Reusability of *Sargassum cristaefolium* in Sorption-Desorption of Pb²⁺, Cu²⁺ and Ni²⁺ in Batch and Fixed-bed Systems

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**Abstract:** As an alternative method to the usual chemical precipitation method for removing heavy metal ions from wastewater, biosorption is considered effective if the biomass can be subjected to repeated sorption-desorption processes. This study had evaluated the reusability of *Sargassum cristaefolium* biomass in repeated sorption-desorption of a multi-metal system containing Pb²⁺, Cu²⁺ and Ni²⁺ in batch-contact process and fixed-bed column reactor. Results suggest that the biomass can be regenerated and reused for multiple sorption-desorption cycle; however, the multiple sorption-desorption cycle had resulted in a low concentration ratio for Cu²⁺ and Ni²⁺. The use of fixed-bed column reactor can offer an advantage over batch-contact because it can achieve better separation and higher concentration ratio over several consecutive sorption-desorption cycles.

**Keywords:** Biosorption • Sorption-desorption • Batch contact • Fixed-bed • Concentration ratio • Equilibrium loading

**INTRODUCTION**

Heavy metals in the environment are toxic; they are a major concern because they pose threat to plant and animal life. Anthropogenic sources of heavy metals include process waste streams from metal plating, mining operations and semiconductor manufacturing operations, among others. Heavy-metal ions in trace quantities are difficult to remove from aqueous waste streams using conventional methods such as chemical precipitation [1]. Scivation by ion exchange appears to be one of the few alternatives available for such situations. Due to the relatively high cost of synthetic ion exchange resins, recent researches have focused on the development of new methods which use low-cost metal sorbents derived from biological materials. Biosorption uses the property of certain type of inactive or dead microbial biomass to bind and concentrate heavy metals even in very dilute aqueous solution.

Nonliving microbial biomass can serve as a basis for the development of potent biosorbent materials for concentration and recovery of valuable heavy metals, nuclear fuels, or radioactive elements [1]. Some agricultural residues and other plant materials [2-5] have also been considered in some studies for their capacity to sequester certain heavy metal ions from liquid matrix. In addition to these, selected species of marine algae or seaweeds possess impressive sorption capacities for a range of heavy metal ions including copper, cadmium, lead and nickel as reported in recent investigations [6-12]. One study has made use of activated carbon prepared from a marine alga as biosorbent [13]. These studies have demonstrated and proven the effectiveness of seaweed biomass to remove heavy metal ions from aqueous solution. However, studies on desorption or recovery of adsorbed metals from the biomass are limited [10, 14, 15]. Desorption of cadmium from algal or fungal biosorbent using such eluants as HCl [16, 17], citric acid [18], EDTA [16], and the other mineral acids, HNO₃ and H₂SO₄ [16] had been specifically considered in some studies. The recovery of the adsorbed metal will allow the regeneration or reuse of the biosorbent. Full regeneration of the biosorbent with minimum amount of residual metal is desirable so that repeated sorption-desorption cycles can be performed using the same material [19].

Studies on desorption of bound metals from loaded biomass have used different techniques and different desorbing solutions or eluant. However, most of these
works involved only a single-metal system in an attempt to quantitatively describe the uptake and recovery of metals in the biomass [6, 10, 15]. This present study has particularly investigated the sorption and desorption of metals in multi-metal biosorption system using hydrochloric acid solution as the eluant. *Sargassum cristaefolium* biomass, which has been loaded with Pb²⁺, Cu²⁺ and Ni²⁺, was used in this study.

This study specifically looked into the performance of *Sargassum cristaefolium* biomass in repeated sorption-desorption cycle in a batch-contact process as well as in fixed-bed column contactor. The objectives are as follows: to determine the effect of repeated sorption-desorption cycle on the % adsorption, % desorption and equilibrium loading of Pb²⁺, Cu²⁺ and Ni²⁺ using varying eluant concentrations in a batch contact process; to determine the effect of repeated sorption-desorption cycle on breakthrough time and equilibrium loading of Pb²⁺, Cu²⁺ and Ni²⁺ in a fixed-bed column packed with *Sargassum cristaefolium* biomass; and, to compare the performance of *Sargassum cristaefolium* biomass in batch contact and in fixed-bed column processes.

This study will eventually provide some insights and information on the design of an operational wastewater treatment process, which will allow the recovery of metals and the regeneration of the biosorbent. The possible effect of other metallic ions that may be initially present on the biomass was not considered.

**MATERIALS AND METHODS**

**Preparation of Biosorbent:** The seaweeds (*Sargassum cristaefolium*) used in this study were gathered from the shores of Ilocos Sur, a province far-north of Manila. The seaweeds were cleaned by removing attached stones, shells and sand and by rinsing with water. Taking on the procedure based on the work of Cabatingan et al. [20], the size reduction and homogenization of the biomass was performed next, followed by immersion-contact of 10 g of the biomass in 1 L of 0.1 M HCl for 24 h. The solution was decanted; the biomass suspended in the solution was filtered; and, the biomass particles collected on the filter was rinsed with distilled water until the pH of the wash water was constant. The washed biomass particles were then dried overnight in a convection oven set at 60°C. The dried product biomass was then stored in desiccator.

**Preparation of Artificial Wastewater:** The artificial wastewater used in this study was prepared by spiking distilled water with analytical grade Pb(NO₃)₂, Cu(NO₃)₂, and Ni(NO₃)₂. Artificial wastewater solution containing all the metal ions, Pb²⁺, Cu²⁺ and Ni²⁺, each of concentration 100 ppm, was prepared. These concentration levels were based on previous studies which proposed an efficient and potentially cost-effective way of removing toxic heavy metals from industrial effluents with metal concentrations in the range 1-100 mg L⁻¹ [1, 21]. The initial pH of the stock solution was neither recorded nor was it adjusted at any point during the contact experiments.

**Sorption-Desorption Cycle:** Sorption-desorption cycle experiments were conducted in a process arrangement similar to that of a stirred-tank batch reactor (batch contact) and fixed-bed column contactor (continuous process). Five (5) cycles of sorption-desorption experiment were conducted for batch contact process while for continuous process 3 cycles. The detailed procedure for the sorption and desorption parts for the two processes is discussed below.

**Batch Contact-Sorption:** The dried protonated biosorbent or biomass was contacted with the prepared artificial wastewater (1.0 g of biomass in 500 mL of wastewater in 500 mL Erlenmeyer flask) in a rotary batch shaker for 2 h at room temperature. The biomass was filtered out using No. 40 Whatman filter paper. The supernatant was analyzed for metal concentration using flame atomic absorption spectrophotometer (FAAS) (AAnalytik 100, Perkin Elmer, USA). The biosorbent uptake qₑₑₑ (mg/g) or metal loading and the % adsorption were estimated, respectively, as follows:

\[ q_{ads} = \frac{q_{des,n-1}m + (C_i - C_f)V}{m} \]  
\[ \% \text{ adsorption} = \frac{\text{metal loaded}}{\text{amount of metal in the wastewater}} \times \frac{(q_{des,n} - q_{des,n-1})m}{CV} \times 100 \]

where \( C_i \) and \( C_f \) are the initial and final metal concentrations of the artificial wastewater, respectively, \( n \) is the corresponding number of sorption-desorption cycle, \( V \) is the batch solution volume, \( m \) is the dry weight of biomass and \( q_{des} \) is the metal content of the biomass after the desorption process.

**Batch Contact-Desorption:** The recovery (desorption) of the metal from the loaded biomass was performed by contacting the loaded biomass with 50 mL of HCl solution
in 125 mL flask. The mixture was placed in a gyra- tory bath shaker set at 150 rpm for 1 h. The mixture was then filtered using No. 40 Whatman filter paper and the supernatant liquid analyzed for metal concentration using FAAS. The amount of metal left (q_{des}) on the biomass after the (desorption) process was computed using the material balance equation:

\[ q_{des} = q_{ads} - \frac{C_L}{m} V_e \]  

(3)

where \( q_{ads} \) is amount of metal remained on the biomass after desorption, \( C_L \) is the metal concentration in the eluant, \( m \) is mass of the biomass and \( V_e \) is the volume of the eluant. The % desorption, which is the percentage of metal desorbed or extracted relative to initial metal loading on the biomass was computed using the equation:

\[ \% \ desorption = \frac{q_{des} \times 100}{q_{ads}} \]  

(4)

The overall process concentration ratio (CR), defined as the ratio of metal concentration in the eluant to metal concentration at which the biomass was loaded, was also computed to assess quantitatively the overall efficiency of the sorption-desorption process.

Three (3) sets of experiment were performed for the batch contact process in which three different eluant concentrations (0.1 M, 0.2 M and 0.3 M) were used. All experiments were done at ambient temperature.

**Fixed-Bed Column Contactor:** The glass column used has a diameter of 2.25 cm and a height of 48 cm. Glass wool was placed at the bottom of the column and approximately 15 g of the protonated biomass packed the column to a height of 23 cm. The column was rinsed with 100 mL of distilled water. A flow regulator was installed at the outlet of the column.

**Fixed-Bed Sorption:** Artificial wastewater stock for a 10-L reservoir was pumped using an acid/base resistant submergeable pump into the top of the column. The flow rate was measured by noting the time needed to fill a 10-mL graduated cylinder. Samples from the effluent were collected every 10 min for the first two hours, after which sample were collected in 1-h intervals. The samples collected were filtered using No. 40 Whatman filter paper and the metal concentration was determined using FAAS. The reservoir was continuously refilled with artificial wastewater to maintain the liquid level in the reservoir.

The flow rate would be checked from time to time so that adjustments be made with the flow regulator to maintain a flow rate of approximately 18 mL/min. Artificial wastewater was continuously fed to the column until the biomass was saturated, i.e., the influent metal concentration = effluent metal concentration. A small sample of the saturated biomass was obtained and analyzed for metal concentration using FAAS.

**Fixed-Bed Desorption:** The metals from the saturated biomass were then extracted using a 750 mL of 0.2 M HCl solution (biomass to eluant ratio, S/L = 20 gL⁻¹). The HCl solution was manually poured into the column (w/out the pump) and collecting it again at the effluent. The HCl solution was made to circulate in the column for about 1 h. The column was rinsed with 1 L, distilled water to remove the entrained HCl solution in the column. A small sample of the biomass was then obtained and analyzed for metal concentration using FAAS. The column was again subjected to metal reloading or sorption.

**Digestion:** Digestion of samples, i.e., loaded biomass, in nitric acid prior to FAAS analysis was performed according to the method we used in our previous work [22].

**RESULTS AND DISCUSSION**

**Batch Contact:** The regeneration of the biomass was conducted for the subsequent reuse of the biomass in a batch contact process. The results of five consecutive Pb²⁺, Cu²⁺ and Ni²⁺ sorption-desorption cycles using varying eluant concentrations are summarized in Fig. 1, 2 and 3. Fig. 1 shows that the equilibrium metal loading on the biomass had increased during the succeeding (sorption-desorption) cycles. The increasing equilibrium metal loading can be explained by considering that complete desorption of the metals from the biomass was not possible (see Fig. 3 and 4). When the biomass, after desorption, was again contacted with fresh metal-bearing solution the remaining metal on the biomass would establish a new equilibrium condition with the metal bearing solution. Hence, the equilibrium metal loading on the biomass would likewise increase since more metal ions would be distributed between the biomass and the solution phase. However, on each sorption cycle the metal adsorption on the biomass does not reach maximum saturation level for each metal ion because of competition.

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Fig. 1: Equilibrium metal loading on Sargassum cristaefolium after each sorption process of five successive sorption-desorption cycle (Eluting solution: aqueous HCl)

Fig. 2: % Adsorption of metal on Sargassum cristaefolium after each sorption process of five successive sorption-desorption cycles (Eluting solution: aqueous HCl)

Fig. 3: Equilibrium metal loading on Sargassum cristaefolium after each desorption process of five successive sorption-desorption cycle (Eluting solution: aqueous HCl)

Fig. 4: % Desorption of Pb$^{2+}$, Cu$^{2+}$ and Ni$^{2+}$ from Sargassum cristaefolium after each sorption process of five successive sorption-desorption cycle
Fig. 5: Concentration ratio of Pb\(^{2+}\), Cu\(^{2+}\) and Ni\(^{2+}\) in five successive adsorption-desorption cycle

Fig. 6: Breakthrough curve of Pb\(^{2+}\) in 3 cycles of repeated sorption-desorption cycle

Fig. 7: Breakthrough curve of Cu\(^{2+}\) in 3 cycles of repeated sorption-desorption process

Fig. 8: Breakthrough curve of Ni\(^{2+}\) in 3 cycles of repeated sorption-desorption process
Although there was accumulation of metals in the biomass, the results shown in Fig. 2 suggest that after the first cycle the Pb
\(^{2+}\), Cu
\(^{2+}\) and Ni
\(^{2+}\) reloading capacity of the biomass in subsequent cycles appeared to remain, on the average, at 75\%, 31.5\% and 17\%, respectively, regardless of the eluant concentration used in desorption process. This finding might suggest that the eluant was able to create additional sites on the biomass on which the metal from the wastewater can bind. If these were not the case, then the % adsorption would have decreased after each succeeding cycle.

Fig. 4 shows that the % desorption of Pb
\(^{2+}\), Cu
\(^{2+}\) and Ni
\(^{2+}\) had decreased after each succeeding (sorption-desorption) cycle. This can be attributed to the increase in equilibrium metal loading on the biomass. Since the amount of metal loaded kept on increasing, then it was expected that the % desorption would decrease since the amount and concentration of the eluant used was the same.

It is also noted in Fig. 4 that the % desorption of metals from the biomass was much higher at higher eluant concentration. It has been suggested that the driving force for desorption results from an activity difference between protons in solution and protons inside the biosorbent producing a chemical potential for proton uptake with compensating release of positive ion \([23]\). Hence, increasing the eluant concentration would increase the ion exchange activity in the biosorbent thus releasing more metal ions to the eluting solution.

The overall process concentration ratio (CR) of Pb
\(^{2+}\), Cu
\(^{2+}\) and Ni
\(^{2+}\) for each sorption-desorption cycle is shown in Fig. 5. It must be noted that biosorption process may be considered as a volume reduction process where large volume of relatively dilute metal waste is treated to yield small volume of highly concentrated metal solution. The CR must be kept as high as possible or the CR must be relatively much greater than 1 so that the sorption-desorption process can be considered effective. As shown in Fig. 5, CR of Ni
\(^{2+}\) was less than one, that Cu
\(^{2+}\) around 1.75. This is an unfavorable result since the objective to have an effective desorption process is to have highly concentrated metal ions in the eluate. The very low CR obtained for Cu
\(^{2+}\) and Ni
\(^{2+}\) can be attributed to the poor uptake of biomass on Cu
\(^{2+}\) and Ni
\(^{2+}\) ions. However, it has been proven in this study that the biomass can be regenerated and reused. This is validated with the results (Fig. 1 and 5) which show that the metal uptake and concentration ratio remained relatively constant after first cycle of sorption-desorption process. This study further suggests that the uptake of copper and nickel be improved so that the process of sorption-desorption cycle will also improve.

**Fixed-Bed Column Contactor:** The fixed-bed approach is used in many applications to process waste stream. In this scheme, the waste stream flows through a stationary mass of adsorbent medium. During the flow through the adsorbent medium most of the pollutants, i.e., heavy metal ions, are expected to come in contact with binding sites, and retained on the surface of the adsorbent, either by physisorption or chemisorption. In this study, the performance of Sargassum biomass in fixed-bed column contactor was analyzed using the effluent concentration versus time curves, referred to as breakthrough curve. The reusability of the biomass was evaluated in terms of the service life of the bed (breakthrough time) over 3 cycles of sorption and desorption of Pb
\(^{2+}\), Cu
\(^{2+}\) and Ni
\(^{2+}\). The service life of the bed was evaluated using the breakthrough curve and based on the predicted service of the bed using the bed-depth-service time (BDST) model \([24]\) for predicting bed height Z and service time t. The linearized BDST model is as follows:

\[
t_b = \frac{N_o Z}{1000VC_o} \left(1 + \frac{1}{kC_o} \ln \left(\frac{C_a}{C_b} - 1\right)\right)
\]

where \(t_b\) is the time until breakthrough, \(C_o\) is the initial concentration of pollutant (g/m\(^3\)), \(C_b\) is the breakthrough concentration of pollutant (g/m\(^3\)), \(V\) is the fluid velocity (m/min), \(N_o\) is the capacity of media for each pollutant in a multi-component solution (g pollutant / m\(^3\) of filter medium) \(N = q_p (1 - \varepsilon)\), \(\varepsilon\) is the porosity of the filter, \(k\) is the quasi-chemical rate constant from Bohart and Adams theory (m\(^2\)-g\(^{-1}\)-min\(^{-1}\)). The breakthrough concentration, \(C_b\), can be arbitrarily chosen. The corresponding time at which this concentration is attained is the breakthrough time, \(t_b\). The breakthrough curves for the sorption of Pb
\(^{2+}\), Cu
\(^{2+}\) and Ni
\(^{2+}\) in 3 cycles of sorption-desorption process are shown in Fig. 6, 7 and 8. It is quite noticeable that the shape of the curves approaches “S-shape”, which is a typical profile obtained for fixed-bed column. The breakthrough curves also manifest that the biomass has a higher sorption capacity for Pb
\(^{2+}\) followed by Cu
\(^{2+}\) and then Ni
\(^{2+}\). These were always the case over the 3 cycles of sorption-desorption process.
Table 1: Equilibrium metal loading, sorption capacity, %desorption and CR of Pb\(^{2+}\), Cu\(^{2+}\) and Ni\(^{2+}\) in the Sargassum biomass

<table>
<thead>
<tr>
<th>Cycle</th>
<th>Sorption Desorption</th>
<th>Sorption capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>qdes, mg/g</td>
<td>CI, ppm</td>
</tr>
<tr>
<td>1 Pb</td>
<td>172.17</td>
<td>2460.00</td>
</tr>
<tr>
<td></td>
<td>Cu</td>
<td>19.16</td>
</tr>
<tr>
<td></td>
<td>Ni</td>
<td>1.29</td>
</tr>
<tr>
<td>2 Pb</td>
<td>175.75</td>
<td>2563.73</td>
</tr>
<tr>
<td></td>
<td>Cu</td>
<td>22.03</td>
</tr>
<tr>
<td></td>
<td>Ni</td>
<td>1.08</td>
</tr>
<tr>
<td>3 Pb</td>
<td>175.00</td>
<td>2454.26</td>
</tr>
<tr>
<td></td>
<td>Cu</td>
<td>21.27</td>
</tr>
<tr>
<td></td>
<td>Ni</td>
<td>1.02</td>
</tr>
</tbody>
</table>

Table 2: Estimated breakthrough time for Pb\(^{2+}\), Cu\(^{2+}\) and Ni\(^{2+}\) at C = 0.5C\(_{r}\)

<table>
<thead>
<tr>
<th>Cycle</th>
<th>Pb Breakthrough time, hr</th>
<th>Cu Breakthrough time, hr</th>
<th>Ni Breakthrough time, hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st Cycle</td>
<td>23.89</td>
<td>2.66</td>
<td>0.18</td>
</tr>
<tr>
<td>2nd cycle</td>
<td>16.84</td>
<td>2.96</td>
<td>0.15</td>
</tr>
<tr>
<td>3rd cycle</td>
<td>18.63</td>
<td>2.74</td>
<td>0.14</td>
</tr>
</tbody>
</table>

Table 3: Estimated rate constant for Pb\(^{2+}\), Cu\(^{2+}\) and Ni\(^{2+}\) over the 3 cycle of sorption-desorption process

<table>
<thead>
<tr>
<th>Cycle</th>
<th>Rate constant, k, m(^{-1})g(^{-1})-min(^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Pb(^{2+})</td>
<td>0.000329</td>
</tr>
<tr>
<td>Cu(^{2+})</td>
<td>0.000314</td>
</tr>
<tr>
<td>Ni(^{2+})</td>
<td>0.000527</td>
</tr>
<tr>
<td>2 Pb(^{2+})</td>
<td>0.000527</td>
</tr>
<tr>
<td>Cu(^{2+})</td>
<td>0.000154</td>
</tr>
<tr>
<td>Ni(^{2+})</td>
<td>0.000418</td>
</tr>
<tr>
<td>3 Pb(^{2+})</td>
<td>0.000342</td>
</tr>
<tr>
<td>Cu(^{2+})</td>
<td>0.000168</td>
</tr>
<tr>
<td>Ni(^{2+})</td>
<td>0.000568</td>
</tr>
</tbody>
</table>

The BDST model (Equation 5) was used to predict the breakthrough time for Pb\(^{2+}\), Cu\(^{2+}\) and Ni\(^{2+}\) for the 3 cycles of sorption-desorption process. The parameters used were as follows: density of the medium (Sargassum) = 674,000 g m\(^{-3}\); average volumetric flowrate of wastewater = 18 mL min\(^{-1}\); loading velocity of wastewater (v) = 0.04527 m min\(^{-1}\); bed porosity (ε) = 0.757; N\(_{0}\) = 28.212 g m\(^{-3}\); sorption capacity of the media (q) is given in Table 4; and quasi-chemical rate constant from Bohart and Adams theory (k). The k values were estimated at different cycles using the corresponding effluent metal ion concentration versus time data, on the assumption that the change in concentration with time followed pseudo-first-order kinetics, with k as the rate constant.

The breakthrough curves of Pb\(^{2+}\), Cu\(^{2+}\) and Ni\(^{2+}\) over the 3 cycles of sorption-desorption process derived from the BDST model were also shown in Fig. 6, 7 and 8. The model shows a symmetric breakthrough curve while the experimental breakthrough curve shows an asymmetric shape; a short leading edge followed by a gradual approach to the feed concentration at the latter stage of the breakthrough. In the first cycle, the BDST model predicted the time required for complete saturation of the column for Pb\(^{2+}\) to be 22 h, while from the experiment it was more than 60 h. This observation was similar in the succeeding cycles. However, for Cu\(^{2+}\) and Ni\(^{2+}\) the breakthrough curve represented by the model almost corresponded with the experimental breakthrough curve particularly in the 1\(^{st}\) and 3\(^{rd}\) cycle.

The breakthrough time (C = 0.5C\(_{r}\)) determined experimentally and the predicted breakthrough time by the BDST model are shown in Table 2. It is evident from the result of the experiment that the breakthrough time for Pb\(^{2+}\) significantly decreased from 1\(^{st}\) cycle to the 2\(^{nd}\) cycle. The reason for this is that in the first cycle the biomass was fresh and free of any cations while in the 2\(^{nd}\) cycle the biomass contained the undesorbed Pb\(^{2+}\). However, for 2\(^{nd}\) and 3\(^{rd}\) cycles the breakthrough time practically remained the same. The breakthrough time can be correlated with the sorption capacity of the biomass. It was observed that the breakthrough time was much longer when the biomass had higher sorption capacity (see Table 1). For Cu\(^{2+}\) and Ni\(^{2+}\) the breakthrough time did not vary much over the 3 cycles of sorption-desorption cycle. The reason for this is that the sorption capacity of the biomass for Cu\(^{2+}\) and Ni\(^{2+}\) relatively remained the same for the 3 cycles of sorption-desorption cycle. The breakthrough time predicted by the BDST model was comparable with the experimental values for C = 0.5C\(_{r}\). However, this may not hold true at other breakthrough concentrations. The equilibrium loading in the biomass did not vary over the 3 cycles of sorption-desorption process (see Table 4). This finding suggests that the biomass was not damaged over the three cycles of repeated sorption-desorption of Pb\(^{2+}\), Cu\(^{2+}\) and Ni\(^{2+}\) in the biomass. Thus, the biomass can be regenerated and reused.

A comparison of the performance of the Sargassum biomass in batch contact process and in fixed-bed column suggests that the Sargassum in fixed-bed column had shown more favorable results. First, the metal loading on the biomass was much higher (Table 1 and Fig. 1). Second, very high CR was obtained for Pb\(^{2+}\) (Table 1) and lastly, % desorption was much higher and did not vary with the repeated sorption-desorption cycle. However, similar problem was encountered with batch contact and fixed-bed column – the low uptake and concentration ratio obtained for Cu\(^{2+}\) and Ni\(^{2+}\).
CONCLUSION

In batch contact process, equilibrium metal loading on the biomass had increased during the consecutive cycles of the five (5) sorption/desorption cycles due to new equilibrium condition established between biomass and wastewater and due to the generation of additional active site in the biomass by the eluting solution. The % desorption of Pb\textsuperscript{2+}, Cu\textsuperscript{2+} and Ni\textsuperscript{2+} had decreased during the succeeding cycles of the five sorption/desorption cycles which resulted in increase in equilibrium metal loading. The % adsorption or the reloading efficiency in the biomass relatively remained constant after 1\textsuperscript{st} cycle of sorption-desorption process. Furthermore, the Sargassum biomass can be regenerated and reused for subsequent sorption-desorption of Pb\textsuperscript{2+}, Cu\textsuperscript{2+} and Ni\textsuperscript{2+} but the uptake of Cu\textsuperscript{2+} and Ni\textsuperscript{2+} still needs to be improved so that sorption-desorption process can be considered effective.

In fixed-bed column, equilibrium loading in the biomass did not vary over the 3 cycles of sorption-desorption process suggesting that the biomass was not damaged. The breakthrough time of Pb\textsuperscript{2+} (C = 0.5C\textsubscript{0}) in the column decreased during the 2\textsuperscript{nd} cycle and remained the same during the 3\textsuperscript{rd} cycle. However, for Cu\textsuperscript{2+} and Ni\textsuperscript{2+} the breakthrough time remained practically the same over the 3 cycles of sorption-desorption.

The performance of Sargassum biomass is better in fixed-bed column than in batch contact process due to high metal loading, higher concentration ratio and higher % desorption, which did not vary with the number of sorption-desorption cycle repeats up to the third cycle.

REFERENCES


