Removal and Recovery of Cr(VI) from Synthetic and Industrial Wastewater using Bark of Pinus roxburghii as an Adsorbent

Rais Ahmad,* Rifaqat Ali Khan Rao and Mir Mohammad Masood

Environmental Research Laboratory, Department of Applied Chemistry, Faculty of Engineering and Technology, Aligarh Muslim University, Aligarh – 202 002 (UP), India

In the present study, the potential of Pinus roxburghii bark as an adsorbent for the removal of heavy metals such as Cr(VI), Ni(II), Cu(II), Cd(II) and Zn(II) from aqueous solution at ambient temperature was investigated. Adsorption capacity of the material was found to be 4.15, 3.89, 3.81, 3.53 and 3.01 mg g⁻¹ for Cr(VI), Zn(II), Cu(II), Ni(II) and Cd(II), respectively, at an initial metal ion concentration of 50 mg L⁻¹ at pH 6.5. The effect of concentration, contact time, adsorbent dose, solution pH, adsorbent particle size, salinity and hardness on the adsorption of Cr(VI) were studied in detail in batch experiments. The equilibrium contact time for Cr(VI) adsorption was found to be 1 h. Adsorption equilibrium data fit well to the Freundlich isotherm in the concentration range studied. The maximum adsorption (96.2%) was recorded at pH 3 for the initial Cr(VI) concentration of 50 mg L⁻¹. The adsorbed metal ions from industrial wastewater were recovered using 0.1 M HCl solution. The column operation was found to be more effective compared to batch process. The percent recovery of Cr(VI) from industrial wastewater by column operation and batch process was found to be 85.8 and 65%, respectively. The results show that Pinus roxburghii bark can be used as a cost-effective adsorbent for the removal and recovery of Cr(VI) from wastewater.

Key words: adsorption, batch experiments, Freundlich isotherm, column operation, cost-effective

Introduction

With water pollution increasing as a result of enhanced industrial activities, the problem of removing pollutants from wastewater is growing daily. Heavy metal pollution is of great concern, due to growing awareness of potentially hazardous effects of elevated levels of these materials in the environment. Toxic metals (i.e., Cr, Cu, Ni, Zn, Cd, Pb) make their way into water bodies via wastewater from metal plating industries, leather industries, pulp and paper mills, refineries and steel work foundries, etc.

Chromium, a highly reactive metal, is widely used in electroplating, leather tanning, metal finishing and textile industries (Ajmal et al. 1996). Normally, industrial waste contains both hexavalent and trivalent forms of chromium, however, Cr(VI) is more hazardous to biological activities. Cr(VI) compounds are carcinogenic and corrosive on tissue and long-term exposure causes nausea, ulceration, skin sensitization and kidney damage (Metcalf and Eddy 2003; Mckee and Wolf 1963; Camp 1963).

Heavy metals present in wastewater are usually removed by reduction, microfiltration, precipitation, reverse osmosis, evaporation and ion-exchange methods. However, most of these methods have drawbacks including high operational costs or the challenges associated with residual metal sludge disposal. In recent years, the adsorption technique has received a great deal of attention for the removal and recovery of heavy metals from solution as it has been found to be an inexpensive, highly effective and simple method for the treatment of effluents bearing heavy metals.

Several low-cost adsorbents such as rice husk carbon (Srinivasan et al. 1988), coconut-shell based activated carbon (Alaets et al. 1989), fertilizer waste slurry (Srivastava et al. 1989), sphagnum moss peat (Sharma and Forster 1993), bark remnants of eucalyptus and Cassia fistula (Tiwari et al. 2000), rice straw (Samanta et al. 2000), saw dust (Srivastava et al. 2000), agricultural byproducts (Farooqui and Kotharkar 2001), bidi leaves (Srivastava et al. 2001), composite chitosan (Boddu et al. 2003), polymer chitin and deacetylated chitin (Satish and Shrivastava 2004) and Japanese cedar bark (Aoyama et al. 2004) have been used previously for the removal of Cr(VI) from aqueous solutions and industrial wastes at solid-solution interface. In our earlier studies, phosphate-treated sawdust (Ajmal et al. 1996) has been used for the removal of Cr(VI) from electroplating wastes.

In the present study, the ability of Pinus roxburghii bark in the removal and recovery of Cr(VI) from synthetic and industrial wastewater has been explored.

* Corresponding author; rais45@rediffmail.com
Material and Methods

Adsorbent

Pinus roxburghii (Himalayan long-leaf pine) bark was collected from one of the joinery mills at Anantnag in Jammu and Kashmir state (India), where it is available in abundance as a waste material, having no economical applications. The collected material was washed, dried and powdered. The powdered material was then washed with double-distilled water to remove the adhering dirt and finally dried in an air oven at 60.0 to 65.0°C for 8 h. After drying, the adsorbent was sieved (44–240 mesh screens) and stored in a desiccator until use.

Adsorbate Solution

All of the chemicals used were of analytical grade. A stock solution of Cr(VI) (1000 mg L⁻¹) was prepared in distilled water using potassium dichromate. All of the working solutions were prepared by diluting the stock solution with distilled water. Solutions of the other metal ions were prepared (1000 mg L⁻¹) by dissolving their chlorides or nitrates in distilled water.

Batch Adsorption Studies

Batch adsorption experiments were carried out by treating 50.0-mL aqueous solutions of Cr(VI) of different concentrations (10–100 mg L⁻¹) with 0.500 g of the adsorbent of 44 mesh screen (355 µm) for different contact times (10 min to 24 h) at an initial solution pH of 6.5 and at 30.0°C in conical flasks using a temperature-controlled shaker. The study of adsorbent doses was carried out by varying the amount of adsorbent (0.200–2.00 g), keeping the volume (50.0 mL) and initial concentration (50 mg L⁻¹) of the Cr(VI) solution constant. At the end of the predetermined time interval the adsorbent was removed by filtration carried out under reduced pressure using a Büchner funnel and a filter pump. The equilibrium concentration was determined in the filtrate by an atomic absorption spectrophotometer (model GBC 902) using an air acetylene flame. The amount of metal ion adsorbed per unit mass of adsorbent was obtained using the equation:

\[ q_e = \frac{(C_i - C_e)V}{m} \]  

(1)

where \( q_e \) is the mass of adsorbate (metal ion) adsorbed per unit mass of adsorbent (mg adsorbate/g adsorbent), \( C_i \) is the initial concentration (mg L⁻¹) of metal ion in solution, \( C_e \) is the final (equilibrium) concentration (mg L⁻¹) of metal ion in solution, \( V \) is the volume (L) and \( m \) is the mass of adsorbent (g) (Metcalf and Eddy 2003).

Effect of pH on Adsorption

The effect of pH on the adsorption of Cr(VI) was studied as follows: 100.0 mL Cr(VI) solution (50 mg L⁻¹) was taken in a beaker and the desired pH of the solution was adjusted by adding dilute solutions of HCl or NaOH. The concentration of Cr(VI) in this solution was then determined (initial concentration). An aliquot (50.0 mL) of this solution was taken in a conical flask and treated with 0.500 g of adsorbent. After equilibrium, the final concentration of Cr(VI) was determined using an atomic absorption spectrophotometer (AAS).

Ion Selectivity and Counter Ion

For this study, 50.0 mL of solution containing 50 mg L⁻¹ of different metal ions viz. Cr(VI), Cu(II), Ni(II), Cd(II), Zn(II) was treated with 0.500 g of the adsorbent of 44 mesh screen (355 µm) in a conical flask for 24 h. The solution was then filtered and filtrate analyzed for each metal ion using an atomic absorption spectrophotometer (AAS).

Desorption of Cr(VI)

The desorption studies of Cr(VI) were conducted by batch as well as by column process under similar conditions. An aliquot (50.0 mL) of the sample containing 50 mg L⁻¹ Cr(VI) was treated with 0.500 g of adsorbent for 24 h at pH 3. The solution was then filtered and filtrate was analyzed for Cr(VI). The adsorbent was then transferred to another conical flask and treated with 50.0 mL of 0.1 M HCl solution. It was then filtered after 24 h and the concentration of the desorbed Cr(VI) was determined in the filtrate.

The column studies were conducted using 0.500 g of adsorbent (powdered bark of Pinus roxburghii) in a glass column (0.6 cm in diameter) with a glass wool support. The adsorbent was washed with distilled water and 50.0 mL of solution (pH 3) containing 50 mg L⁻¹ of Cr(VI) was passed through the column. The solution was recycled several times so that adsorption of Cr(VI) was maximum. The Cr(VI) adsorbed was then eluted with 0.1 M HCl solution at a flow rate of 1 mL min⁻¹. The eluted Cr(VI) was collected and the concentration was then determined by an atomic absorption spectrophotometer.

Recovery of Cr(VI) from Industrial Wastewater

The removal and recovery of Cr(VI) from industrial wastewater was carried out by batch as well as by column operations. A sample (50.0 mL) of the wastewater was placed in a conical flask and its pH was adjusted to 3 and then treated with 0.500 g of adsorbent. Removal and recovery were carried out as described above.
In another experiment, 50.0 mL of the wastewater was taken in a beaker and the pH was adjusted to 3. This solution was passed through the column containing 0.500 g of adsorbent. The removal and recovery of Cr(VI) was carried out as mentioned above.

Adsorption Isotherm

Freundlich isotherm was used to analyze the adsorption data. The Freundlich equation is empirical, based on sorption on a heterogeneous surface, which is commonly presented as:

\[ q_e = K_f C_e^{1/n} \]  

(2)

where \( K_f \) (mg g\(^{-1}\)) and \( n \) are Freundlich constants related to adsorption capacity and adsorption intensity (Freundlich 1926). The Freundlich equation can be linearized in logarithmic form for the determination of Freundlich constants as below:

\[ \ln q_e = \frac{1}{n} \ln C_e = \ln K_f \]  

(3)

Results and Discussion

The adsorption capacity of Pinus roxburghii bark for different metal ions at pH 6.5 is shown in Table 1. Metal uptake capacity was found to be in the order: Cr(VI) > Zn(II) > Cu(II) > Ni(II) > Cd(II). The percent adsorption behaviour of these metal ions on the adsorbent is shown in Fig. 1. The adsorption behaviour of Cr(VI) was studied in detail.

Effect of Contact Time on Cr(VI) Adsorption

The percent adsorption versus time curve (Fig. 2) shows that adsorption of Cr(VI) increases sharply with time and attains equilibrium at about 1 h for all concentrations studied (20–100 mg L\(^{-1}\)). After equilibrium, adsorption is negligible.

Adsorption Isotherm

Initial concentrations (\( C_i \)) of Cr(VI) in the solution were varied between 20 to 100 mg L\(^{-1}\) for adsorption by a constant quantity of Pinus roxburghii powdered bark of 10 g L\(^{-1}\) (0.500 g/50.0 mL) at 30.0ºC and an initial solution pH of 6.5. The adsorption data were converted to a

<table>
<thead>
<tr>
<th>Metal ion</th>
<th>Initial concentration ( C_i ) (mg L(^{-1}))</th>
<th>Final concentration ( C_e ) (mg L(^{-1}))</th>
<th>Adsorption capacity (mg g(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cr(VI)</td>
<td>50.0</td>
<td>8.5</td>
<td>4.15</td>
</tr>
<tr>
<td>Cu(II)</td>
<td>50.0</td>
<td>11.8</td>
<td>3.81</td>
</tr>
<tr>
<td>Ni(II)</td>
<td>50.0</td>
<td>14.7</td>
<td>3.53</td>
</tr>
<tr>
<td>Cd(II)</td>
<td>50.0</td>
<td>19.9</td>
<td>3.01</td>
</tr>
<tr>
<td>Zn(II)</td>
<td>50.0</td>
<td>11.1</td>
<td>3.89</td>
</tr>
</tbody>
</table>

\( ^{a} \)Conditions: Volume of solution = 50.0 mL; amount of adsorbent = 0.500 g; pH = 6.5; temperature = 30.0ºC; contact time = 24 h. All values are mean of three independent observations.
Pinus roxburghii as a Low-Cost Adsorbent

Freundlich isotherm (Fig. 4). The correlation coefficient ($R^2$) was found to be 0.99 which indicates a good positive relationship with the data and suggests the applicability of the Freundlich model. Freundlich constants $K_f$ and $1/n$ were calculated as $K_f = 1.61$ mg g$^{-1}$ and $1/n = 0.42$. The value of $1/n$ indicates higher adsorption affinity at lower concentrations (Faust and Aly 1987).

The experimental data fits validly to the Freundlich model for the $C_i$ range of 20 to 100 mg L$^{-1}$, at which the adsorbent is expected to be used under practical conditions.

Effect of Adsorbent Dose

The adsorption densities (mg g$^{-1}$) and percent adsorption of Cr(VI) at different doses (0.200–2.00 g) of Pinus roxburghii bark are shown in Fig. 5. It is observed that percent adsorption of Cr(VI) increases from 63.4 to 100%, while adsorption density decreases from 7.93 to 1.25 mg g$^{-1}$ when the adsorbent dose is increased from 0.200 to 2.00 g. The decrease in adsorption density may be attributed to the fact that some of the adsorption sites remain unsaturated during the adsorption process, whereas the number of available adsorption sites increases by increasing the adsorbent doses and this results in the increase of removal efficiency (Sharma and Forster 1993).

Effect of pH on Adsorption

The effect of pH on Cr(VI) adsorption is presented in Fig. 6. It is seen that solution pH plays a very important role in the adsorption of Cr(VI). The percent adsorption increases from 55.6 to 96.2% as the initial pH of the solution is increased from 1 to 3. The percent adsorption decreases steadily to 88.9% when pH is increased from 3 to 5 and decreases further to 78.8% as pH is increased to 8. The material can therefore be used effectively at pH 3 for the removal of Cr(VI) from wastewater. The maximum adsorption of Cr(VI) in the lower pH range has been observed by many authors (Sharma and Forster 1993; Ajmal et al. 1996; Aoyama et al. 2004).

Effect of Particle Size

The adsorption of Cr(VI) increases with a decrease in adsorbent particle size (Table 2) and the peak value was observed by the finest particle of 240 mesh screen (63 µm), probably because of the large surface area available (Ajmal et al. 2001).

Effect of Salinity and Hardness

In order to utilize Pinus roxburghii bark as an adsorbent for the treatment of wastewater, it is important to see the effect of various ions usually present in wastewater. Therefore, the adsorption of Cr(VI) was studied in the presence of various ions generally present in wastewater, such as Na$^+$, Mg$^{2+}$, Ca$^{2+}$, SO$_4^{2-}$, HCO$_3^-$, Cl$^-$, etc. These results are summarized in Table 3.

It can be seen from the results that presence of Na$^+$ ion has no significant influence on Cr(VI) adsorption while the presence of Ca$^{2+}$ and Mg$^{2+}$ ions (present in tap
water) and the presence of HCO$_3^-$ and SO$_4^{2-}$ ions lead to an insignificant decrease in Cr(VI) adsorption.

**Ion Selectivity and Counter Ion Study**

Figure 7 shows the adsorption percentage of the heavy metal ions Cr(VI), Zn(II), Cu(II), Ni(II) and Cd(II) from a solution (50.0 mL) containing an equal amount (50 mg L$^{-1}$) of each metal ion on *Pinus roxburghii* powdered bark. This study was performed to determine the adsorption selectivity of the above-mentioned metal ions on the adsorbent and also to investigate the effect of adsorption of Cr(VI) in the presence of other metal ions in solution, which are usually present in wastewater. It is evident from Fig. 1 and 7 that adsorption of Cr(VI) as well as that of Cu(II) and Cd(II) is enhanced in the presence of other metal ions in solution, whereas the adsorption of Zn(II) and Ni(II) is suppressed by the presence of other metal ions in solution. The selectivity of adsorption of these metal ions on the adsorbent has been found to follow the order: Cr(VI) > Cu(II) > Cd(II) > Zn(II) = Ni(II). Thus, the metal ion best adsorbed is still Cr(VI).

**Desorption Studies**

The adsorption of Cr(VI) on *Pinus roxburghii* powdered bark is highly dependent upon pH. Therefore, its desorption is possible by controlling the pH. The desorption of Cr(VI) starts when a solution of 0.1 M HCl solution is passed through the column. The desorption is fast and 87.2% Cr(VI) could be eluted in 50.0 mL of effluent from the column. However, the desorption of Cr(VI) by batch process is slow and incomplete. The desorption of Cr(VI) from a solution containing 50 mg L$^{-1}$ Cr(VI) in a batch process was 71.5% (Table 4).

**Removal and Recovery of Cr(VI) and other Metal Ions from Industrial Wastewater**

*Pinus roxburghii* powdered bark as an adsorbent was utilized for the removal and recovery of Cr(VI) and other metal ions from industrial wastewater by batch process and column operation. The analysis of industrial wastewater collected from a company (Link Locks Manufacturing Company India Ltd.) in Aligarh (India) was carried out in our laboratory and results are shown in Table 5. The adsorbed metal ions were recovered with 0.1 M HCl solution. These results are summarized in Table 6 (batch process) and in Fig. 8 (column operation). It is evident from the results that the removal and

**TABLE 2. Effect of particle size on the adsorption process$^a$**

<table>
<thead>
<tr>
<th>Mesh screen (µm)</th>
<th>Amount of Cr(VI) adsorbed (mg L$^{-1}$)</th>
<th>Adsorption (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>52 (300)</td>
<td>41.9</td>
<td>83.8</td>
</tr>
<tr>
<td>100 (150)</td>
<td>42.0</td>
<td>84.0</td>
</tr>
<tr>
<td>150 (106)</td>
<td>42.2</td>
<td>84.4</td>
</tr>
<tr>
<td>200 (75)</td>
<td>42.3</td>
<td>84.5</td>
</tr>
<tr>
<td>240 (63)</td>
<td>42.5</td>
<td>85.0</td>
</tr>
</tbody>
</table>

$^a$Conditions: initial concentration of Cr(VI) = 50 mg L$^{-1}$; volume of the solution = 50.0 mL; contact time = 24 h; adsorbent dose = 0.500 g; temperature = 30.0°C. All values are mean of three independent observations.

**TABLE 3. Effect of various ions on removal of Cr(VI) using powdered bark of Pinus roxburghii as an adsorbent$^a$**

<table>
<thead>
<tr>
<th>Salt added</th>
<th>Volume of the solution (mL)</th>
<th>Amount of Cr(VI) adsorbed (mg L$^{-1}$)</th>
<th>Adsorption (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NaCl (100 mg L$^{-1}$)</td>
<td>50.0</td>
<td>41.8</td>
<td>83.6</td>
</tr>
<tr>
<td>Na$_2$SO$_4$ (100 mg L$^{-1}$)</td>
<td>50.0</td>
<td>40.7</td>
<td>81.4</td>
</tr>
<tr>
<td>NaHCO$_3$ (100 mg L$^{-1}$)</td>
<td>50.0</td>
<td>40.0</td>
<td>80.0</td>
</tr>
<tr>
<td>Tap water</td>
<td>50.0</td>
<td>40.4</td>
<td>80.8</td>
</tr>
<tr>
<td>Distilled water</td>
<td>50.0</td>
<td>41.5</td>
<td>83.0</td>
</tr>
</tbody>
</table>

$^a$Conditions: initial concentration of Cr(VI) in each solution = 50 mg L$^{-1}$; volume of the solution = 50.0 mL; temperature = 30.0°C; time = 24 h; adsorbent particle size = 44 mesh screen (355 µm). All values are mean of three independent observations.
recovery of metal ions by column operations is much higher compared to the batch process.

Conclusions

*Pinus roxburghii* bark is available in abundance in the Kashmir province of Jammu and Kashmir state, India. It was studied for its ability to adsorb the heavy metal ions Cr(VI), Cu(II), Ni(II), Cd(II) and Zn(II) from synthetic and industrial wastewater. Adsorption studies show that metal uptake capacity of the material for these heavy metal ions is in the order of Cr(VI) > Zn(II) > Cu(II) > Ni(II) > Cd(II) from aqueous solutions. Detailed studies were carried on the adsorption of Cr(VI) using *Pinus roxburghii* powdered bark as an adsorbent. Adsorption studies show that:

- Equilibrium was attained in 1 h and the adsorption of Cr(VI) decreases with an increase in initial Cr(VI) concentration.
- The experimental data fit the Freundlich isotherm in the Cr(VI) concentration range of 20 to 100 mg L⁻¹.
- The adsorption of Cr(VI) is pH-dependent and maximum removal occurs at pH 3. The material can thus be used effectively at pH 3 for the removal of Cr(VI) from wastewater.
- The adsorption increases with a decrease in particle size of adsorbent.
- The study of adsorbent efficiency for Cr(VI) removal in the presence of ions such as Na⁺, Ca²⁺, Mg²⁺, HCO₃⁻ and SO₄²⁻, and heavy metal ions such as Cu(II), Zn(II), Ni(II) and Cd(II) (usually present in wastewater) show that the presence of Na⁺ ions have no significant influence on Cr(VI) adsorption and the presence of Ca²⁺, Mg²⁺, HCO₃⁻ and SO₄²⁻ ions leads to an insignificant decrease in Cr(VI) adsorption. The presence of heavy metal ions enhances Cr(VI) adsorption.
- The utility of *Pinus roxburghii* bark as an adsorbent has been demonstrated by removing Cr(VI) along with other metal ions from industrial wastewater. A concentration of Cr(VI) ions as high as 80 mg L⁻¹ in wastewater can be reduced to 7.7 mg L⁻¹. The adsorbed Cr(VI) ions could be recovered with 0.1 M HCl solution; however, the percent recovery of Cr(VI) is increased by column operation (85.8%) under similar conditions of elution.

Acknowledgements

We express gratitude to the Chairman, Department of Applied Chemistry, Aligarh Muslim University, Aligarh, for providing the research facilities.

<table>
<thead>
<tr>
<th>Metal</th>
<th>Initial concentration (mg L⁻¹)</th>
<th>Amount adsorbed (mg L⁻¹)</th>
<th>Adsorption (%)</th>
<th>Amount recovered (mg L⁻¹)</th>
<th>Recovery (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cr(VI)</td>
<td>50.0</td>
<td>48.1</td>
<td>96.2</td>
<td>96.2</td>
<td>71.5</td>
</tr>
</tbody>
</table>

*Conditions: volume of solution = 50.0 mL; adsorbent dose = 0.500 g; temperature = 30.0°C; pH = 3; contact time = 24 h. All values are mean of three independent observations.*

| TABLE 4. Removal and recovery of Cr(VI) from synthetic wastewater by batch process
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Metal</td>
<td>Initial concentration (mg L⁻¹)</td>
<td>Amount adsorbed (mg L⁻¹)</td>
<td>Adsorption (%)</td>
<td>Amount recovered (mg L⁻¹)</td>
</tr>
<tr>
<td>Cr(VI)</td>
<td>50.0</td>
<td>48.1</td>
<td>96.2</td>
<td>96.2</td>
</tr>
</tbody>
</table>

*Conditions: volume of solution = 50.0 mL; adsorbent dose = 0.500 g; temperature = 30.0°C; pH = 3; contact time = 24 h. All values are mean of three independent observations.*

| TABLE 5. Analysis of industrial wastewater
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Conductivity (mS cm⁻¹)</td>
<td>144</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cr(VI) (mg L⁻¹)</td>
<td>80</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cu(II) (mg L⁻¹)</td>
<td>6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ni(II) (mg L⁻¹)</td>
<td>35</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zn(II) (mg L⁻¹)</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cd(II) (mg L⁻¹)</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mn(II) (mg L⁻¹)</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pb(II) (mg L⁻¹)</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pH</td>
<td>6.8</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| TABLE 6. Removal and recovery of metal ions from industrial wastewater by a batch process
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Metal</td>
<td>Initial concentration (mg L⁻¹)</td>
<td>Amount adsorbed (mg L⁻¹)</td>
<td>Adsorption (%)</td>
<td>Amount recovered (mg L⁻¹)</td>
</tr>
<tr>
<td>Cr(VI)</td>
<td>80.0</td>
<td>72.3</td>
<td>90.4</td>
<td>47.0</td>
</tr>
<tr>
<td>Cu(II)</td>
<td>6.0</td>
<td>6.0</td>
<td>100.0</td>
<td>1.5</td>
</tr>
<tr>
<td>Ni(II)</td>
<td>35.0</td>
<td>22.0</td>
<td>62.8</td>
<td>14.0</td>
</tr>
<tr>
<td>Zn(II)</td>
<td>10.0</td>
<td>7.0</td>
<td>70.0</td>
<td>1.8</td>
</tr>
</tbody>
</table>

*Conditions: volume of wastewater = 50.0 mL; adsorbent dose = 0.500 g; temperature = 30.0°C; pH = 3; contact time = 24 h. All values are mean of three independent observations.*
References


Received: November 16, 2004; accepted: July 8, 2005.