EFFECT OF CONTACT TIME & ADSORBATE CONCENTRATION

With chemicals, it’s shoot first and ask questions later.

-Al Meyerhoff,
a co-author of the Environmental Protection Initiative of 1990

4.1 INTRODUCTION

The study of the effect of the initial adsorbate concentration on the treatment of water and wastewater and dose of biosorbent is of great importance, as the rate of removal of pollutants is significantly influenced by the concentration at a particular temperature, pH and particle size. Apart from this the contact time between adsorbate and biosorbent species is of equal importance. A rapid uptake of adsorbates and attainment of equilibrium in a short interval indicates the ability of the biosorbent for its use in such wastewater treatment. The study of adsorption dynamics at which the removal of adsorbates approaches to the state of equilibrium cannot be ignored in view of a better understanding of the process involved. The kinetics of the removal process governs the retention time between the adsorbate and biosorbent. In the view of the use of adsorption technique in water pollution control, it is thus significant to study the effect of concentration and the agitation period of biosorbent and adsorbate.

The present section of the dissertation deals with the study of removal of Cd(II), Pb(II) and Cr(VI) by Mucor heimalis and Spirogyra sp. at different concentrations of adsorbate solutions.

4.2 EXPERIMENTAL

The experimental procedure was basically the same as described earlier in materials and methods chapter. The initial pH of lead nitrate, cadmium chloride and potassium dichromate was maintained at 6.5, 8.1 and 2.0 respectively, and the experiments were performed at 30°C. The findings of the present investigations are given in Tables 4.1 - 4.3 and are shown graphically in Figures 4.1 - 4.6.
4.3 RESULTS AND DISCUSSION

The results show that the extent of adsorption increases rapidly in the initial stages and becomes slow in the later stages till saturation in all the cases. It is clear from the results (Tables 4.1 - 4.3 and Figures 4.1 - 4.6) that the time required to attain equilibrium in case of adsorption of Cd(II) on *Mucor heimalis* and *Spirogyra sp.* is 100 and 110 minutes respectively and that of Pb(II) on the same biosorbent is 100 and 120 minutes respectively, while in case of removal of Cr(VI) by above biosorbents is 130 and 140 respectively. These findings indicate that the equilibrium time in all systems is independent of the initial adsorbate concentrations. A comparative study of the uptake of each adsorbate, both, at equilibrium and pre-equilibrium stages of adsorption shows that the removal of Cd(II), Pb(II) and Cr(VI) by *Mucor heimalis* and *Spirogyra sp.* under similar conditions of concentration, temperature, and pH are in the following order.

*Mucor heimalis* > *Spirogyra sp.*

The result further indicates that the extent of removal is highly dependent of concentration for instance, the percentage removal of Cd(II) at pH 8.1, Pb(II) at pH 6.5, Cr(VI) at pH 2.0 by *Mucor heimalis* and *Spirogyra sp.* are 96.95, 92.15 and 85.8; 94.25, 88.33 and 82.30; 94.00, 89.65 and 83.40; 89.50, 84.35 and 78.65; 97.10, 92.08 and 86.45; 91.36, 86.87 and 80.75 respectively at Cd(II) concentration of 100, 125 and 150 mgL\(^{-1}\); Pb(II) concentration of 200, 400 and 600 mgL\(^{-1}\); Cr(VI) concentration of 100, 150, and 200 mgL\(^{-1}\) respectively at 30\(^{0}\)C. The Figures 4.1 - 4.6 show that the uptake of adsorbate species is rapid in the initial stages and becomes slow with the lapse of time till saturation and thereafter it becomes constant. The curves thus obtained are single, smooth and continuous suggesting the formation of monolayer coverage of the adsorbate on the surface of the biosorbents. These findings are in good agreement with those reported earlier.\(^{1-8}\)

The comparative study of the feasibility of the biosorbents employed in the removal of Cd (II), Pb (II) and Cr (VI) indicates form Table 4.1–4.3, that both the biosorbents are good for the removal of heavy metal pollutants, however, *Mucor heimalis* is better biosorbent than *Spirogyra sp.*
**TABLE 4.1**

**EFFECT OF INITIAL ADSORBATE CONCENTRATION ON THE REMOVAL OF Cd(II) USING DIFFERENT BIOSORBENT**

Temperature: 30°C  
Agitation speed: 125 rpm  
P pH : 8.1  
Particle size : < 180 \( \mu \)m

<table>
<thead>
<tr>
<th>Biosorbent</th>
<th>Adsorbate</th>
<th>Initial Conc. (mgL(^{-1}))</th>
<th>Amount adsorbed (mgg(^{-1}))</th>
<th>% Removal</th>
<th>Equilibrium Time (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mucor heimalis</strong></td>
<td>Cd(II)</td>
<td>100</td>
<td>4.84</td>
<td>96.95</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td></td>
<td>125</td>
<td>5.76</td>
<td>92.15</td>
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<td>150</td>
<td>6.44</td>
<td>85.80</td>
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<tr>
<td><strong>Spirogyra sp.</strong></td>
<td>Cd(II)</td>
<td>100</td>
<td>4.71</td>
<td>94.25</td>
<td>110</td>
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<td></td>
<td></td>
<td>125</td>
<td>5.52</td>
<td>88.33</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>150</td>
<td>6.17</td>
<td>82.30</td>
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</tr>
</tbody>
</table>
### TABLE 4.2

**EFFECT OF INITIAL ADSORBATE CONCENTRATION ON THE REMOVAL OF Pb(II) USING VARIOUS BIOSORBENT**

| Temperature: | 30°C | Agitation speed: | 125 rpm | pH : | 6.5 | Particle size : | < 180 μm |

<table>
<thead>
<tr>
<th>Biosorbent</th>
<th>Adsorbate</th>
<th>Initial Conc. (mgL⁻¹)</th>
<th>Amount adsorbed (mgg⁻¹)</th>
<th>% Removal</th>
<th>Equilibrium Time (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Mucor heimalis</em></td>
<td>Pb(II)</td>
<td>200</td>
<td>9.40</td>
<td>94.00</td>
<td>100</td>
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<tr>
<td></td>
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<td>400</td>
<td>17.95</td>
<td>89.65</td>
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<td>600</td>
<td>25.05</td>
<td>83.40</td>
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<tr>
<td><em>Spirogyra sp.</em></td>
<td>Pb(II)</td>
<td>200</td>
<td>9.00</td>
<td>89.50</td>
<td>120</td>
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<td></td>
<td></td>
<td>400</td>
<td>16.95</td>
<td>84.35</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>600</td>
<td>23.60</td>
<td>78.65</td>
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</tr>
</tbody>
</table>
TABLE 4.3

EFFECT OF INITIAL ADSORBATE CONCENTRATION ON THE REMOVAL OF Cr(VI) USING VARIOUS BIOSORBENT

Temperature: 30°C  
Agitation speed: 125 rpm  
pH : 2.0  
Particle size : < 180 µm

<table>
<thead>
<tr>
<th>Biosorbent</th>
<th>Adosorbate</th>
<th>Initial Conc. (mgL⁻¹)</th>
<th>Amount adsorbed (mgg⁻¹)</th>
<th>% Removal</th>
<th>Equilibrium Time (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mucor heimalis</td>
<td>Cr (VI)</td>
<td>100</td>
<td>4.86</td>
<td>97.10</td>
<td>130</td>
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<td></td>
<td></td>
<td>150</td>
<td>6.91</td>
<td>92.08</td>
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<td></td>
<td></td>
<td>200</td>
<td>8.65</td>
<td>86.45</td>
<td></td>
</tr>
<tr>
<td>Spirogyra sp.</td>
<td>Cr (VI)</td>
<td>100</td>
<td>4.57</td>
<td>91.36</td>
<td>140</td>
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<tr>
<td></td>
<td></td>
<td>150</td>
<td>6.52</td>
<td>86.87</td>
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<td></td>
<td></td>
<td>200</td>
<td>8.08</td>
<td>80.75</td>
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</tbody>
</table>
Fig. 4.1 TIME VARIATION PLOT FOR ADSORPTION OF Cd(II) ON *Mucor heimalis* AT DIFFERENT CONCENTRATION

Particle size: <180 μm
Temperature: 30°C
pH : 8.1

Fig. 4.2 TIME VARIATION PLOT FOR ADSORPTION OF Cd(II) ON *Spirogyra sp.* AT DIFFERENT CONCENTRATION

Particle size: <180 μm
Temperature: 30°C
pH : 8.1
Fig. 4.3 TIME VARIATION PLOT FOR ADSORPTION OF Pb(II) ON *Mucor heimalis* AT DIFFERENT CONCENTRATION

Fig. 4.4 TIME VARIATION PLOT FOR ADSORPTION OF Pb(II) ON *Spirogyra sp.* AT DIFFERENT CONCENTRATION
Fig. 4.5 TIME VARIATION PLOT FOR ADSORPTION OF Cr(VI) ON *Mucor heimalis*
AT DIFFERENT CONCENTRATION

Fig. 4.6 TIME VARIATION PLOT FOR ADSORPTION OF Cr(VI) ON *Spirogyra sp.*
AT DIFFERENT CONCENTRATION
The biosorbent used here is mostly enriched in different oxides and the water molecules in the neighbourhood play a key role in the uptake of anions and cations from aqueous solution through sorption process. When the biosorbents brought in to intimate contact with water dipoles, a redistribution of charge and potential takes place at the solid solution interface. The electrochemical potential of the charge carried in both phases becomes equal at equilibrium and an electrical double layer is formed due to non distribution of charge and potential. Many physico-chemical properties of the bulk phase such as structure, composition, conductivity and stoichiometry\textsuperscript{9} cumulatively control the electrical and electrochemical properties of double layer. The water dipoles, during adsorption are first chemi-sorbed at the surface forming a monolayer and thereby yielding aqua-complexes of metal ion\textsuperscript{10}. These complexes are amphoteric in nature and may yield protons from co-ordinately bound water molecules or may furnish protons to hydroxyl ions as follows:

\[
\begin{align*}
\text{M}^{n+}(\text{OH})_n(\text{OH}_2)_m & \longleftrightarrow [\text{M}^{n+}(\text{OH})_{n+1}(\text{OH}_2)_{m-1}]^+ \text{H}^+ \quad (4.1) \\
\text{M}^{n+}(\text{OH})_n(\text{OH}_2)_m + \text{H}^+ & \longleftrightarrow [\text{M}^{n+}(\text{OH})_{n-1}(\text{OH}_2)_{m+1}]^+ \quad (4.2)
\end{align*}
\]

The co-ordination number of metal ions in the above equilibrium has been assumed to be constant. Acidity or basicity of the metal ions depends on the polarisation of water molecules or hydroxyl ions which depends on the charge and radius of the metal ion.\textsuperscript{11}

The biosorbents employed in the present investigation are having oxides which forms oxide water interface. It is thus clear that $\text{H}^+$ and $\text{OH}^-$ ions are the constituent parts of the oxide-solution interface and surface is in a state of thermodynamic reversibility with respect to these ions at the surface of the biosorbents. Hence, $\text{H}^+$ and $\text{OH}^-$ ions are the potential determining ions with respect to the resulting hydroxylated oxide surfaces in contact with aqueous solutions. In other words, the progress of sorption is governed by the kinetics of surface hydroxylation and subsequent acid base dissociation of the aqua complex of oxides. Protonation and deprotonation of surface hydroxyls may yield\textsuperscript{12}. 

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Where \( S\text{--OH} \) is the surface hydroxyl group. It is thus expected from the above equation that \( S\text{--O}^- \) surface will be favourable for cationic adsorption while \( S\text{--OH}_2^+ \) for anionic adsorption. This mechanism which also gets support from the Levine-Smith\textsuperscript{13} model for the adsorption, explains the sorption of Cd (II), Pb (II) and Cr (VI) on biosorbents used. The surface reaction of adsorbate ions and its species owing to adsorption decreases with the lapse of contact time and eventually approaches to saturation. The significant change in the adsorption with the contact period of biosorbents and adsorbates is satisfactorily borne out by the surface hydroxylation mechanism as envisaged in the present study.

A more appropriate double layer model for interpreting the mechanism of uptake of ions at the oxide-solution interface was given by Wright and Hunter\textsuperscript{14}. According to this, the following equilibrium exists, at the surface and in the bulk of the solution.

\[
\begin{align*}
\text{MOH}_\text{S} & \rightleftharpoons \text{MOH}_\text{b} \\
\text{MOH}_\text{b} & \rightleftharpoons \text{M}_\text{b}^+ + \text{H}_2\text{O} \quad \text{(in the bulk)} \\
\text{MOH}_\text{S} + \text{H}_\text{b}^+ & \rightleftharpoons \text{M}_\text{S}^+ + \text{H}_2\text{O}_\text{b} \quad \text{(at the surface)}
\end{align*}
\]

Where, \( \text{MOH} \) signifies any multivalent metal hydroxide \( \text{M(OH)}_v \), and \( \text{M}^+ \) and \( \text{MO}^- \) represent \( \text{M(OH)}^{+v-1}_v \) and \( \text{M(OH)}^{-v+1}_v \) respectively. Thus, the double layer model of Wright and Hunter seems to be more appropriate to explain the surface reactions involved in such type of oxide solution system.

### 4.4 ADSORPTION DYNAMICS

The study of adsorption dynamics is very essential with respect to the fundamental information about the application of selected biosorbents in the treatment of water containing Cd (II), Pb (II), Cr (VI) as pollutants. The dynamics of adsorption involved in the present investigation was studied by considering the following steps:
4.4.1 ADSORPTION RATE CONSTANT STUDY

The rate constant, $k_{ad}$, for adsorption of the Cd (II), Pb (II) and Cr (VI) carried out in the light of Lagergreen rate equation\textsuperscript{15}

$$\log(q_e - q) = \log q_e - \frac{k_{ad}}{2.303}.t$$

(4.8)

Where $q_e$ and $q$ (both in mg g\textsuperscript{-1}) are the amount of the metal adsorbed at equilibrium and at any time to respectively. The linear plots of log ($q_e$-$q$) vs $t$ (Figures 4.7 - 4.9) show the validity of the above equation, consequently suggesting the first order kinetics of the uptake of Cd (II), Pb (II) and Cr (VI). The values of rate constants of each system at 30\textdegree C were calculated from the slopes of these plots and noted in Table 4.4.

4.4.2 INTRAPARTICLE RATE CONSTANT STUDY

All the adsorption experiments were performed by agitating the adsorbate solution with the biosorbent in a batch reactor. During such mode of operation, the possibility of transport of adsorbate species in to the pores of biosorbent, which is often the rate controlling step in many adsorption processes, cannot be overlooked\textsuperscript{16-19}. The previous studies on the intraparticle transport indicates that the amount of solute adsorbed varies almost proportionally with the half power of time, $t^{1/2}$, rather that the time itself\textsuperscript{20}. This probability has been verified by graphical relationship between amount adsorbed and square root of time (Figures 4.10 - 4.12). The double nature of these plots may be due to varying extent of adsorption in initial and final stages. The initial curved positions of the plots are due to the boundary layer diffusion effects\textsuperscript{21}, while the final linear portion to the intraparticle diffusion effects\textsuperscript{22}. However, the prevailing linear portion of these plots indicates the possibility of intraparticle diffusion as the rate controlling step. The slope of linear portion of the plot has been defined as a rate parameter $k_{id}$, a characteristic of the rate of adsorption in the region where intraparticle diffusion is rate controlling step.

The value of $k_{id}$ for different systems were determined from the slopes of these plots and recorded in Table 4.5.
The intraparticle diffusion coefficients $\bar{D}$, for the adsorption of Cd (II), Pb (II), Cr (VI) were calculated using the following equation\textsuperscript{23}.

$$\bar{D} = \frac{0.03r^2}{t_{1/2}}$$ (4.9)

Where $r$ (cm) is the average radius of the biosorbent particle and $t_{1/2}$ (min) is the time for half of the adsorption. According to Michelsen et al., 1975 a $\bar{D}$ (cm\textsuperscript{2} sec\textsuperscript{-1}) value of the order of $10^{-11}$ is indicative of intraparticle diffusion as the rate determining step. In this investigation, the values of $\bar{D}$ (Table 4.5) obtained was in order of $10^{-9}$ which was more than two order of magnitude higher, indicated that the intraparticle diffusion was not the only rate controlling step\textsuperscript{24}. It was concluded that both boundary layer and intraparticle diffusion were involved in this removal process.

### 4.4.3 MASS TRANSFER STUDY

The uptake of adsorbate from liquid phase to solid surface (biosorbent) is carried out by transfer of mass from the former to the later. A number of steps can be considered participating in the process and out of various models tried for the present studies, overall sorption process is assumed to occur using a three-step McKay et al. 1981 model\textsuperscript{25}:

1. Mass transfer of adsorbate from the aqueous phase on to the solid surface.
2. Sorption of solute on to the surface sites, and
3. Internal diffusion of solute via either a pore diffusion model or homogeneous solid phase diffusion model.

During the present investigation, step (2) has been assumed rapid enough with respect to the other steps and therefore it is not rate limiting in any kinetic study. Taking in to account these probable steps, Mckay et al., 1981 model has been used for the present investigation:

$$\ln \left( \frac{C_A}{C_{A_0}} - \frac{1}{1+mK} \right) = \ln \left( \frac{mK}{1+mK} \right) - \left( \frac{1+mK}{mK} \right) \beta_1 S_k t$$ (4.10)
where, m is the mass of the biosorbent per unit volume, K is the constant obtained by multiplying $Q^0$ and b (Langmuir's constants), $\beta_1$ is the mass transfer coefficient, $S_s$ is the outer specific surface of the biosorbent particles per unit volume of particle-free slurry. The values of m and $S_s$ were calculated using the following relations:

$$m = \frac{W}{V},$$

(4.11)

$$S_s = \frac{6m}{d_p \delta \rho (1 - \varepsilon_p)},$$

(4.12)

where, W is the weight of the adsorbent, V the volume of particle-free slurry solution, and $d_p$, $\delta \rho$ and $\varepsilon_p$ are the diameter, density and porosity of the adsorbent particles, respectively. The values of mass transfer coefficient $\beta_1$ were calculated from the slopes and intercepts of the plots (Fig. 4.13 – 4.18) of $\ln (C_t/C_0 - 1/1 + mK)$ versus t (min.) and presented in the Table 4.6 – 4.8. The values of mass transfer coefficient $\beta_1$ obtained show that the rate of transfer of mass from bulk solution to the biosorbent surface was rapid enough so it cannot be rate controlling step (Singh et al., 1998). It can also be mentioned that the deviation of some of the points from the linearity of the plots indicated the varying extent of mass transfer at the initial and final stages of the sorption.
Fig. 4.7 RATE CONSTANT PLOT FOR ADSORPTION OF Cd (II) ON DIFFERENT BIOSORBENT

Particle size: <180 µm
Concentration: 125 mg/l
Temperature: 30°C
pH : 8.1

Fig. 4.8 RATE CONSTANT PLOT FOR ADSORPTION OF Pb (II) ON DIFFERENT BIOSORBENT

Particle size: <180 µm
Concentration: 400 mg/l
Temperature: 30°C
pH : 6.5
Fig. 4.9 RATE CONSTANT PLOT FOR ADSORPTION OF Cr(VI) ON DIFFERENT BIOSORBENT

- Mucor
- Spirogyra

Particle size: <180 μm
Conc.: 150 mg L\(^{-1}\)
Temperature: 30 °C
pH: 2.0
Fig. 4.10 INTRAPARTICLE DIFFUSION PLOT FOR ADSORPTION OF Cd(II) ON DIFFERENT BIOSORBENT

Particle size: <180 μm
Conc.: 125 mg L\(^{-1}\)
Temperature: 30 °C
pH: 8.1

Fig. 4.11 INTRAPARTICLE DIFFUSION PLOT FOR ADSORPTION OF Pb(II) ON DIFFERENT BIOSORBENT

Particle size: <180 μm
Conc.: 400 mg L\(^{-1}\)
Temperature: 30 °C
pH: 6.5
Fig. 4.12 INTRAPARTICLE DIFFUSION PLOT FOR ADSORPTION OF Cr(VI) ON DIFFERENT BIOSORBENT

Particle size: <180 \( \mu \text{m} \)
Conc.: 150 mg L\(^{-1}\)
Temperature: 30 \(^\circ\)C
pH: 2.0
**Fig. 4.13** MASS TRANSFER PLOT FOR ADSORPTION OF Cd (II) ON *Mucor heimalis* AT DIFFERENT ADSORBATE CONCENTRATION

- Particle size: <180 μm
- Temperature: 30 °C
- pH: 8.1

**Fig. 4.14** MASS TRANSFER PLOT FOR ADSORPTION OF Cd (II) ON *Spirogyra sp.* AT DIFFERENT ADSORBATE CONCENTRATION

- Particle size: <180 μm
- Temperature: 30 °C
- pH: 8.1
Fig. 4.15 MASS TRANSFER PLOT FOR ADSORPTION OF Pb(II) ON *Mucor heimalis* AT DIFFERENT ADSORBATE CONCENTRATION

\[
\ln(C_t/C_0 - 1/(1 + mK))
\]

- Time (min.)
- 200 mg L\(^{-1}\)
- 400 mg L\(^{-1}\)
- 600 mg L\(^{-1}\)
- Particle size: <180 \(\mu\)m
- Temperature: 30 °C
- pH: 6.5

Fig. 4.16 MASS TRANSFER PLOT FOR ADSORPTION OF Pb(II) ON *Spirogyra sp.* AT DIFFERENT ADSORBATE CONCENTRATION

\[
\ln(C_t/C_0 - 1/(1 + mK))
\]

- Time (min.)
- 200 mg L\(^{-1}\)
- 400 mg L\(^{-1}\)
- 600 mg L\(^{-1}\)
- Particle size: <180 \(\mu\)m
- Temperature: 30 °C
- pH: 6.5
Fig. 4.17 MASS TRANSFER PLOT FOR ADSORPTION OF Cr(VI) ON *Mucor heimalis* AT DIFFERENT ADSORBATE CONCENTRATION

- Particle size: <180 μm
- Temperature: 30 °C
- pH: 2.0

Fig. 4.18 MASS TRANSFER PLOT FOR ADSORPTION OF Cr(VI) ON *Spirogyra sp.* AT DIFFERENT ADSORBATE CONCENTRATION

- Particle size: <180 μm
- Temperature: 30 °C
- pH: 2.0

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TABLE 4.4

ADSORPTION RATE CONSTANT ($k_{ad}$) FOR DIFFERENT ADSORBATE-BIOSORBENT SYSTEMS.

Temperature: $30^0$C  
Particle size: < 180 $\mu$m

<table>
<thead>
<tr>
<th>Biosorbents</th>
<th>Adsorbates</th>
<th>$k_{ad}$ (min$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Mucor heimalis</em></td>
<td>Cd (II)</td>
<td>$5.711 \times 10^{-2}$</td>
</tr>
<tr>
<td></td>
<td>Pb (II)</td>
<td>$4.261 \times 10^{-2}$</td>
</tr>
<tr>
<td></td>
<td>Cr (VI)</td>
<td>$4.675 \times 10^{-2}$</td>
</tr>
<tr>
<td><em>Spirogyra sp.</em></td>
<td>Cd (II)</td>
<td>$5.343 \times 10^{-2}$</td>
</tr>
<tr>
<td></td>
<td>Pb (II)</td>
<td>$4.168 \times 10^{-2}$</td>
</tr>
<tr>
<td></td>
<td>Cr (VI)</td>
<td>$4.215 \times 10^{-2}$</td>
</tr>
</tbody>
</table>

Ci: 125 mgL$^{-1}$, 400 mgL$^{-1}$ and 150 mgL$^{-1}$ for Cd (II), Pb (II) and Cr (VI) respectively.

pH: 8.1, 6.5 and 2.0 for Cd (II), Pb (II) and Cr (VI) respectively.
TABLE 4.5
RATE CONSTANT OF INTRAPARTICLE TRANSPORT ($k_{id}$) AND INTRAPARTICLE DIFFUSION COEFFICIENT ($D$) FOR DIFFERENT ADSORBATE-BIOSORBENT SYSTEMS.

Temperature: 30°C  
Particle size: <180 μm

<table>
<thead>
<tr>
<th>Biosorbents</th>
<th>Adsorbate</th>
<th>Intraparticle rate constant $k_{id}$ (mg g⁻¹ min⁻¹/²)</th>
<th>Intraparticle diffusion coefficient ($D$) (Cm² sec⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Mucor heimalis</em></td>
<td>Cd (II)</td>
<td>1.02 X 10⁻²</td>
<td>7.426 X 10⁻⁹</td>
</tr>
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<td>Pb (II)</td>
<td>6.23 X 10⁻³</td>
<td>5.828 X 10⁻⁹</td>
</tr>
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<td>Cr (VI)</td>
<td>9.13 X 10⁻³</td>
<td>6.280 X 10⁻⁹</td>
</tr>
<tr>
<td><em>Spirogyra sp.</em></td>
<td>Cd (II)</td>
<td>9.42 X 10⁻³</td>
<td>3.600 X 10⁻⁹</td>
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<td>Pb (II)</td>
<td>5.68 X 10⁻³</td>
<td>2.646 X 10⁻⁹</td>
</tr>
<tr>
<td></td>
<td>Cr (VI)</td>
<td>8.77 X 10⁻³</td>
<td>3.029 X 10⁻⁹</td>
</tr>
</tbody>
</table>

Ci: 125 mgL⁻¹, 400 mgL⁻¹ and 150 mgL⁻¹ for Cd (II), Pb (II) and Cr (VI) respectively.
pH: 8.1, 6.5 and 2.0 for Cd (II), Pb (II) and Cr (VI) respectively.
TABLE 4.6
EFFECT OF INITIAL ADSORBATE CONCENTRATION ON MASS TRANSFER COEFFICIENT $\beta_1$ USING DIFFERENT BIOSORBENT

Temperature: $30^\circ$C  Agitation speed: 125 rpm
pH : 8.1  Particle size : < 180 $\mu$m

<table>
<thead>
<tr>
<th>Biosorbents</th>
<th>Adsorbate</th>
<th>Initial Adsorbate Conc. (mg L$^{-1}$)</th>
<th>$\beta_1$ (cm sec$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Mucor heimalis</em></td>
<td>Cd (II)</td>
<td>100</td>
<td>$5.585 \times 10^{-5}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>125</td>
<td>$4.965 \times 10^{-5}$</td>
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<td>150</td>
<td>$4.126 \times 10^{-5}$</td>
</tr>
<tr>
<td><em>Spirogyra sp.</em></td>
<td>Cd (II)</td>
<td>100</td>
<td>$5.225 \times 10^{-5}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>125</td>
<td>$4.670 \times 10^{-5}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>150</td>
<td>$4.020 \times 10^{-5}$</td>
</tr>
</tbody>
</table>
TABLE 4.7
EFFECT OF INITIAL ADSORBATE CONCENTRATION ON MASS TRANSFER COEFFICIENT $\beta_1$ USING DIFFERENT BIOSORBENT

Temperature: 30°C  Agitation speed: 125 rpm
pH : 6.5  Particle size : < 180 μm

<table>
<thead>
<tr>
<th>Biosorbents</th>
<th>Adsorbate</th>
<th>Initial Adsorbate Conc. (mg L$^{-1}$)</th>
<th>$\beta_1$ (cm sec$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mucor heimalis</strong></td>
<td>Pb (II)</td>
<td>200</td>
<td>4.990 X 10$^{-5}$</td>
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<td></td>
<td>400</td>
<td>4.475 X 10$^{-5}$</td>
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<td></td>
<td>600</td>
<td>3.885 X 10$^{-5}$</td>
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<tr>
<td><strong>Spirogyra sp.</strong></td>
<td>Pb (II)</td>
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<td>4.750 X 10$^{-5}$</td>
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<td>400</td>
<td>4.355 X 10$^{-5}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>600</td>
<td>3.575 X 10$^{-5}$</td>
</tr>
</tbody>
</table>
TABLE 4.8
EFFECT OF INITIAL ADSORBATE CONCENTRATION ON MASS TRANSFER COEFFICIENT $\beta_1$ USING DIFFERENT BIOSORBENT

Temperature: 30°C  
Agitation speed: 125 rpm  
P pH : 2.0  
Particle size : < 180 μm

<table>
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<th>Adsorbate</th>
<th>Initial Adsorbate Conc. (mg L(^{-1}))</th>
<th>$\beta_1$ (cm sec(^{-1}))</th>
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<tr>
<td><strong>Mucor heimalis</strong></td>
<td>Cr (VI)</td>
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<td>5.790 X 10(^{-5})</td>
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<td>4.665 X 10(^{-5})</td>
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<td><strong>Spirogyra sp.</strong></td>
<td>Cr (VI)</td>
<td>100</td>
<td>5.425 X 10(^{-5})</td>
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<td></td>
<td>200</td>
<td>3.895 X 10(^{-5})</td>
</tr>
</tbody>
</table>
REFERENCES


