Removal of Zinc [Zn^{2+}] Ions with Crab Shell Particles from Aqueous Solutions

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ABSTRACT

Crab shell particles were tested for its ability to remove Zn^{2+} ions from aqueous solution and were evaluated in a batch reactor and in a fixed-bed column. The binding of Zn^{2+} ions by crab shell was found to be affected significantly by pH, with maximum sorption capacity 71.46 mg/g observed at pH 4.5. The sorption isotherm of Zn^{2+} ions on crab shell particles was modeled on the application of Langmuir followed by Sips, Redlich-Peterson and Freundlich. It was observed from the kinetic data that the biosorption process using crab shells follow Pseudo-second-order kinetics. The influence of temperature on metal uptake showed that the sorption process is favorable at room temperature and increasing temperature decreases the Zn^{2+} ion uptake. The influence of the co-ions (Na^{+}, K^{+}, Ca^{2+} and Mg^{2+}) along with the Zn^{2+} ion present in the aqueous solution was also studied. A glass column (2 cm I.D and 35 cm height) was used to study the continuous zinc biosorption performance of crab shell particles with different bed heights. At 25 cm (bed height), 5 mL/min (flow rate) and 100 mg/L (initial lead concentration), crab shell particles exhibited Zn^{2+} ions uptake of 43.83 mg/gm.

Keywords: Biosorption, Crab shell particles, kinetics, packed bed column, Zn^{2+} uptake

1. Introduction

Water is a valuable resource under increasing demand worldwide and is exposed to numerous sources of pollution. Industries such as mining, steel and electroplating, discharge aqueous effluents containing relatively high levels of heavy metals such as silver, cadmium, copper, cobalt, chromium, zinc, iron and lead. Untreated effluents from these manufacturing processes have an adverse impact on the environment (Macaskie and Dean, 1984: Malone, 1989: Nakajima and Sakaguchi, 1986: Norberg and Persson, 1984: Scott et al 1986: Silver 1991) and remedial action is needed. A wide range of geological factors like sulphur deposition, global climate change, etc. and anthropogenic modifiers like acid wash of the metals in the electroplating industries, other heated discharges, riparian vegetation removal, flow modifications, etc. influences the thermal environment contributing increase in the concentrations of dissolved metals. Physical and chemical methods can be used to remove metal ions from industrial effluent, but these are not commercially viable because of high operating cost or difficulty in treating the solid wastes generated (Silver 1991).

Heavy metal biosorption by biological materials, such as bacteria (Cabral, 1992) and fungi (Tobin et al 1984) presents few problems when operated in continuous mode of operation, among these solid/liquid separation is a major constrain. Even though immobilization may solve this problem, chemical costs and mechanical strength should be taken into
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consideration (Veglio and Beolchini, 1997). For these reasons, recent research attention has focused on low cost and waste materials (Bailey et al 1999). Among these crab shell, due to its high mechanical strength and easy availability, was selected for the present study. Crab shell comprises of mainly calcium carbonate, chitin along with some proteins. Chitin and its de-acetylated form (chitosan) have been recognized as effective biosorbents for metal removal. Chitin or chitosan itself is nontoxic, readily biodegradable, and hence environmentally acceptable (Chui et al 1996). Chitin acts as an anion exchanger in acidic medium (Hoshi et al 1997). The poor solubility of chitin is the major limiting factor in its utilization. Whereas chitosan has a natural selectivity for heavy metal ions and is useful for the treatment of waste water (Ravikumar 2000).

Chitosan is soluble in the dilute acidic solutions, while chitin is resistant to the action of acids (Gyliene et al 2002). Among some interesting properties of chitosan, chelating ability arisen from its characteristic structure is especially noteworthy. This high adsorption capacity was ascribable primarily to its remarkable hydrophilicity in cooperation with the relatively high amino group content. But difficulties were sometimes encountered in isolating the adsorption products owing to the solubility in waste water with low pH range (Kang et al 1999). Zinc metal was chosen based on their industrial applications and potential pollution impact on the environment. The increasing demand for alkaline Zn manganese batteries, instead of mercury based ones, brings serious problems when those batteries are not disposed off properly (Andres et al 2000). The purpose of the present study was to utilize the shells of Portunus sanguinolentus in the removal of Zn^{2+} ion from aqueous solution.

2. Materials and Method

2.1 Materials

Waste shells of P. sanguinolentus commonly known as 3 spot crabs were collected from Marina beach, India and were sun dried and crushed to desired sizes using ball mill. The pretreatment of crab shells were carried out by washing with 0.1M HCl for 4 hours to remove CaCO_3. The treated shells were then washed with de-ionized water and dried naturally and the weight loss was found to be approximately 50%. The pretreated crab shell particles obtained will be referred to as “CSP” in this paper. The pretreated shells were then soaked in 1% NaOH at room temperature overnight to remove bulk of protein. The residue (chitin) was then rinsed with de-ionized water and dried at 100°C. Chitin was converted to chitosan by soaking in 50% NaOH for 2 hours at 100°C to remove some or all of the acetyl residues and dried naturally (Kin and Park, 2001). Analytical grades of HCl, NaOH, KCl, CaCl_2.2H_2O, and MgCl_2.6H_2O were purchased from Ranbaxy Fine Chemicals Ltd., India.

2.2 Sorption experiments

The surface of contact between any sorbent and the liquid phase plays an important role in the phenomena of sorption (Benguella and Benaissa, 2002). The effect of particle size of CSP on the Zn^{2+} ion removal was studied using four particle viz. size-1 (0.456 mm), size-2 (0.598 mm), size-3 (0.767 mm) and size-4 (1.117 mm). In general, smaller particles (0.456 to 0.767 mm) which yield larger surface areas results in high metal uptake capacity and percentage removal efficiency. In all cases, the largest CSP size (1.117 mm) resulted in very low biosorption performance. Even though the smallest particle size (0.456 mm) resulted in slightly better biosorption performance compared to 0.598 and 0.767 mm CSP sizes, its increase in uptake and removal efficiency were within 5% compared to other two CSP sizes. It is always preferable to use rigid and slightly large particles especially in sorption column
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processes so that they can withstand extreme conditions employed in regeneration processes (Volesky 2010). Since the CSP size 0.767 mm performed very closely to CSP size 0.456 mm (Considering that the difference is within 5%), it was subsequently used in all biosorption experiments.

The CSP (0.5 g) was added into the conical flasks containing 100 ml of 100 mg/L of metal solution at desired pH conditions (using 0.1 M HCl and 0.1 M NaOH). The flasks were agitated at desired rate for 12 h. After equilibrium was reached, the reaction mixture was centrifuged at 3000 rpm for 10 min (Senthilkumar et al 2007). The final \(Zn^{2+}\) ion concentrations were measured using Atomic Absorption Spectrophotometer (AAS 6VARIO; Analytik Jena, Germany). In the biosorption isotherm experiments, the pH and temperature were varied and the same amount of CSP was added to the solutions with varying \(Zn^{2+}\) ion concentrations. In the kinetic experiments, the CSP was added to the solutions of different initial \(Zn^{2+}\) ion concentration and samples were taken at periodic time intervals and analyzed using AAS. Biosorption of the \(Zn^{2+}\) ions \((Q)\) in the sorption system was calculated using the mass balance

\[
Q = (C_0 - C_f) \times V / m
\]

where \(V\) is the solution volume (L), \(m\) is the amount of biomass (g), \(C_o\) and \(C_f\) were the initial and final concentration of \(Zn^{2+}\) ion in solution respectively.

2.3 Sorption models

The equilibrium data were analyzed using four of the most commonly used isotherm equations such as Langmuir (Langmuir 1918), Freundlich (Freundlich 1907), Redlich Peterson (Redlic and Peterson, 1959) and Sips (Ho et al 2002) isotherm expressions. They were given by the following equations (Davis et al 2003).

- **Langmuir model**: \[ Q = \frac{Q_{\text{max}} b C_f}{1 + b C_f} \]  

- **Freundlich model**: \[ Q = K_F C_f^{1/n} \]

- **Redlich-Peterson model**: \[ Q = \frac{K_{RP} C_f}{1 + a_{RP} C_f^{\beta_{RP}}} \]

- **Sips model**: \[ Q = \frac{K_S C_f^{\beta_S}}{1 + a_S C_f^{\beta_S}} \]

where \(Q_{\text{max}}\) is the maximum metal uptake (mg/g), \(b\) is the Langmuir equilibrium constant (L/mg), \(K_F\) is the Freundlich constant (L/g), \(n\) is the Freundlich constant, \(K_{RP}\) is the Redlich-Peterson isotherm constant (L/g), \(a_{RP}\) is the Redlich-Peterson isotherm constant (L/mg); \(\beta_{RP}\) is the Redlich-Peterson model exponent, \(K_S\) is the Sips model isotherm constant (L/g); \(a_S\) is the Sips model constant (L/mg) and \(\beta_S\) is the Sips model exponent. All the model parameters were evaluated by non-linear regression using MATLAB® software.

2.4 Column studies

Continuous flow sorption experiments were conducted in a glass column of 2 cm I.D. and 35 cm height. A known quantity of biomass was placed in the column to yield a desired bed height. A solution of 100 mg \(Zn^{2+}/L\) was pumped upward through the column at a desired
flow rate by a peristaltic pump. Samples were collected at the exit of the column at different time intervals and analyzed for zinc concentration. Operation of the column was stopped when the effluent zinc concentration exceeded a value of 99.6 mg/L. All the experiments were carried out in duplicates, and the deviations were within 5%. The total quantity of metal mass biosorbed in the column (m_{ad}) is calculated from the area above the breakthrough curve (outlet metal concentration versus time) multiplied by the flow rate. Dividing the metal mass (m_{ad}) by the biosorbent mass (M) leads to the uptake capacity (Q) of the biomass.

The other column parameters were calculated as described below (Vijayaraghavan et al 2005).

Overall sorption zone:
$$\Delta t = t_e - t_b$$  \hspace{1cm} (6)

Total amount of metal ions sent to column:
$$m_{total} = \frac{C_0 \cdot F \cdot t_e}{1000}$$  \hspace{1cm} (7)

Total metal removal (%):
$$\text{Removal} (%) = \frac{m_{ad}}{m_{total}} \times 100$$  \hspace{1cm} (8)

where $C_0$ is the inlet metal ion concentration (mg/L), $F$ the volumetric flow rate (ml/min), $t_e$ is the exhaustion time (h) and $t_b$ is the breakthrough time (h). The slope of the breakthrough curve from $t_b$ to $t_e$ was represented by $dc/dt$. All experiments were done in duplicates and the data presented are the average values of two replicate experiments.

3. Results and Discussions

3.1. Biosorption isotherm

![Graph](image)

**Figure 1**: Biosorption isotherms at different pH conditions for zinc by CSP.

The experimental results for zinc biosorption by CSP at different initial pH conditions are shown in Figure 1. The pH on the metal uptake by CSP was studied by varying the pH from 4 to 5. The results describes that the zinc uptake was maximum at pH 4.5 and then zinc uptake decreases further increase in pH. This was not only because of the hydrogen ion competition at low pH, but also may be due to sorbate lyophobic behavior. Since the solubility of many
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metal complexes in solution decreases with increasing pH, the sorption also increases with increasing pH. On changing the initial zinc concentration from 250 to 1000 mg/L, the uptake increased from 36.27 to 69.5 mg/g at pH 4.5. However, the percent zinc removal decreased as the concentration increases.

Table 1: Langmuir and Freundlich model parameters at different pH conditions

<table>
<thead>
<tr>
<th>Metal</th>
<th>pH</th>
<th>Langmuir parameters</th>
<th>Freundlich parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>(Q_{\text{max}}) (mg/g)</td>
<td>(b) (l/mg)</td>
</tr>
<tr>
<td>Zinc</td>
<td>4.0</td>
<td>65.12</td>
<td>0.012</td>
</tr>
<tr>
<td></td>
<td>4.5</td>
<td>71.46</td>
<td>0.048</td>
</tr>
<tr>
<td>Zinc</td>
<td>5.0</td>
<td>70.00</td>
<td>0.016</td>
</tr>
</tbody>
</table>

Sips model described the equilibrium data reasonably well at all conditions examined. The Sips model constant, \(K_S\), observed maximum at the optimum conditions, whereas other two constants (\(a_S\) and \(\beta_S\)) were lowest (Table 2). A typical example of batch biosorption isotherm fitted using four examined models.

3.2 Sorption kinetics

The prediction of batch sorption kinetics is necessary for the design of industrial sorption columns. The nature of the sorption process depends on physical or chemical characteristics of the biosorbent and also on the system conditions. In this study, the applicability of the pseudo-first-order and pseudo-second-order model has been tested for the sorption of Zn\(^{2+}\) ion onto CSP. The best-fit model was selected based on the non linear regression coefficient, \(R^2\) values.

![Figure 2](image)

Figure 2: Effect of initial metal concentration on Zn\(^{2+}\) biosorption by CSP (M=2 g/L; pH=4.5)

Figure 2 shows a plot of the Zn\(^{2+}\) ion uptake versus contact time for different initial metal concentrations. From the figure it was observed that the Zn\(^{2+}\) ion uptake increased with contact time at all initial Zn\(^{2+}\) ion concentrations. It was also observed that Zn\(^{2+}\) ion uptake
was rapid for the first 2 h and thereafter it proceeds at a slower rate and finally attains saturation. These observations showed that the initial Zn\(^{2+}\) ion concentration has no effect on equilibrium time. The higher sorption rate at the initial period (2 h) may be due to an increased number of vacant sites available at the initial stage (Senthil Kumar et al 2006), as a result there exist increased concentration gradient between sorbate in solution and sorbate in the biosorbent surface. As time increases, this concentration was reduced due to the accumulation of Zn\(^{2+}\) ion in the vacant sites, leading to a decrease in sorption rate at later stages of 2 to 8 hr.

### 3.3. Pseudo-first-order kinetics

The pseudo-first-order kinetic model has been widely used to predict the sorption kinetics (Ho et al 2005). The expression of pseudo-first-order kinetics is given by,

\[
\ln(Q_e - Q_t) = lnQ_e - k_1t
\]

Thus the rate constant \(k_1\) (L/min) can be calculated from the slope of the plot of \(ln (Q_e - Q_t)\) versus time \(t\). The calculated \(k_1\) values and the corresponding linear regression coefficient values are shown in Table 3. Further it was observed that the regression coefficients were low for all ranges of initial Zn\(^{2+}\) ion concentrations studied. This confirms that the pseudo-first-order model is not applicable in predicting the kinetics of Zn\(^{2+}\) ion biosorption onto CSP.

### 3.4. Pseudo-second-order kinetics

The kinetic data were further analyzed using pseudo-second-order kinetics (Ho and KcKay, 1998) which is represented by,

\[
\frac{t}{Q_t} = \frac{1}{k_2Q_e^2} + \frac{1}{Q_e} t
\]

where \(k_2\) is the pseudo-second-order rate constant (g/mg min), \(Q_e\) and \(Q_t\) represent the metal uptake at equilibrium and at any time \(t\) respectively.

The rate constant \(k_2\), and predicted \(Q_e\) can be calculated from the plot of \(t/Q_t\) versus time \(t\) using the equation (10). The pseudo-second-order rate constant, theoretical and experimental metal uptake and the non linear regression coefficient were tabulated in Table 4. From Table 4, it was observed that the \(R^2\) values were found to be higher at all initial Zn\(^{2+}\) ion concentrations compared to the pseudo-first-order and it shows that the sorption process follows a pseudo-second-order mechanism.

### 3.5. Influence of co-ions

Industrial wastewaters usually contain respectable amounts of different cations, which may influence the biosorption processes investigated (Kratochvil et al 1997: Volesky and Schiewer, 1999). Thus experiments were performed with four different cations such as K\(^{+}\), Na\(^{+}\), Ca\(^{2+}\) and Mg\(^{2+}\) along with Zn\(^{2+}\) ion. Co-ions concentrations were varied by keeping the Zn\(^{2+}\) ion concentration constant. Figure 3 represents the variation in the percentage of change in Zn\(^{2+}\) ion uptake for different co-ions concentrations.
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Figure 3: Effect of co-ions on Zn\(^{2+}\) biosorption by CSP. Co-ions

The change in uptake was calculated by the ratio of Zn\(^{2+}\) ion uptake without the presence of co-ions to the Zn\(^{2+}\) ion uptake with the presence of co-ions. Among the light metals, Ca\(^{2+}\) had an appreciable effect on the metal uptake followed by Mg\(^{2+}\) ions. The presence of sodium and potassium ions also influenced the lead uptake. In general, the suppression in zinc uptake was well pronounced in the case of divalent ions (Ca\(^{2+}\) and Mg\(^{2+}\)), when compared to monovalent ions (Na\(^{+}\) and K\(^{+}\)).

4. Column Studies

4.1 Effect of bed height

Figure 4. Column breakthrough curves for zinc biosorption onto CSP at different bed heights.

Table 3: Pseudo-first order model constants

<table>
<thead>
<tr>
<th>(C_0) (mg/L)</th>
<th>((Q_e)_{exp}) (mg/g)</th>
<th>Pseudo-first order</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>(K_i) (1/min)</td>
</tr>
<tr>
<td>250</td>
<td>36.27</td>
<td>0.012</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(Q_e) (mg/g)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>32.21</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(R^2)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.971</td>
</tr>
</tbody>
</table>
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<table>
<thead>
<tr>
<th>C$^0$ (mg/L)</th>
<th>($Q_e$)$_{exp}$ (mg/g)</th>
<th>Pseudo-second order</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$K_2$ (g/mg min)</td>
<td>$Q_e$ (mg/g)</td>
<td>$R^2$</td>
</tr>
<tr>
<td>250</td>
<td>36.27</td>
<td>0.0003</td>
<td>43.66</td>
<td>0.992</td>
</tr>
<tr>
<td>500</td>
<td>58.98</td>
<td>0.0002</td>
<td>74.70</td>
<td>0.984</td>
</tr>
<tr>
<td>750</td>
<td>66.98</td>
<td>0.0002</td>
<td>78.74</td>
<td>0.993</td>
</tr>
<tr>
<td>1000</td>
<td>69.5</td>
<td>0.0002</td>
<td>81.96</td>
<td>0.995</td>
</tr>
</tbody>
</table>

Table 4: Pseudo-second order model constants

<table>
<thead>
<tr>
<th>Bed height (cm)</th>
<th>Uptake (mg/g)</th>
<th>$t_b$ (h)</th>
<th>$t_e$ (h)</th>
<th>$\Delta t$ (h)</th>
<th>(dc/dt) (mg/L h)</th>
<th>$V_{eff}$ (l)</th>
<th>Total removal (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>32.50</td>
<td>20.2</td>
<td>52.6</td>
<td>32.4</td>
<td>3.086</td>
<td>15.78</td>
<td>70.66</td>
</tr>
<tr>
<td>20</td>
<td>36.10</td>
<td>24.2</td>
<td>71.5</td>
<td>47.3</td>
<td>2.130</td>
<td>21.45</td>
<td>73.65</td>
</tr>
<tr>
<td>25</td>
<td>39.20</td>
<td>31.5</td>
<td>90.1</td>
<td>58.6</td>
<td>1.706</td>
<td>27.03</td>
<td>75.33</td>
</tr>
</tbody>
</table>

Table 5: Column data and parameters obtained at different bed heights for zinc biosorption by CSP

BDST is a simple model, which states that bed height ($Z$) and service time ($t$) of a column bears a linear relationship. The equation can be expressed as follows (Hutchins, 1973).

$$t = \frac{N_0 Z}{C_0 \nu} - \frac{1}{K_a C_0} \ln \left( \frac{C_0}{C_b} - 1 \right)$$

(11)

where $C_b$ is the breakthrough metal concentration (mg/L); $N_0$ is the sorption capacity of bed (mg/L); $\nu$ is the linear velocity (cm/h) and $K_a$ is the rate constant (l/mg h). The plot of service time against bed height at a flow rate of 5 ml/min was linear ($R^2 = 0.991$) indicating the validity of BDST model for the present system. The sorption capacity of the bed per unit bed
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Volume, \(N_0\), was calculated from the slope of BDST plot, assuming initial concentration, \(C_0\), and linear velocity, \(v\), as constant during the column operation. The rate constant, \(K_a\), calculated from the intercept of BDST plot, characterizes the rate of solute transfer from the fluid phase to the solid phase (Cooney 1999). The computed \(N_0\) and \(K_a\) were 10891 mg/L and 0.025 L/mg h, respectively. If \(K_a\) is large, even a short bed will avoid breakthrough, but as \(K_a\) decreases a progressively longer bed is required to avoid breakthrough (Cooney, 1999). The BDST model parameters can be useful to scale up to the process for other flow rates without further experimental run.

4.2. Effect of flow rate

Flow rate is one of the important characteristics in evaluating sorbents for continuous treatment of metal-laden effluents on an industrial scale. The effect of flow rate on zinc biosorption by CSP was studied by varying the flow rate from 5 to 15 mL/min, while the bed height and initial Zinc concentration were held constant at 25 cm and 100 mg/L, respectively. The breakthrough curves of zinc biosorption at different flow rates are shown in Figure 5. Breakthrough and exhaustion occurred faster at higher flow rates (Table 6). Also as the flow rate increased, metal concentration in the effluent increased rapidly resulting in much sharper breakthrough curves. The flow rate also strongly influenced the zinc uptake capacity of CSP 43.82, 39.43 and 36.11 mg/g, were recorded at 5, 10 and 15 mL/min, respectively. This behavior may be due to insufficient time for the solute inside the column and the diffusion limitations of the solute into the pores of the sorbent at higher flow rates (Vijayaraghavan et al 2005). Even though more shortened mass transfer zone (usually preferable) was observed at higher flow rates, the total zinc removal percentage (a reflective of system performance) was actually recorded as 85.18, 67.50 and 52.59 % at 5, 10 and 15 mL/min, respectively.

![Figure 5: Column breakthrough curves for lead and zinc biosorption onto CSP at different flow rates. (---) Predicted using Thomas model](image)

4.3. Column data modeling

The breakthrough data obtained by varying the flow rate were fitted using the Thomas model.

\[
\frac{C_0}{C} = 1 + \exp \left( \frac{k_{TH}}{F} \left( Q_0 M - C_0 V_{eff} \right) \right)
\]  

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where \(k_{TH}\) is the Thomas model rate constant (L/mg h); \(Q_0\) is the maximum solid-phase concentration of the solute (mg/g); \(V_{eff}\) is the volume of metal solution passed into the column. The Thomas model is one of the most widely used methods to describe column biosorption data. The Thomas model, which assumes Langmuir kinetics of sorption-desorption and no axial dispersion is derived with the sorption that the rate driving force obeys second-order reversible reaction kinetics (Aksu and Gonen, 2003). In the present study, the Thomas model predicted the breakthrough curves well at all flow rates examined with very high correlation coefficients (Table 7). Also, the predicted zinc uptake values coincided well with the experimental uptake values. The rate constant \((k_{TH})\), which characterize the rate of solute transfer from the liquid to the solid phase, increased with increase in flow rate.

**Table 6:** Column data and parameters obtained at different flow rates for lead and zinc biosorption by CSP

<table>
<thead>
<tr>
<th>Flow rate (mL/min)</th>
<th>Uptake (mg/g)</th>
<th>(t_b) (h)</th>
<th>(t_e) (h)</th>
<th>(\Delta t) (h)</th>
<th>((dc/dt)) (mg/L h)</th>
<th>(V_{eff}) (L)</th>
<th>Total removal (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>43.82</td>
<td>30.0</td>
<td>90.0</td>
<td>60.0</td>
<td>1.660</td>
<td>27.00</td>
<td>85.18</td>
</tr>
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<td>10</td>
<td>39.43</td>
<td>20.0</td>
<td>60.0</td>
<td>40.0</td>
<td>2.497</td>
<td>36.00</td>
<td>67.50</td>
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<tr>
<td>15</td>
<td>36.11</td>
<td>15.0</td>
<td>42.0</td>
<td>27.0</td>
<td>3.700</td>
<td>37.80</td>
<td>52.59</td>
</tr>
</tbody>
</table>

**Table 7:** Parameters predicted from Thomas model for zinc sorption onto CSP at different flow rates

<table>
<thead>
<tr>
<th>Metal</th>
<th>Flow rate (mL/min)</th>
<th>(Q_{exp}) (mg/g)</th>
<th>(k_{TH}) (L/mg h)</th>
<th>(Q_0) (mg/g)</th>
<th>(R^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zinc</td>
<td>5</td>
<td>43.83</td>
<td>0.0011</td>
<td>44.78</td>
<td>0.989</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>39.43</td>
<td>0.0025</td>
<td>38.50</td>
<td>0.997</td>
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<td></td>
<td>15</td>
<td>36.12</td>
<td>0.0037</td>
<td>35.26</td>
<td>0.993</td>
</tr>
</tbody>
</table>

5. Conclusion

The present investigation resulted in identifying a more potent biosorbent, crab shell, for the removal \(\text{Zn}^{2+}\) ions from aqueous solutions. The results obtained indicate the high sorptive capacity of crab shell. Chitin and proteins were identified as the major constituents responsible for \(\text{Zn}^{2+}\) ions removal by CSP. Kinetic studies showed that the maximum \(\text{Zn}^{2+}\) ions biosorption occurred within 2 h. Pseudo-second-order kinetic equation represented the experimental data well. The influence of \(\text{Mg}^{2+}\) ions was found to be more in \(\text{Pb}^{2+}\) ions biosorption, compared to \(\text{K}^+\), \(\text{Ca}^{2+}\) and \(\text{Na}^+\) ions. The study also demonstrated that CSP could be effective for continuous removal of \(\text{Zn}^{2+}\) ions from aqueous solution. Therefore, CSP is satisfactory as a good biosorbent for \(\text{Zn}^{2+}\) ions removal because of the high heavy metal removal rate and removal capacity.

6. References


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