Biosorption of Cobalt from Aqueous Solutions by Wet and Dried Biomass of Oscillatoria sp.

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A cyanobacterium, Oscillatoria sp., isolated from the Mazandaran Rivers, Iran, was studied for its ability to eliminate Co(II) ions from aqueous solutions. Optimum conditions for biosorption of Co(II) ions by Oscillatoria sp. were investigated in terms of critical parameters such as pH, temperature, contact time, biomass concentration, initial metal concentration and influence of co-ions. Dried biomass of Oscillatoria sp. exhibited higher biosorption capacity than wet biomass. The maximal Co(II) ion biosorption capacities of the dried and wet biomass were recorded at pH 7 and 5, respectively. The range of initial Co(II) ion concentration tested was 5–200 mg/L and the experimental biosorption data was found to fit the Langmuir model better than the Freundlich model. Maximum biosorption capacity calculated for dried biomass of Oscillatoria sp. was 30.12 ± 0.10 mg/g based on the Langmuir model and optimum conditions were pH 7, 25°C, 0.08 mg/mL of biomass, 50 mg/L initial Co(II) and 6 h of contact time. Biosorption of Co(II) was reduced in the presence of equimolar amounts of co-ions. Lastly, the capacity of the dried biomass was tested for removal of Co(II) from river water samples supplemented with ~14 mg/L Co(II), under the optimized experimental conditions.

Introduction
Heavy metal pollution in aquatic systems is one of the most serious environmental problems today, a by product of industrialization. Various industries such as those related to fertilizers and pesticides, energy and fuel production, metal processing, etc., produce and discharge into the environment, wastes containing various heavy metals. These heavy metal pollutants are a threat to human health and the ecosystem because these are non-degradable and recalcitrant. Three kinds of heavy metals are of major concern: toxic metals such as Hg, Cr, Pb, Zn, Ni, Co; precious metals such as Ag and Au; and radio nuclides such as U and Ra (Wang and Chen, 2009). Bioremediation of heavy metals by biosorption has received increasing attention in recent years and various types of biomaterial, such as bacteria, fungi, yeasts, and plants have been employed (Nagase et al., 2005; Wang and Chen, 2009). The removal of metals or metalloid species, chemical compounds and particulates from solutions can be achieved by biosorption, which is mainly dependent on the affinity between metal ions and the binding sites on the cell surface. Both live and dead biomass as well as cellular products such as polysaccharides can be used for metal removal (Wang and Chen, 2009). Biosorption refers to the passive process for adsorption of metal ions by metabolically inactive biomass while bioaccumulation is the term usually employed to describe the active sequestering of metal ions by metabolically active biomass (Katircioğlu et al., 2008). Hence, while biosorption is possible using either live or dead biomass, bioaccumulation is mediated only by living biomass (Gupta et al., 2000; Bishnoi and Garima, 2004; Ahiuluwalia and Goyal, 2007).

Cyanobacteria or blue-green algae are the largest and most diverse group of photosynthetic prokaryotes whose habitats range from fresh and marine water to terrestrial environments (Katircioğlu et al., 2008). The microorganism selected for this study was a...
filamentous, photosynthetic cyanobacterium, Oscillatoria sp. From freshwaters of Mazandaran Rivers, which has the potential to eliminate heavy metal ions from aqueous wastes. The purpose of this study was to establish optimum conditions for Co(II) biosorption by this Oscillatoria sp. in a batch system. The effects of critical parameters such as pH, temperature, contact time, concentration of algal biomass, initial metal concentration, pretreatment of the biomass, as well as influence of co-ions were tested.

1. Materials and Methods

1.1 Cyanobacterial growth conditions

The Oscillatoria sp. used in this study was collected from freshwaters of Mazandaran Rivers and was previously isolated in Molecular and Cellular Biology Laboratory at the University of Mazandaran, Iran (unpublished data). Pure cultures of Oscillatoria sp. were grown in BG-11 medium containing NaNO₃ (1.5 g/L), K₂HPO₄ (0.04 g/L), MgSO₄·7H₂O (0.075 g/L), CaCl₂·2H₂O (0.036 g/L), citric acid (0.006 g/L), ferric ammonium citrate (0.006 g/L), Na₂-EDTA (0.001 g/L), Na₂CO₃ (0.02 g/L), and trace metal mix 1 mL/L. The composition of trace metal mix was H₂BO₃ (2.86 g/L), MnCl₂·4H₂O (1.81 g/L), ZnSO₄·7H₂O (0.222 g/L), Na₂MoO₄·2H₂O (0.39 g/L), CuSO₄·5H₂O (0.079 g/L), Cu(NO₃)₂·6H₂O (0.0494 g/L). The cultures were grown in BG-11 minimal medium at pH 7.1 at 25°C under cool white fluorescent light in a 12 h light–dark cycle for 10–15 days in an incubator suitable for cultivating photosynthetic organisms. The biomass was harvested in the exponential phase of growth after 15 days of incubation, by centrifugation at 10,000 rpm for 10 min in a centrifuge (Universal 320R, Hettich, German). The cell pellet was washed thoroughly with double distilled water to improve the metal binding properties. The washed algae were either used directly as wet biomass or were dried at 90°C for 12 h and ground to powder prior to use in metal biosorption experiments. To determine the correlation of wet weight and dry weight (DW) of the biomass, four samples of 50 mg wet weight were dried to a constant weight at approximately 90°C for 12 h on tared watch glasses and the mean dry weight for dried biomass was accounted 3 mg (Cain et al., 2008).

1.2 Reagents

All the chemicals used in media preparation were analytical grade (BDH). The working solutions were prepared by diluting the stock solution in double distilled water. To study the effect of pH on the Co(II) biosorption, the following buffers were used at 10 mM each to obtain specific pH ranges as follows: acetic acid buffer, pH 3-5; PIPES (Piperazine-1,4-bis(2-ethane-sulfonic acid), pH 6-7; and HEPES (2-(4-(2-hydroxyethyl)-1-piperazinyl)ethanesulfonic acid) buffer, pH 7-8 (Dabbagh et al., 2007). Hydrochloric acid and tetramethylammonium hydroxide were used for adjusting the pH values using a pH meter (744 digital pH meters, Metromin, German). Blank samples were used as controls.

1.3 Estimation of Co(II) ions

The metal ion concentrations in supernatant phase were analyzed by flame atomic absorption spectrophotometer (FAAS) at 240.7 nm wavelength (slit width 0.2 nm) (SpectraAA-10, Varian, USA). Limit of detection of Co(II) for the method used, was 0.084 mg/L. A standard solution of Co(II) (Merck), 1000 mg/L was used for calibration.

1.4 Batch mode studies

All the biosorption experiments were carried out in 50 mL capacity flasks containing 25 mL of various solutions, shaken at 125 rpm on a rotary shaker-incubator (NB-205QF, N-Biotech, Korea). For most experiments, the initial Co(II) concentration was 10 mg/L. The time, temperature, pH, etc. were varied according to the experiment. Biomass was separated from metal-bearing solution by centrifugation at 10,000 rpm for 10 min at room temperature. The supernatant was appropriately diluted and the residual Co(II) content was estimated as described above. Metal-free and biomass-free blanks were used as controls during estimation of the exact initial concentration of Co(II) by dilution. All experiments were repeated three times.

1.5 Effect of co-ions on cobalt biosorption

Solutions of Co(II) (10.0 mg/L) were prepared individually with one additional metal ion included Ni(II), Cd(II), Cu(II), Zn(II) or a mixture of all the above co-ions in equimolar concentrations of each co-ions [4.9 × 10⁻⁵ mol/L]. Dried biomass (3 mg) was allowed to contact the Co(II)/co-ion solutions at 25°C and pH 7 for 6 h contact time. Supernatants were collected by centrifugation and analyzed by FAAS.

1.6 Biosorption of cobalt ions from river water samples

The concentration of Co(II) in river water sample was almost undetectable by the method used (limit of detection, 0.084 mg/L), without any sample pretreatment. The river water samples were supplemented with 14 mg/L of...
Co(II) ions and biosorption batch experiments were carried out under optimum conditions using solutions that were prepared in the river water instead of double distilled water. Hence, in order to assess the performance of dried *Oscillatoria* sp. biomass in Co(II) biosorption standard addition method was used. The precise initial and final concentrations of cobalt were determined by FAAS as described above. The biosorption capacity was estimated as usual and expressed as mg Co(II) removed/g of biomass.

1.7 Data analysis

The metal uptake capacity in mg/g (Q) was calculated based on the measured initial (Cᵢ) and the final (residual) concentration (Cₑ) (mg/L) of the metals according to the equation:

\[
Q = \frac{V(Cᵢ - Cₑ)}{M}
\]

where V is the liquid sample volume and M is the biomass dry weight (g) (Cain *et al.*, 2008).

1.8 Equilibrium studies

The effect of various initial concentrations of Co(II) ions on the biosorption of Co(II) by dried biomass, was also studied within the range of 5 - 200 mg/L Co²⁺ at 25°C, pH 7, with shaking at 125 rpm for the required period of contact time (optimum conditions for all parameters were used) while maintaining biomass concentration at 0·08 mg/mL. Samples of supernatant were then collected by centrifugation and analyzed by FAAS.

1.9 Equilibrium isotherms

The two most commonly used adsorption isotherms are the Langmuir and Freundlich isotherms. The Langmuir isotherm assumes a surface with homogeneous binding sites, equivalent sorption energies, and no interaction between the sorbed species. The linear form of the Langmuir model is:

\[
\frac{1}{Qₑ} = \frac{1}{Qₑ} \left( \frac{1}{Qₘₚ} + \frac{1}{bCₑ} \right)
\]

where \(Qₑ\) is the metal uptake at equilibrium, \(Qₘₚ\) the maximum adsorption capacity under the given conditions, \(Cₑ\) the equilibrium concentration, and b relates to the affinity of the sorbent for the binding sites. The Freundlich isotherm is an empirical equation based on an exponential distribution of sorption sites and energies. The linear form of this model takes the form:

\[
\log Qₑ = \log k_f + \frac{1}{n} \log Cₑ
\]

where \(k_f\) and \(1/n\) are related to the sorbent capacity and sorption intensity, respectively (Al-Qodah, 2006; Lokeshwari and Joshi, 2009).

2. Results and Discussion

2.1 Effect of pH on cobalt biosorption

The pH of the solution can play a key role in the adsorption and bioaccumulation of cobalt as it influences both binding of the metal to sites on the cell surface and the chemistry of metal in solution (Katircioglu *et al.*, 2008; Yalcın *et al.*, 2008). In order to determine the optimum pH for biosorption, wet biomass of *Oscillatoria* sp. equivalent to 3 mg DW and dried biomass (3 mg) were placed in contact with 25 mL of Co(II) solutions (10 mg/L Co²⁺) at 25°C in buffers (10 mM) of different pH values between 3 and 8. The biomass was separated by centrifugation and aliquots of the supernatant were analyzed by FAAS for residual Co(II) ion content (Figure 1).

2.2 Cobalt sorption increased with increasing pH in case of both, wet and dried biomass. Maximum cobalt removal occurred at pH 5 and 7 for wet and for dried biomass, respectively. At pH values above 7, the metal ion solubility is lowered due to the formation of metal hydroxides. Within the pH range of 4–5, Co(II) uptake capacities of the biosorbent increased rapidly and reached a maximum value of 7.46 ± 0.81 mg Co²⁺ per g of biomass dry weight at pH 5 for wet biomass which is the pKa range of carboxyl groups. This suggests that these species probably have a greater role in cobalt uptake for wet biomass. However the Co(II) uptake of dried biomass stayed low up to pH 5, increased rapidly (496% ± 151.44) between pH 5.5 and pH 7 and maximum uptake of 11.92 ± 0.93 mg Co²⁺ per g of biomass dry weight was obtained at approximately pH 7. Phosphate groups of lipopolysaccharides (LPS) and phospholipids present in outer membrane would play a large role in Co(II) adsorption by dried biomass.
because dissociation and change to negatively-charged form around pH 7 (Cain et al., 2008). Therefore, all further studies were performed at pH 5 for wet biomass and at pH 7 for dried biomass. Dried biomass showed (60% ± 17.8) higher biosorption capacity at pH 7 than wet biomass at pH 5.

2.2 Optimum contact time for cobalt biosorption

In order to examine the time-dependence of the biosorption of Co(II) by wet and dried biomass, samples equivalent to 3 mg DW were placed in contact with 25.0 mL samples of Co(II) solution (10 mg/L Co²⁺) adjusted to pH 5 for wet biomass and to pH 7 for dried biomass. As shown in Figure 2, the uptake of Co(II) at 25°C by the dried biomass was found to be rapid during the first 2 h and subsequently only a very low increase in the metal uptake was observed, reaching a maximum value of 13.57 ± 0.23 mg Co²⁺ per g of biomass dry weight after 6 h. In case of the wet biomass the initial rapid phase was slower compared to that of the dried biomass and the equilibrium was attained after approximately 6 h with a maximum uptake of 11.62 ± 0.24 mg Co²⁺ per g of biomass dry weight. Dried biomass showed (16.8% ± 2.83) higher biosorption capacity than wet biomass. Based on the above results, a contact time of 6 h was set in order to ensure that equilibrium conditions are attained. Since the dried (dead) biomass could sequester cobalt to a higher extent in comparison with wet biomass, the metal ion removal was considered to be mainly due to passive physicochemical biosorption rather than an active uptake.

2.3 Effect of temperature on cobalt biosorption

The temperature of the adsorption medium can influence biosorption, especially by energy-dependent mechanisms in microbial cells (Arca et al., 2005). As shown in Figure 3, biosorption of cobalt increased 115.4% ± 9.65 with increase in temperatures from 22°C to 25°C, and decreased slightly 2.5% ± 0.12 between 25°C and 45°C. There was no significant change in the sorption capacity at temperatures between 30°C and 45°C. Hence 25°C was considered as the optimum temperature for efficient biosorption by the dried biomass.

Fig. 2 Time-dependence profile of Co(II) uptake by wet biomass or dried biomass at 25°C, with an initial Co(II) concentration of 10 mg/L. The pH of the samples was adjusted to 5 for the wet biomass and to 7 for the dried biomass.

2.4 Effect of the amount of biomass on cobalt biosorption

Figure 4 shows the effect of varying biomass concentration on the biosorption process. The maximum removal of Co(II) was obtained at 0.08 mg/mL, while that with biomass concentrations ranging from 0.12 mg/mL to 0.2 mg/mL were statistically similar and were lower than at 0.08 mg/mL. Amount of Co(II) removed by 0.08 mg/mL dried biomass was 115.48% ± 16.26 higher than that at 0.04 mg/mL and also 26.43% ± 4.03 higher than that at 0.2 mg/mL. More biomass may provide an increased number of binding sites, and hence a better biosorption capacity. However beyond a threshold value, higher biomass concentration leads to formation of aggregates that can reduce the effective biosorption area and sites available for metal binding (Ahuja et al., 1999b; Arca et al., 2005).

Fig. 3 Temperature-dependence profile of Co(II) uptake by dried biomass at initial concentration of 10 mg/L; pH 7.

Fig. 4 Biomass concentration-dependence profile of Co(II) uptake by dried biomass at 25°C, with an initial Co(II) concentration of 10 mg/L; pH 7.
2.5 Effect of initial concentration of cobalt on biosorption

The initial Co(II) concentration remarkably influenced the equilibrium in metal uptake (Figure 5). The uptake of Co(II) increased with increasing initial concentration of Co(II) in the solution. The maximum retention of Co(II) by dried biomass was obtained at a cobalt concentration of approximately 50 mg/L, yielding a maximum uptake of 28.12 mg Co²⁺ per g of biomass dry weight.

![Figure 5](image1)

Fig. 5 Effect of initial Co(II) concentration on biosorption of Co(II) at 25 °C; pH 7 with 0.08 mg/L of dried biomass.

2.6 Langmuir and Freundlich adsorption isotherms

The plots of linearized Langmuir and Freundlich adsorption isotherms were obtained based on the data from equilibrium biosorption experiments at 25°C and pH 7 (Figures 6A, 6B). The Langmuir and Freundlich adsorption constants evaluated from these isotherms are given in Table 1. Correlation regression coefficients indicate that the sorption process follows the Langmuir equation ($R^2 = 0.9721$) more closely.

![Figure 6](image2)

**Fig. 6** Langmuir (A) and Freundlich (B) adsorption isotherms for *Oscillatoria* sp.

2.7 Effect of co-ions on the cobalt biosorption.

To determine the effect of co-ions on the biosorption of Co(II), competitive biosorption experiments were conducted with Ni(II), Cd(II), Cu(II), Zn(II) at equimolar concentrations [$4.9 \times 10^{-5}$ mol/L] because of their known presence in most industrial effluents (Cain et al., 2008).

![Figure 7](image3)

**Fig. 7** Effect of co-ions on the uptake of Co(II) by dried biomass at 25°C; pH 7; with an initial concentration of cobalt 10 mg/L; and of co-ions (equimolar): Ni²⁺, 2.9 mg/L; Cd²⁺, 5.5 mg/L; Cu²⁺, 3.1 mg/L; Zn²⁺ 3.3 mg/L. Maximum inhibition (80%) of Co(II) ion uptake was seen when all the co-ions were present together as a mixture of co-ions with equimolar concentrations.

### Table 1 Langmuir and Freundlich parameters for the adsorption isotherms of biomass adsorbent for Co(II) ions

<table>
<thead>
<tr>
<th>Biosorbent</th>
<th>Langmuir</th>
<th>Freundlich</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$Q_{\text{max}}$ (mg/g)</td>
<td>$b$</td>
</tr>
<tr>
<td>Dried biomass of <em>Oscillatoria</em> sp.</td>
<td>30.12 ± 0.10</td>
<td>0.06 ± 0.11</td>
</tr>
</tbody>
</table>

The values obtained experimentally were used to calculate the above parameters.
2.8 Biosorption of cobalt from river water samples by the standard addition method

River water samples were adjusted to pH 7 and simulated to carry a detectable quantity of cobalt by addition of about 14 mg/L of Co(II) ions. Varying amounts of dried biomass (2 and 3 mg in 25 mL) were added to the samples to test biosorption under optimum conditions as described for the other experiments. Metal-free and biomass-free blanks were used as controls during estimating the initial concentration precisely by FAAS. Accordingly, 13.98 mg/L of Co(II) was found to be present in the simulated sample. The standard addition method was used for determination of removal of Co(II) from these samples. Calibration curves were drawn to determine Co(II) concentration and Co(II) biosorption capacities for Co(II) were strongly dependent on the pH of the solution. In highly acidic conditions, the extent of biosorption is insignificant due to competition protons with the cations to bind to the cell surface sites, thereby making these unavailable for other cations (Bishnoi and Garima, 2004). There was appreciable binding of cobalt at pH 5 by wet biomass and at pH 7 by dried biomass (Figure 1). This is in agreement with the observation of Pal, Ghosh, and Paul (2006) who showed the optimum pH for Co(II) removal by fungi was 7.0 and also Esmaeili et al., (2007) who reported the maximum Co(II) uptake of Sargassum sp. (marine brown algae) at pH 7 (Pal et al., 2006; Esmaeili et al., 2007). Co(II) biosorption could be divided into two stages for both dried and wet biomasses: a fast initial rate was followed by a much slower biosorption rate (Figure 2). The fast initial metal biosorption rate was attributed to the surface binding between the negatively charged cell surface ligands and metal cations and the subsequent slower sorption was attributed to saturation of available sites in dried biomass, slower interior penetration and/or saturation of available sites in wet biomass. The observation is in agreement with the work of Hamdy et al., 2000; Arca et al., 2005 and Kumar and Kaladharan (2006) who reported a similar pattern. Various parameters influence equilibrium time such as size and form of biomass, its physiological state, number and kind of biosorption sites and type of metal (Jalali-Rad et al., 2004). The dried biomass of Oscillatoria sp. showed a higher biosorption capacity than the wet biomass. The use of dead microbial cells in industrial application may offer some advantages over living cells, such as lower sensitivity to toxic metal ion concentrations and to adverse operating conditions (Arca et al., 2005). Different chemical and physical pretreatments can modify the surface characteristics, either by removing or masking chemical groups or by exposing metal-binding sites (Gupta et al., 2000; Dabbagh et al., 2008). But in this study,

### Table 2 Statistical parameters for biosorption of Co(II) from simulated river water samples by dried biomass of Oscillatoria sp.

<table>
<thead>
<tr>
<th>Oscillatoria sp. dry weight (mg)</th>
<th>Least square equation</th>
<th>Correlation coefficient (R²)</th>
<th>Initial concentration of Co(II) (mg/L±sCx)</th>
<th>Residual amount of Co(II) removed</th>
<th>Co(II) biosorption capacity (mg/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>( y = 0.0491 x + 0.1026 )</td>
<td>0.9991</td>
<td>13.06 ± 0.32</td>
<td>0.92 ± 0.33</td>
<td>11.50 ± 0.33</td>
</tr>
<tr>
<td>3</td>
<td>( y = 0.0509 x + 0.1049 )</td>
<td>0.9963</td>
<td>12.88 ± 0.43</td>
<td>1.12 ± 0.44</td>
<td>9.16 ± 0.44</td>
</tr>
</tbody>
</table>

Dried biomass was added to 25 mL of river water samples that were adjusted to pH 7 and supplemented with ~14 mg/mL of Co(II). Biosorption was allowed for 6 h at 25°C with shaking at 125 rpm. Initial and residual Co(II) were estimated by atomic adsorption spectroscopy.

**sCx**: standard deviation

The goal of this work was to explore the potential use of Oscillatoria sp. biomass as a low-cost biosorbent for the removal of Co(II) heavy metal ion from aqueous solutions. Batch experiments showed that Oscillatoria sp. has a remarkable ability to take up Co(II) heavy metal ion. According to the results obtained, biosorption capacities for Co(II) were strongly dependent on the pH of the solution. In highly acidic conditions, the extent of biosorption is insignificant due to competition protons with the cations to bind to the cell surface sites, thereby making these unavailable for other cations. However, there was appreciable binding of cobalt at pH 5 by wet biomass and at pH 7 by dried biomass (Figure 1). This is in agreement with the observation of Pal, Ghosh, and Paul (2006) who showed the optimum pH for Co(II) removal by fungi was 7.0 and also Esmaeili et al., (2007) who reported the maximum Co(II) uptake of Sargassum sp. (marine brown algae) at pH 7 (Pal et al., 2006; Esmaeili et al., 2007). Co(II) biosorption could be divided into two stages for both dried and wet biomasses: a fast initial rate was followed by a much slower biosorption rate (Figure 2). The fast initial metal biosorption rate was attributed to the surface binding between the negatively charged cell surface ligands and metal cations and the subsequent slower sorption was attributed to saturation of available sites in dried biomass, slower interior penetration and/or saturation of available sites in wet biomass. The observation is in agreement with the work of Hamdy et al., 2000; Arca et al., 2005 and Kumar and Kaladharan (2006) who reported a similar pattern. Various parameters influence equilibrium time such as size and form of biomass, its physiological state, number and kind of biosorption sites and type of metal (Jalali-Rad et al., 2004). The dried biomass of Oscillatoria sp. showed a higher biosorption capacity than the wet biomass. The use of dead microbial cells in industrial application may offer some advantages over living cells, such as lower sensitivity to toxic metal ion concentrations and to adverse operating conditions (Arca et al., 2005). Different chemical and physical pretreatments can modify the surface characteristics, either by removing or masking chemical groups or by exposing metal-binding sites (Gupta et al., 2000; Dabbagh et al., 2008). But in this study,
additional pretreatment of the dried biomass such as heat or acid treatment improved the efficiency of biosorption marginally (Data is not shown). Thus, drying of the algal biomass at 90°C was found to provide an efficient biosorbent for removal of Co(II) ions from aqueous solution, without any pretreatment. Co(II) uptake rate was found to be dependent on the initial Co(II) concentration (C_i) such that an increase in C_i caused an increase in the saturation point also (Figure 5). In addition, presence of other metal ions had an inhibitor effect on the uptake of Co(II) ion by Oscillatoria sp. (Figure 7). The decrease of Co(II) ion uptake in this experiment was thought to be a response to increased competition between the same charged species i.e. co-ions for binding sites on the biomass (Wang and Chen, 2006). Lastly, the dried biomass was demonstrated to effectively remove Co(II) from the simulated river water samples containing about 14 mg/L Co(II).

Conclusion

Results presented in this study have revealed the parameters that can influence biosorption of Co(II) ions by Oscillatoria sp. Drying of the biomass was found to be a better option than using wet biomass. Optimum conditions of pH (7.0), temperature (25°C), initial Co(II) concentration (50 mg/L), biomass concentration (0.08 mg/mL) and contact time (6 h) were established using dried biomass in the batch system. These data can be useful for optimizing the operating conditions for a large scale, economical process for wastewater treatment. The present report also demonstrates that cyanobacteria, which are photosynthetic autotrophs and hence easy to cultivate, are ideal candidates that can be further exploited for bioremediation.

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