pantoea sp.* TEM18. *Chem. Eng. J.*, 102: 249–253.
33. Loukidou, M.X., Zouboulis, A.I., Karapantsios, T.D., and Matis, K.A. (2004) Equilibrium and kinetic modeling of chromium (VI) biosorption by *Aeromonas caviae.*. *Colloid Surface A.*, 242: 93–104.
34. Bai, R.S. and Abraham, T.E. (2001) Biosorption of Cr(VI) from aqueous solution by *Rhizopus nigricans*. *Biores. Technol.*, 79: 73–81.
35. Hussein, H., Ibrahim, S.F., Kandeel, K., and Moawad, H. (2004) Biosorption of heavy metals from waste water using *Pseudomonas sp*. *Electron. J. Biotechno.*, 7: 38–46.
36. Sannasi, P., Kader, J., Ismail, B.S., and Salmijah, S. (2006) Sorption of Cr(VI), Cu(II), and Pb(II) by growing and non-growing cells of a bacterial consortium. *Biores. Technol.*, 97: 740–747.