

Biosorption of Cr (VI) ions from electroplating industrial effluent using immobilized *Aspergillus niger* biomass

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Abstract: A fungus, *Aspergillus niger* was chemically treated with 0.1 M H₂SO₄ and 0.1N NaOH to form biosorbent and it was immobilized in calcium alginate beads. The biosorption capacity of immobilized biosorbents for Cr (VI) was found to depend on pH, contact time, biosorbent dose and initial concentration of Cr(VI). The maximum uptake of Cr (VI) was 92.5, 95.9 and 98.4 mg respectively at a pH of 1.5 and with an increase in pH up to 10.5 the metal uptake decreased gradually upto 38.75, 50.19 and 65.28 mg respectively for acid treated, untreated and base treated fungal biosorbents. Increase in biosorbent dose up to 1g of biomass and contact time up to 60 min resulted in an increase in biosorption from 19.6, 15.6 and 26.1 mg at a biosorbent dose of 0.1g 100 ml⁻¹ to 92.45, 95.7 and 98.52 mg at a biosorbent dose of 1.0 g 100 ml⁻¹ and then further increase in adsorbent dose and contact time did not resulted in more Cr (VI) adsorption by per unit weight of biosorbent. The value of K_{ad} (adsorption rate constant) revealed the pseudo-first order nature of biosorption. The percentage metal uptake by the biosorbent was found to decrease upto 62.33, 52.67 and 83.5 percent respectively for acid treated, untreated and base treated fungal biosorbents at the 300 mg l⁻¹ Cr (VI) ion concentration. The resulted data was found to fit well in Langmuir model of adsorption isotherm with a high value of correlation coefficient. The value of Q_{max}, b (Langmuir constants), R_L (separation factor) and ΔG (Gibb's free energy) revealed the favourable nature of adsorption. The biosorbed metal was eluted from the biosorbent by using 0.1M H₂SO₄ as elutant. Immobilized biosorbent can be reused for, five consecutive biosorption/desorption cycles without apparent loss of efficiency after its reconditioning. The biosorbent was found to perform well in the electroplating industrial effluent.

Key words: *Aspergillus niger*, Adsorption, Immobilization, Isotherm, Chromium
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Introduction

In the wake of industrialization, consequent urbanization and ever increasing population, the basic amenities of life viz. air, water and land are being polluted continuously. Industrial complexes have become the focus of environmental pollution (Shukla *et al.*, 2007a). The main pollutant from these industrial complexes is the effluent which contains heavy metals such as Cu, Ni, Zn, Pb, Cr, Hg, Cd *etc.* and various organic compounds such as phenols, formaldehyde *etc.* (Rajendran *et al.*, 2003). The biomagnification of these heavy metals in ecosystem is a major threat to human life (Yigit and Altindag, 2006; Hooda, 2007). To comply with the permissible limits, various techniques are used for the removal of heavy metals. The recovery of heavy metals using conventional techniques is neither economical nor eco-friendly (Sarkar and Gupta, 2003; Shukla *et al.*, 2007b). So, there is a continuous search for an economic and ecofriendly approach of heavy metals removal.

In this endeavor, biosorption, a biological method of environmental control, has emerged as an alternative to conventional waste treatment facilities as it has advantages of low operating cost, effective in dilute solutions, generates minimum secondary waste, completes with in a short time period and have no toxicity limits for heavy metals (Dadhich *et al.*, 2004; Ahalya *et al.*, 2007). Biosorption is the process in which physico-chemical interaction between the charged surface groups of micro-organisms and ions in solution takes place by the process of complexation, ion exchange, microprecipitation *etc.* (Mise and Rajamanya, 2003). Biosorption is attractive since naturally occurring biomass or spent biomass from

various fermentation industries can be effectively utilized (Gupta *et al.*, 2000). These advantages have served as potential incentives for promoting biosorption as viable cleanup technology for heavy metal pollution. Immobilization of biosorbent leads to its stability and it can be used repeatedly with ease for the process of adsorption/desorption (Srinath *et al.*, 2003). Biotechnological exploitation of biosorption technology depends on the efficiency of regeneration of biosorbent after metal desorption. Therefore, recovery of biosorbent by mild and cheap desorbing agents is desirable for regeneration of biomass for use in multiple biosorption cycles.

In the light of these observations, studies on biosorption of Cr (VI) to immobilized fungal biomass were carried out in the present research study. *Aspergillus niger* was used for the removal of Cr (VI) from electroplating industrial effluent and highlighted the prospects of its future uses as a biosorbent material for the Cr(VI) removal.

Materials and Methods

Chemicals and reagents: All the chemicals used were of analytical grade and the chemicals were supplied by Qualigens Fine Chemicals (Bombay, India). Stock metal solutions of Cr (VI) were prepared by dissolving appropriate quantities of pure analytical grade metal salts in double distilled water. The stock solutions were diluted further with deionized distilled water to obtain working solutions of different concentrations.

Characterization of industrial effluent: The effluent was collected from Luxmi Precision Screws Ltd. (Rohtak) which is an electroplating



Table - 1: Physico-chemical properties of electroplating industrial effluent

| | |
|------------------------|------------|
| Color | Dark green |
| Total dissolved solids | 21,375 |
| Oil and grease | 23 |
| pH(1.2) | 4.1 |
| BOD | 173 |
| COD | 456 |
| Sulphate | 187 |
| Phosphate | 0.86 |
| Cr(VI) | 117 |
| Zn(II) | 94.8 |
| Cu | 0.63 |
| Fe | 7.63 |
| Ni | 13.87 |
| CN- | 9.5 |

All units are in mg l^{-1} except pH

Table - 2: Constants and correlation coefficient for immobilized *A. niger*

| Biosorbents | Q_{max} (mg g^{-1}) | b (mg l^{-1}) | r^2 | R_L | ΔG | K_{ad} |
|--------------|--|-------------------------------|--------|--------|------------|-----------------|
| Acid treated | 20.1613 | 0.10894 | 0.9987 | 0.0841 | -9.1666 | 0.025 |
| Base treated | 26.666 | 0.3495 | 0.9910 | 0.0278 | -5.3298 | 0.0339 |
| Untreated | 16.3934 | 0.3041 | 0.9893 | 0.0318 | -5.3067 | 0.0313 |

industry. The effluent collected from industry, was analyzed for different physico-chemical properties (Table 1) viz. total dissolved solids, hydrogen ion concentration, colour, oil and grease, BOD, COD, sulphate, phosphate, chromium, copper, nickel and zinc. The concentration of each of the component was determined as per the procedure outlined in APHA (2005).

Estimation of Cr(VI): Chromium analysis was carried out by spectrophotometric method by using 1,5-Di-phenyl carbazide according to APHA (2005). The hexavalent chromium is determined colorimetrically by reaction with diphenylcarbazide in acid solution. A red-violet color is produced. The reaction is very sensitive, the absorptivity based on chromium being about $40000 \text{ l g}^{-1} \text{ cm}^{-1}$ at 540 nm wavelength.

Isolation, growth and processing of cells: Pure cultures of *A. niger* were obtained from IARI, New Delhi and were routinely maintained by streaking on a rose bengal agar medium and incubating at 25°C . For mass culturing, liquid broth was used as a culture medium which was having the following composition (g l^{-1}): Bactodextrose, 20; Bactopeptone, 10; NaCl, 0.2; $\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$, 0.1; KCl, 0.1; K_2HPO_4 , 0.5; NaHCO_3 , 0.05; MgSO_4 , 0.25 and $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$, 0.005. The liquid phase pH was adjusted to 4.5 by using the 0.1M HCl and 0.1N NaOH.

The liquid broth was inoculated with a loop of culture grown on rose bengal agar medium and incubated on an orbital shaker (Orbitek, Sci. Genics Biotech Ltd.) at 125 rpm and 25°C for five days in 250 ml conical flasks. The biomass produced was collected by vacuum filtration and washed twice with extra pure double distilled water. The washed biomass was dried at 60°C in an oven and dry

material was ground and sieved through 100 mm screen. In order to generate active sites and enhance the metal biosorption capacity, the dry biomass was conditioned in batches ($1.5 \text{ g } 100 \text{ ml}^{-1}$) by treatment with 0.1 M H_2SO_4 and 0.1N NaOH for 30 min at 60°C . The treated biomass was collected by centrifugation and washed twice with extra pure double distilled water. After washing, the biomass was dried at 60°C in an aluminum foil till the weight of biomass became constant. It was then ground and sieved through a screen with pore size of 100 mm and stored at 60°C .

Immobilization of biosorbent: To establish a simple and cost effective granulation of the biomass, it was immobilized in Ca-alginate matrix. The immobilization of fungal biosorbent via entrapment was carried out as follows: 3% (w/v) Na-alginate was dissolved in distilled water and mixed with 5% (w/v) of fungal biosorbent. The mixture was stirred for 1 hour at 30°C and then, the slurry solution was dripped through a nozzle into 4% (w/v) CaCl_2 solution (Dong, 2004). Durable, spherical beads containing biomass were formed immediately by a phase inversion process as the alginate was cross-linked by Ca^{2+} . Bead size varied according to the diameter of injection nozzle. The gel beads ($3.2 \text{ mm} \pm 0.1 \text{ mm}$) were moderately agitated in the double distilled water for 2 hr at 4°C . The curing procedure hardened the beads and resulted in the formation of a favourable micro-porous structure. Finally, the beads were stored at 4°C in ultrapure double distilled water until further use.

Batch studies: The batch adsorption studies were carried out in triplicate in the 250 ml conical flasks at temperature $28^\circ\text{C} \pm 0.15^\circ\text{C}$ (Srinath *et al.*, 2003). The incubated shaker (Orbitek, Scigenics Biotech Ltd.) was used for batch studies at 150 rpm. A predetermined amount of biosorbent was mixed with 100 ml of heavy metal solutions in 250 ml conical flasks. After a desired contact period conical flasks were removed and the solutions were filtered through Whatman filter paper 42 and the filtrate was analyzed for residual Cr(VI) concentration. The Cr(VI) removal affinity of biosorbent was determined from batch experiments as a function of contact time, pH, biosorbent dosage and initial concentration of metal ions. The adsorption data was analyzed by employing Langmuir adsorption isotherm.

Metal desorption and biosorbent reutilization: For metal desorption assays, the biosorbent was prior exposed to metal solutions under optimum conditions, as described above and then separated (Srinath *et al.*, 2003). The metal loaded biosorbent was incubated for 1 hr at 28°C with 50 ml of 0.1 M H_2SO_4 in rotary shaker for continuous stirring at 150 rpm. The solution was then filtered through whatmann filter paper 42 and the filtrate was used to determine the metal released. The total desorbed metal was established by comparing the metal released to the amount of metal previously adsorbed to the biosorbent. All experiments were run in triplicates. The metal stripped biosorbent was rinsed with 50 ml of ultrapure double distilled water for 15 min for two times. The acid treated and base treated biomass was activated by treating them with 0.1 M H_2SO_4 and 0.1N NaOH respectively for 30 min at 150 rpm. The resulting biomass was then reloaded with metal solutions as described above and the desorption treatment was repeated.

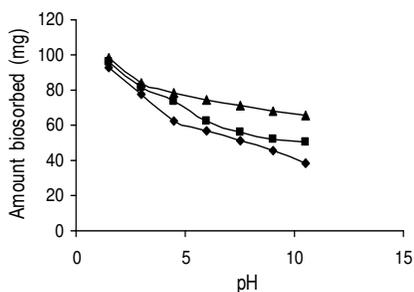


Fig. 1: Cr(VI) biosorption by immobilized acid treated, untreated and base treated *A. niger* at various pH

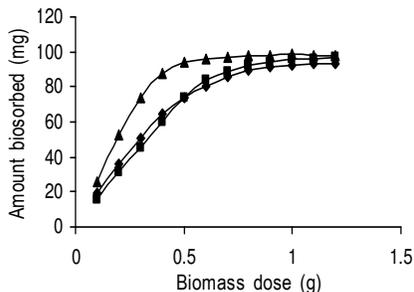


Fig. 2: Cr(VI) biosorption by immobilized acid treated, untreated and base treated *A. niger* at various biomass doses

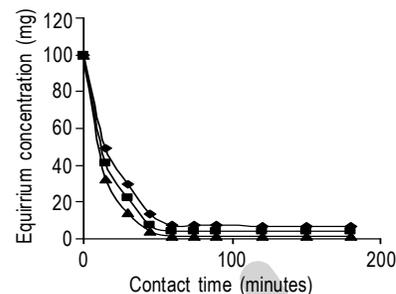


Fig. 3: Cr(VI) biosorption by immobilized acid treated, untreated and base treated *A. niger* at various contact time periods

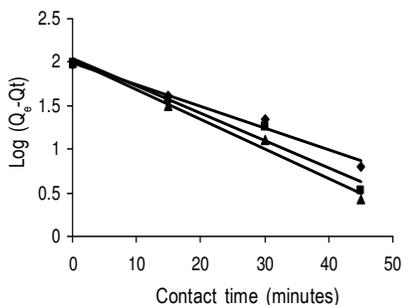


Fig. 4: Lagergren's plot for immobilized acid treated, untreated and base treated *A. niger*

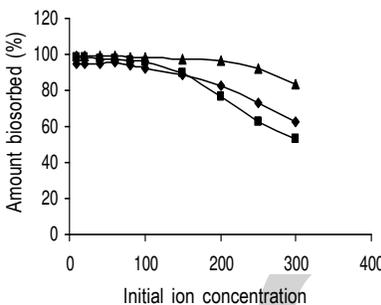


Fig. 5: Metal biosorption by immobilized acid treated, untreated and base treated *A. niger* at different initial ion concentration of Cr(VI)

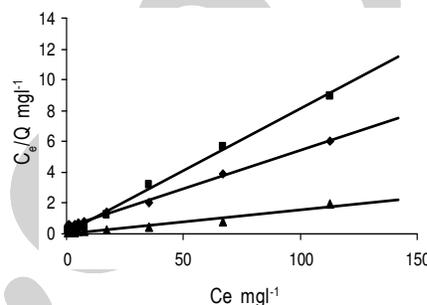


Fig. 6: Langmuir adsorption isotherm plot for immobilized acid treated, untreated and base treated *A. niger*



Results and Discussion

Characterization of Industrial effluent: The dark green colored turbid effluent was found to be odorless (Table 1). The amount of chromium was found to be higher than CPCB (Central Pollution Control Board) standards, which possess a great threat to the ecosystem. The main form of the metal present in the effluent was Cr(VI).

Effect of pH: To study the effect of pH, experiments were conducted with 1g biomass dose of biosorbent for a contact time of 60 min. The pH varied from 1.5 to 10.5 with the help of 0.1 M H₂SO₄ and 0.1 N NaOH. The results as depicted in Fig. 1 showed that the metal uptake was optimum at pH 1.5. Further increase in pH beyond optimal value(1.5) resulted in decrease of metal uptake. This observation agrees with the earlier reports on Cr(VI) removal by different biosorbents (Mise and Rajamanya, 2003). As the pH of the system increases, the number of negatively charged sites increases and the number of positively charged sites decreases. A negatively charged surface site on the adsorbent does not favour the adsorption of anions due to the electrostatic repulsion (Neelavathi *et al.*, 2004). The reduction in adsorption at higher pH may be possible due to the abundance of OH⁻ ions causing increased hindrance to the diffusion of metal ions (Vasanthy *et al.*, 2003).

Effect of biomass dose: The optimum pH from above experiments with contact time of 60 minutes was kept to find the optimum dose of biomass. Various doses (0.1 to 1.2 g) of biomass were tested for Cr(VI) removal from synthetic solutions of 100 mg l⁻¹ concentration. 1g of biomass dose was sufficient for the optimum removal of Cr(VI) ions as shown in Fig. 2. Increase in biomass dose after optimum value did not show corresponding increase in the metal ion uptake from the solution. Interaction of biosorbent and metal ions is generally electrostatic in nature on the binding sites present on the surface of biosorbent. For a given constant biosorbent concentration, the initial metal ion adsorption increased up to the stage of saturation of all the binding sites and further increase in the dose of biosorbent did not change the metal adsorption / biomass ratio. Also, the high concentration of biosorbent resulted in screen effect of dense outer layer of cells and blocking the binding site from metal ions, resulting in lower metal removal per unit biosorbent (Meena *et al.*, 2004).

Selection of optimum contact time: Relationship between contact time and Cr(VI) removal was investigated by using immobilized biosorbent with 1g biomass dose of each. The pH of the 100 mg l⁻¹ Cr(VI) solution was adjusted to 1.5. The maximum amount of Cr(VI) uptake was observed after 60 min as shown in Fig. 3. Increase in contact time from 60 to 180 min did not result in corresponding increase in uptake capacity of biosorbent. It was observed that



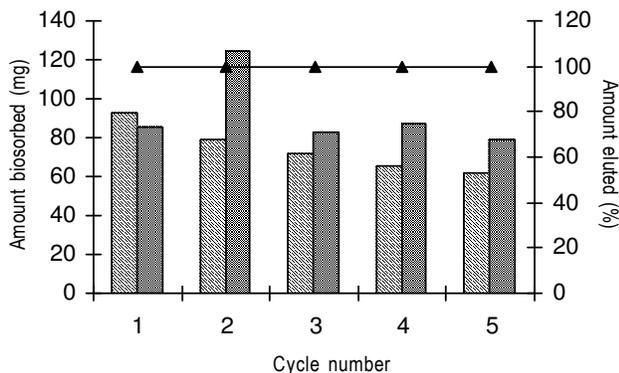


Fig. 7: Biosorption/desorption cycle for chromium removal by immobilized acid treated *A. niger*

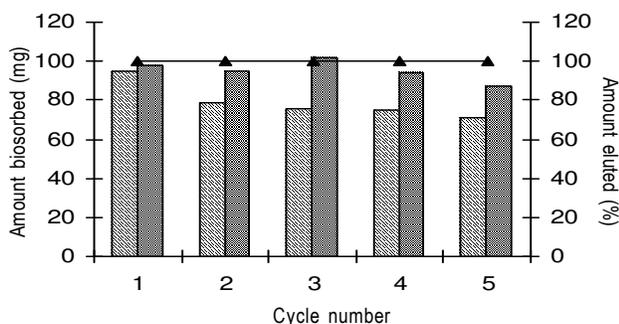


Fig. 8: Biosorption/desorption cycles for chromium removal by immobilized untreated *A. niger*

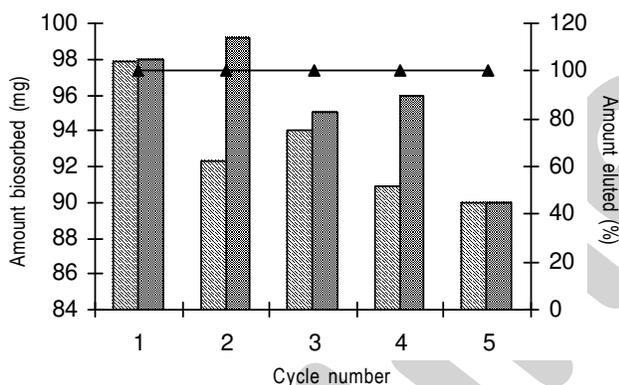
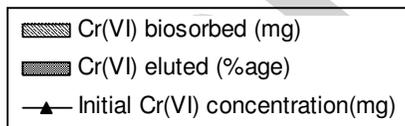


Fig. 9: Biosorption/desorption cycles for chromium removal by immobilized base treated *A. niger*



biosorption is a rapid process as most of the adsorption (80-85%) was completed in the initial 45 min. These results indicated that the adsorption sites were bind up in the initial 60 min by the metal ions passively. After this, the increase in contact time might not help for more adsorption of metal ions with this biosorbent (Meena *et al.*, 2004). As a result, 60 min was chosen as optimum contact time for

further studies. The Lagergren's plot (Fig.4) revealed the pseudo first order reaction rate of biosorption process.

Effect of initial metal ion concentration: The uptake of metal ions was observed for different initial ion concentration of Cr(VI) at optimum contact time and biosorbent dose. The results revealed that an increase in metal ion concentration resulted in gradual decrease in percent biosorption of Cr(VI) up to 100 mg^l⁻¹ and after that a sharp decrease in metal uptake percentage as shown in Fig. 5. An increase in initial concentration of metal ions resulted in the lowering of metal ion uptake due to reduction in ratio of sorptive surface to ion concentration. (Chandra *et al.*, 2005; Meena *et al.*, 2004).

Adsorption Isotherm: Equilibrium occurring during adsorption at a definite concentration range could be represented by Langmuir isotherm for adsorption (Dhar *et al.*, 2005; Dong, 2006). The equilibrium data was analyzed with the help of Langmuir adsorption isotherm (Fig. 6).

The Langmuir equation is given by,

$$Q_e = \frac{Q_{max} b C_e}{1 + b C_e}$$

Where, Q_e is the amount of metal adsorbed per unit mass of biosorbent (mgg⁻¹)

C_e is the equilibrium concentration of metal ion (mg^l⁻¹)

Q_{max} and b are Langmuir constants

The value of r^2 (correlation coefficient) showed that the adsorption data for Cr (VI) was fitted well into Langmuir adsorption isotherm (Table 2). It was found to be linear over a wide range of concentration. Langmuir constants ' Q_{max} ' which is a measure of adsorption capacity expressed in mg g⁻¹ and ' b ' which is a measure of energy of adsorption expressed in mg^l⁻¹ were calculated from the slope and intercept of plots (Baran *et al.*, 2005) are shown in Table 2.

The Langmuir model assumes about constant adsorption energy. The agreement of the experimental data with the model showed that constant adsorption energy existed for the experimental conditions. The essential characteristics of Langmuir isotherm can be expressed in terms of dimensionless constant, R_L (Dhar *et al.*, 2005) separation factor for equilibrium parameter, which is defined by,

$$R_L = \frac{1}{(1 + b C_i)}$$

Where C_i is the initial concentration of metal ion (mg^l⁻¹) and b is Langmuir constant (mg^l⁻¹). The R_L values obtained in the present studies for different metal ions indicated favorable adsorption on the biosorbent surface (Meena *et al.*, 2004). Thus, heavy metal removal by *A. niger* is considered to be a chemical, equilibrated and site specific mechanism on the biosorbent surface.

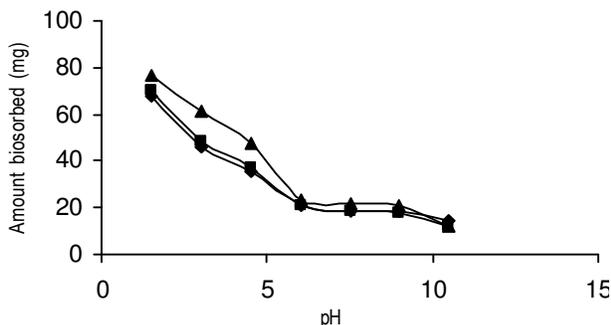


Fig. 10: Removal of Cr(VI) from industrial effluent by immobilized acid treated, untreated and base treated *A. niger*



Free energy change (ΔG) was calculated using the following equation:

$$\Delta G = -RT \ln b$$

where,

- ΔG = Free energy change
- R = Universal gas constant
- T = Absolute temperature
- b = Langmuir constant

The values of ΔG (Table 2) observed to be negative, thus, indicating the spontaneous and exothermic nature of the adsorption process (Chandra *et al.*, 2005). The higher negative values reflect a more energetically favorable adsorption process (Sarin and Pant, 2006).

Desorption of metal ions and reutilization of biosorbent:

The total amount of metal biosorbed and desorbed in each subsequent cycle by immobilized biosorbents were calculated as shown in Fig. 7, 8, 9. The amount of Cr(VI) adsorbed in the 5th cycle was comparable to the first cycle. Also, the amount of metal desorbed after each loading cycle corresponded well to the amount of metal biosorption, which showed that a complete elution took place.

Performance of immobilized biosorbent in industrial effluent:

The batch study was carried out with 100 ml industrial effluent at $28 \pm 0.15^\circ\text{C}$ and 150 rpm in 250 ml Erlenmeyer flasks. Immobilized biosorbent with a biomass dose of 1 g was used for a contact period of 40 minutes and it was found that biosorption of Cr(VI) was less in industrial effluent as compared to single metal ion synthetic solutions as shown in Fig. 10. This may be due to interference and binding of other metal ions to the binding sites which was not the case with single metal ion synthetic solutions as all the binding sites were available for just single metal species. Overall, the performance was good in present electroplating industrial effluent. The tendency of biosorbents for metal removal in the present effluent was found in order of base treated > untreated > acid treated.

The present study showed that base treated biosorbent performed better than acid treated and untreated biosorbent. The explanation offered is that the increase in the metal uptake may be

due to unmasking of some of cellular groups, which cannot participate in the sorption process without the treatment of alkali. Muzzarelli *et al.* (1980) also found that alkali treatment of *Aspergillus niger* mycelia improved their capacity to chelate various metal ions. Leuf *et al.* (1991), in trying to explain the increase in metal uptake by *A. niger* after NaOH treatment, thereby suggesting that the removal of certain polysaccharides from the cell wall by alkali treatment generates more accessible spaces with in the β -glucan chitin skeleton, thus allowing more metal ions to be sequestered by this structure. Immobilization of biosorbent increases the efficiency and ease of handling the process. The effect of pH and the higher sorption capacity suggests the electrostatic attraction of metal ions onto the fungal surface. The favorable values of Langmuir constants, R_L factor and "G" showed that *A. niger* is a good option for the removal of Cr(VI) from electroplating industrial effluent.

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Index words:

- M = Molarity
- N = Normality
- Cr = Chromium
- Q_e = Metal uptake per unit mass of biosorbent, mg g^{-1}
- C_e = Equilibrium concentration of metal ions, mg l^{-1}
- C_i = Initial concentration of metal ion
- Q_{max} = Langmuir constant for adsorption capacity, mg g^{-1}
- b = Langmuir constant for energy of adsorption, mg l^{-1}
- r^2 = Coefficients of correlation
- R_L = Separation factor
- w/v = Weight/volume, mg l^{-1}
- X = Amount of metal uptake
- Q_t = Equilibrium concentration at time 't', mg l^{-1}

References

- Ahalya, N., R.D. Kanamadi and T.V. Ramachandra: Cr(VI) and Fe (III) removal using *Cajanus cajan* husk. *J. Environ. Biol.*, **28**, 765-769 (2007).
- APHA: Standard methods for the examination of water and wastewater. 21st Edn. Washington, D.C. (2005).
- Baran, A., S.H. Baysal and A. Sukatar: Removal of Cr^{6+} from aqueous solution by some algae. *J. Environ. Biol.*, **26**, 329-333 (2005).
- Chandra, N., N. Agnihotri, P. Sharma, S. Bhasin and S.S. Amritphale: Separation of lead ions from aqueous solutions by adsorption at talc surface. *J. Scientific and Industrial Research*, **64**, 674-678 (2005).
- Dadhich, A.S., S.K. Deebi and G.V. Kavitha: Adsorption of Ni(II) using Agrowaste, Rice Husk. *J. Environ. Sci. Eng.*, **46**, 179-185 (2004).
- Dhar, N.R., A.K.M.B. Khoda, A.K. Khan, P. Bala and M.F. Karim: A study of effects of acid activated saw dust on the removal of different dissolved tannery dyes (acid dyes) from aqueous solutions. *J. Environ. Sci. Eng.*, **47**, 103-108 (2005).
- Dong, X.: A comparative study of Cu (II) biosorption on Ca-alginate and immobilized live and inactivated *Cladosporium* sp. *J. Environ. Biol.*, **25**, 337-341 (2004).
- Dong, X.: Biosorption of Cu^{2+} from aqueous solutions by pretreated *Cladosporium* sp. *J. Environ. Biol.*, **27**, 639-643 (2006).



- Gupta, R., P. Ahuja, S. Khan, R.K. Saxena and H. Mohapatra: Microbial biosorbents: Meeting challenges of heavy metal pollution in aqueous solutions. *Curr. Sci.*, **78**, 967-972 (2000).
- Hooda, V.: Phytoremediation of toxic metals from soil and wastewater. *J. Environ. Biol.*, **28**, 367-376 (2007).
- Leuf, E., T. Prey and C.P. Kubicek: Biosorption of zinc by fungal mycelial waste. *J. Appl. Microbial Biotech.*, **34**, 688-692 (1991).
- Meena, A.K., G.K. Mishra, S. Kumar, C. Rajagopal and P.N. Nagar: Adsorption of Cd(II) ions from aqueous solution using different adsorbents. *Ind. J. Scientific Indus. Res.*, **63**, 410-416 (2004).
- Mise, S.R. and V.S. Rajamanya: Adsorption studies of chromium(VI) on activated carbon derived from *Sorghum vulgare* (Dried Stem of Jowar). *Ind. J. Environ. Hlth.*, **45**, 49-58 (2003).
- Muzzarelli, R.A.A., F. Tanfani and G. Scarpini: Chelating, film forming and coagulating ability of the chitosan-glucon complex from *Aspergillus niger* industrial waste. *J. Biotech. Bioeng.*, **22**, 885-896 (1980).
- Neelavathi, A., K.B. Chandrashekhar, C. Rameshbabu and K.N. Jayaveera: Removal of toxic Cr(VI) by the adsorption of activated carbons prepared from Simarouba shells. *J. Environ. Sci. Eng.*, **46**, 137-142 (2004).
- Rajendran, P., J. Muthukrishnan and P. Gunasekaran: Microbes in heavy metal remediation. *Ind. J. Exp. Biol.*, **41**, 935-944 (2003).
- Sarin, V. and K.K. Pant: Removal of chromium from industrial waste by using eucalyptus bark. *Bioresource Technol.*, **97**, 15-20 (2006).
- Sarkar, S. and A. Gupta: Treatment of chrome plating waste water (Cr⁶⁺) using activated alumina. *Ind. J. Environ. Hlth.*, **45**, 73-82 (2003).
- Shukla, O.P., U.N. Rai, N.K. Singh, S. Dubey and V.S. Baghel: Isolation and characterization of chromate resistant bacteria from tannery effluent. *J. Environ. Biol.*, **28**, 399-403 (2007b).
- Shukla, V., M. Dhankhar, J. Prakash and K.V. Sastry: Bioaccumulation of Zn, Cu and Cd in *Channa punctatus*. *J. Environ. Biol.*, **28**, 395-397 (2007a).
- Srinath, T., S.K. Garg and P.W. Ramteke: Biosorption and elution of chromium from immobilized *Bacillus Coagulans* biomass. *Ind. J. Exp. Biol.*, **41**, 986-990 (2003).
- Vasanthy, M., M. Sangeetha and C. Kavitha: Removal of chromium from aqueous solutions using a mixture of flyash and activated carbon. *Ind. J. Environ. Protect.*, **23**, 1321-1325 (2003).
- Yigit, Sibel and Ahmet Altindag: Concentration of heavy metals in the food web of Lake Egirdir, Turkey. *J. Environ. Biol.*, **27**, 475-478 (2006).