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Ş. Öztürk[a]; B. Aslım[a]; A. R. Türker[b]
[a] Department of Biology, Science and Art Faculty, Gazi University, Ankara, Turkey [b] Department of Chemistry, Science and Art Faculty, Gazi University, Ankara, Turkey

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Ş. Öztürk,[1] B. Aslım,[1] and A. R. Türker[2]
[1]Department of Biology, Science and Art Faculty, Gazi University, Ankara, Turkey
[2]Department of Chemistry, Science and Art Faculty, Gazi University, Ankara, Turkey

Abstract: The biosorption of cadmium ions from aqueous solution by dried, immobilized dried and immobilized live *Synechocystis* sp. was investigated. Sorption of plain Ca-alginate beads, which were used as substrate for immobilization, was also studied for comparison. Removal efficiency of biosorbents was studied as a function of pH (2–8), temperature (20–40°C), initial cadmium ion concentration (50–300 mg/L), and contact time (0–120 min). The maximum biosorption capacities of the dried, immobilized dried, and immobilized live *Synechocystis* sp. and plain Ca-alginate beads were found as 75.7, 4.9, 4.3, and 3.9 mg/g, respectively at optimum conditions. Biosorption equilibrium was established in about 15 min. Dried biomass of *Synechocystis* sp. was found to be more suitable and an efficient biosorbent for the removal of cadmium ion from aqueous solution. Both of the isotherm models (Langmuir and Freundlich) were suitable for describing the biosorption of cadmium by the dried biomass of *Synechocystis* sp. All the tested cyanobacterial forms could be recovered more than 90% and reused in five biosorption–desorption cycles without any considerable loss in the biosorption capacity.

Keywords: Biosorption, cadmium(II) removal, cyanobacteria, *Synechocystis* sp.

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Address correspondence to A. R. Türker, Gazi University, Science and Art Faculty Department of Chemistry, Ankara 06500, Turkey. Fax: +90 312 2122279. E-mail: aturker@gazi.edu.tr

INTRODUCTION

Contamination of the aqueous environments by heavy metals is a worldwide environmental problem due to their toxic effects and accumulation through the food chain (1). Cadmium is the heavy metal with the greatest potential hazard to humans and the environment due to its acute toxicity. The industrial uses of cadmium are widespread and increasing in electroplating, fertilizers, battery manufacturing, paint pigments, plastics, alloy preparation, mining, ceramics, and batteries (2–4).

There are different methods for the removal of heavy metal pollutants from wastewaters when they are present in high concentrations, such as chemical precipitation, solvent extraction, electro-deposition, ion exchange, and membrane processes. However, removing of such contaminants at very low concentrations is much more difficult. Processes suitable at high concentrations are often either ineffective or cost prohibitive when applied to dilute wastes with low heavy metal concentrations (5,6). In recent years, removal of heavy metals from dilute samples with biosorption process has emerged as an alternative technology (7,8).

Biosorption is a term that describes the adsorption of species to be considered by the passive binding to nonliving microorganisms (bacteria, fungi, and algae) and other biomass (such as peat, rice hull, fruit peel, leaves, and bark of tree) from an aqueous solution (9,10). Biosorption has many advantages including low operating costs, the selective removal of species, regeneration possibility, higher recovery potentiality, rapid adsorption rates, desorption easiness, and no sludge generation. Biosorption technology has been shown to be a feasible alternative for removing heavy metals from wastewater (11,12).

In recent years, cyanobacteria have been used as biosorbent for metal removal. Cyanobacteria are the largest and most diverse group of photosynthetic prokaryotes whose habitats vary from fresh and marine water to terrestrial environments. Cyanobacterial cells surrounded by thick polysaccharide capsules or slimy investments should possess a larger number of binding sites for metal ions as compared to non-capsulated isolates (13). Cyanobacteria are suggested as biosorbent to have some added advantages over other microorganisms because of their large surface area, greater mucilage volume with high binding affinity, and simple nutrient requirements (7,14). The cyanobacteria strain selected for this study was a unicellular cyanobacterium, *Synechocystis* sp. In particular, the unicellular cyanobacterium *Synechocystis* sp. PCC 6803 (hereinafter referred to as *Synechocystis* sp.) is a widely used model system to study photosynthesis and other metabolic processes. *Synechocystis* sp. is the first photosynthetic organism for which the complete genome sequence was determined (15). It is suitable to be genetically manipulated, so

becoming transformable by exogenous DNA upon homologous recombination and integration. Its metabolic versatility allows it not only to survive in a wide variety of environments but also to live under non-photosynthetic conditions if a suitable carbon source, such as glucose, is available (16). Also, *Synechocystis* sp. has shown good adsorbing characteristics and it is not a hazardous microorganism for human (no toxicity). All these features make *Synechocystis* sp. the subject for research in heavy metal biosorption studies. Chong et al. (17) have tested *Synechocystis* sp. as biosorbent for Ni(II) and Zn(II) and found that it did not remove any nickel ion and only remove zinc ion about 40%.

The present study describes the applicability of *Synechocystis* sp. as biosorbents for the removal of Cd(II) from aqueous samples. The effect of immobilization and inactivation of the cyanobacterium has also been evaluated. The effects of pH, temperature, initial concentration of cadmium, and contact time on the biosorption were investigated. The effectiveness of desorbing agent (HCl) in stripping adsorbed cadmium(II) ions from immobilized biomass was also investigated. Langmuir and Freundlich adsorption isotherms are employed to understand the nature of sorption processes. Finally, to assess the applicability of cyanobacterial species in wastewater treatment technologies, reusability and ability to regenerate of *Synechocystis* sp. preparations was also evaluated.

EXPERIMENTAL

Apparatus

A Varian 240 FS model flame atomic absorption spectrometer (FAAS) equipped with deuterium lamp background correction, hollow cathode lamp (HCL) and air acetylene burner was used for the determination of cadmium. Absorption measurements were performed under the following conditions: wavelengths, 228.8 nm; air flow rate, 13.50 L/min; acetylene flow rate, 2.00 L/min; HCL lamp current, 4.0 mA; bandpass, 0.5 nm and integration time, 4 s. All pH measurements were performed with a JENWAY 3010 model digital pH meter.

Reagents

All chemicals were of analytical reagent grade unless otherwise specified. Doubly distilled deionized water was used throughout the study. Cadmium stock solution (1000 mg/L) was prepared by dissolving a calculated amount of $CdCl_2$ (Merck). The working solutions were prepared by

diluting the stock solution to appropriate volumes. Britton-Robinson (B-R) buffer solution was prepared by dissolving 2.3 mL of glacial acetic acid, 2.7 mL of phosphoric acid and 2.5 g of boric acid in doubly distilled water and diluted to 1.0 L. 100 mL portions of this solution were taken and the desired pH was adjusted between 2.0 and 8.0 by addition of appropriate amount of 2.0 M NaOH (18).

Microorganism and Growth Conditions

Cyanobacterial strain, *Synechocystis* sp. was isolated from the freshwater samples obtained from Mogan lake in Turkey using standard plating, isolating and culturing techniques (19). 100 mL of BG-11 medium was used as culture medium for *Synechocystis* sp. Composition of BG-11 medium used is: $NaNO_3$ (15 g/L), K_2HPO_4 (0.4 g/L), $MgSO_4 \cdot 7H_2O$ (0.75 g/L), $CaCl_2 \cdot 2H_2O$ (0.36 g/L), citric acid (0.06 g/L), iron (III) ammonium citrate (0.06 g/L), Na_2-EDTA (0.01 g/L), Na_2CO_3 (0.2 g/L) and trace metal mix (1 mL) containing H_3BO_3 (61 mg/L), $MnSO_4 \cdot H_2O$ (169 mg/L), $ZnSO_4 \cdot 7H_2O$ (287 mg/L), $(NH_4)_6Mo_7O_{24} \cdot 4H_2O$ (12.5 mg/L), $CuSO_4 \cdot 5H_2O$ (2.5 mg/L). pH of BG-11 medium was 6.8. Cultures were incubated at 22 to 25°C with light/dark cycle of 12/12 h by using an incubator shaker (MINITRON) for 21 days, which is suitable for photosynthesis. The intensity of light during the light period was 3000 lux at 25°C. Cells were removed from the culture medium by centrifugation (6000 rpm, 5 min) and were washed three times with deionised water in order to remove the remaining culture medium.

Identification Method of Cyanobacterial Isolate

Genomic DNA extraction was done by DNeasy® Blood & Tissue Kit (Cat. No.: 69504, QIAGEN). Cyanobacterial 16S rDNA sequences were amplified using cyanobacteria-specific primers as previously described by Nubel et al. (20) and Thacker and Starnes (21) as CYA106 F (CGGACGGGTGAGTAACGCGTGA-3) and CYA781 R (5-GACTACAGGGGTATCTAATCCCTTT-3). Also BACF (5-GCCAGGGGAGCGAAAGGGATTAGA-3) and BACR (5-CATGGTGTGACGGGCGGTGTG-3) primers which were designed by one of the authors (B. Aslım) were used for amplification. PCR amplifications were performed with a Hybaid thermocycler (ThermoHybaid, UK) and conditions were evaluated as described by Nübel et al. (20). The sequencing process was performed by the REFGEN (Ankara, Turkey), and the sequences obtained were searched against The Gen Bank DNA database using the blast function.

Immobilization of Microorganism

Cyanobacterial cells harvested at 21st day stage were washed and dried at 70°C for 24 h and grounded. For immobilization of the cyanobacteria in alginate gel in the form of beads, 0.1 g of dried and live biomass of *Synechocystis* sp. was suspended in 5 mL of double distilled water, mixed with 10 mL of 2 % (m/v) sodium alginate solution and dropped through a syringe (4.0 mm i.d.) into 10 mL of 0.1 mol/L calcium chloride solution forming algal beads (4.0 ± 0.1 mm diameter). The beads were kept overnight at 4°C in 0.5 mol/L of $CaCl_2$ solution for completing the process of gel formation. Plain Ca-alginate beads (without algae) were also prepared by using similar procedure. The beads were rinsed with deionized water before use.

Biosorption Experiments (Batch Procedure)

Each experiment was repeated 3 times and results given are the average values. Five measurements for each sample were done by FAAS to compute the mean value. Calibrations were performed within a linear calibration range of Cd(II), and the calibration curves with correlation coefficients less than 0.990 were repeated. The difference between the initial and remaining metal ion concentrations was assumed to be taken up by the biosorbent. The amount of adsorbed Cd(II) ions per unit biosorbents (mg metal ions/g dry adsorbent) was obtained by using Equation (1).

$$q = \frac{(C_0 - C)V}{m} \tag{1}$$

Where, q is the amount of cadmium ion adsorbed onto the unit amount of the adsorbents (mg/g), C_0 and C are the concentrations of the cadmium ion (mg/L) in the solution initial and after biosorption, respectively, V is the volume of the aqueous phase (L) and m is the amount of the adsorbent (g).

Effect of pH on the Biosorption Capacity

Synthetic sample solution (50 mL) containing 100 mg/L Cd(II) ion and 0.05 g of dried, 0.950 g of immobilized dried biomass (30 beads), 0.987 g of immobilized live biomass (30 beads) and 0.900 g of plain Ca-alginate (30 beads) was mixed separately in a flask. The pH of the solution was adjusted to 7.0 by addition of the Britton-Robinson (B-R)

buffer and the mixture was agitated magnetically at 100 rpm for 60 min at $23 \pm 2°C$. Dried biomass was separated by centrifugation. Determination of Cd(II) ion was performed in liquid phase (supernatant) by flame atomic absorption spectrometer.

Effect of Temperature, Contact Time, and Initial Cd(II) Concentrations on the Biosorption Capacity

The experiments were carried out at five different temperatures, i.e., 20, 25, 30, 35, and 40°C. The extent of adsorption was determined at definite time intervals (0, 5, 10, 15, 30, 60, and 120 min.) Adsorption by cyanobacterium (*Synechocystis* sp.) forms was also carried out at five initial cadmium(II) concentrations (50, 100, 150, 200, 250, and 300 mg/L) at 25°C for 60 min. The amount of biomass and the adsorption procedures were same as described for the effect of pH on biosorption capacity.

Desorption

In order to determine the reusability of the biosorbents, consecutive biosorption-desorption cycles were repeated five times using the same cyanobacterial forms. Desorption of Cd(II) ions was performed by 50 mL of 0.1 M HCl. The dried biomass, immobilized dried, immobilized live *Synechocystis* sp. and plain Ca-alginate beads loaded with Cd(II) ions were placed in the desorption medium and were stirred at 100 rpm for 1 h at 23°C. After each cycle of adsorption-desorption, biomass was reconditioned by washing with 0.85% saline solution (22). The final chromium ions concentration in the aqueous phase was determined by FAAS as described above. The desorption ratio was calculated from the amount of metal ions adsorbed on the biomass and the final metal ions concentration in the adsorption medium. Desorption ratio was calculated from the following equation (Eq. (2)) (23):

$$\text{Desorption ratio} = (\text{Amount of Cd(II) desorbed} / \text{Amount of Cd(II) adsorbed}) \times 100 \quad (2)$$

RESULTS AND DISCUSSION

Identification of Cyanobacterial Isolate

The isolate was identified by amplification and sequencing of its 16S rRNA gene. Sequence was initially analyzed at NCBI server

(http://www.ncbi.nlm.nih.gov/) using BLAST (blastn) tool and corresponding sequences were downloaded. By the use of internal primers, the sequence showed 98% similarity with *Synechocystis* sp. PCC 6803 (BA000022.2). On the basis of 16S rRNA gene sequence analysis the isolate (BASO670) is identified as *Synechocystis* sp.

Effect of pH on the Biosorption Capacity

Previous studies on heavy metal biosorption have shown that pH was the most important parameter affecting the biosorption process (24,25). Both the surface functional groups on the cell walls of the biosorbent and the metal chemistry in solution are affected by the pH of a medium (26). At very low pH values, the surface ligands are closely associated with the hydronium ions (H_3O^+) and restricted the approach of metal cations (26). Therefore, metal biosorption on a biosorbent depends on pH value of a medium. Furthermore, the pH dependency on the metal ions uptake by biomasses can also be justified by the association–dissociation of certain functional groups, such as the carboxyl and hydroxyl groups present on the biomass. Most of the carboxylic groups are not dissociated at low pH and cannot bind the metal ions in solution, although they take part in complex formation reactions (27). The variation of equilibrium uptake for cadmium(II) ions at different initial pH values (2.0 to 8.0) for dried, immobilized dried, immobilized live biomass and plain Ca-alginate beads were given in Fig. 1. It shows that cadmium(II) ions are adsorbed by dried biomass more strongly than

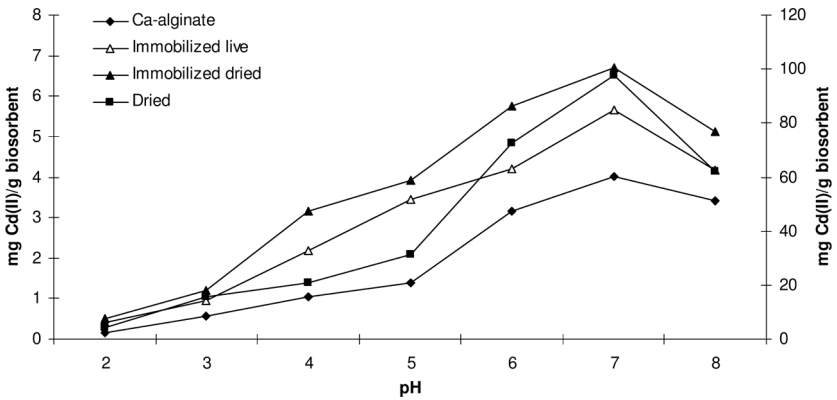

Figure 1. Effect of pH on the biosorption of dried biomass, immobilized dried and immobilized live cells of *Synechocystis* sp. for Cd(II) ions (C_0, 100 mg/L; temperature, 25°C, 60 min). y axis at right side is belong to dried biomass.

the immobilized dried biomass, immobilized live biomass and plain Ca-alginate beads. As can be seen from Fig. 1 the biosorption of Cd(II) increases from pH 2.0 to 7.0 and then declined with further increase in pH. Decrease in biosorption at higher pH (pH > 7) may be due to the formation of soluble hydroxilated complexes of the metal ions and their competition with the active sites, and as a consequence, the retention would decrease. The greatest capacity of biosorption was obtained at pH 7.0 for Cd(II) ions. Therefore, all the biosorption experiments were carried out at pH 7 for further experiments.

Effect of Temperature on the Biosorption Capacity

In the literature, the effect of temperature on the biosorption process is explained by different and opposite behaviors. Some of the researchers (28,29) have reported higher uptake capacities of cadmium on different organisms have been obtained for higher temperatures. On the other hand, others have reported (30,31) that there is no effect of temperature on metal uptake of the biosorbent. In contrast, there are also reports showing a decrease in the uptake capacity with temperature increase (32,33).

The temperature of the adsorption medium is important for energy-dependent mechanisms in metal biosorption by microbial cells (34). Adsorption is mostly an exothermic process, although few examples of endothermic adsorption have also been reported (35).

The biosorption of Cd(II) by dried biomass, immobilized dried biomass, immobilized live biomass and plain Ca-alginate beads appears to be temperature-dependent over the temperature range tested. The biosorption of the dried, immobilized dried biomass, immobilized live biomass, and plain Ca-alginate beads for Cd(II) ions increased about 4.0-, 1.5-, 1.3-, and 1.6-fold, respectively by increasing temperature from 20 to 25°C. From 25 to 40°C, the biosorption of the tested biomass decreased for Cd(II). The temperature is known to affect the stability of the cell wall, its configuration, and can also cause ionization of chemical moieties. These factors may simultaneously affect the binding sites on biosorbent causing reduction in heavy metal removal by increasing temperature (36). The optimum temperature for the maximum biosorption was found to be 25°C as indicated in Fig. 2.

Effect of Contact Time on Biosorption

Effect of contact time on biosorption and also biosorption rate was investigated by monitoring the decrease of the concentration of Cd(II) ions within the adsorption medium with time. Cadmium(II) uptake by the

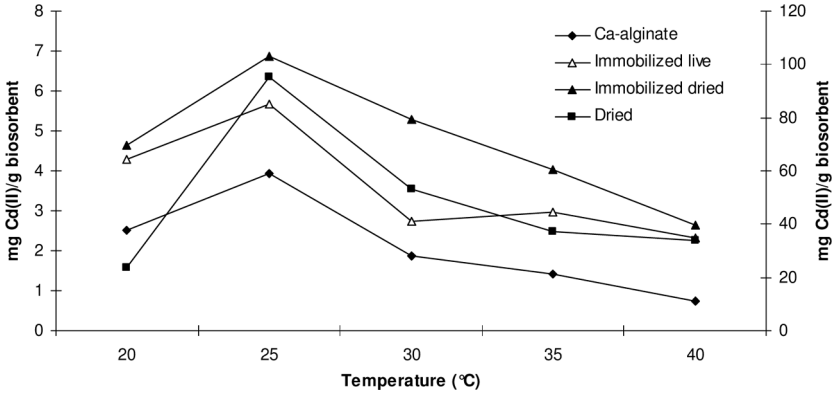

Figure 2. Effect of temperature on the biosorption of dried biomass, immobilized dried and immobilized live cells of *Synechocystis* sp. for Cd(II) ions (C_0, 100 mg/L; pH, 7.0, 60 min). y axis at right side is belong to dried biomass.

studied biosorbent forms as a function of time was shown in Fig. 3. Equilibrium was almost reached at about 15 min for Cd(II) ion. After this equilibrium period, the amount of biosorbed Cd(II) ions on each *Synechocystis* sp. forms did not changed significantly. Higher adsorption rates suggest that the binding may occur with the functional groups present on the biosorbent surface (37). Microbial metal uptake by nonliving cells is a metabolism-independent passive binding process to

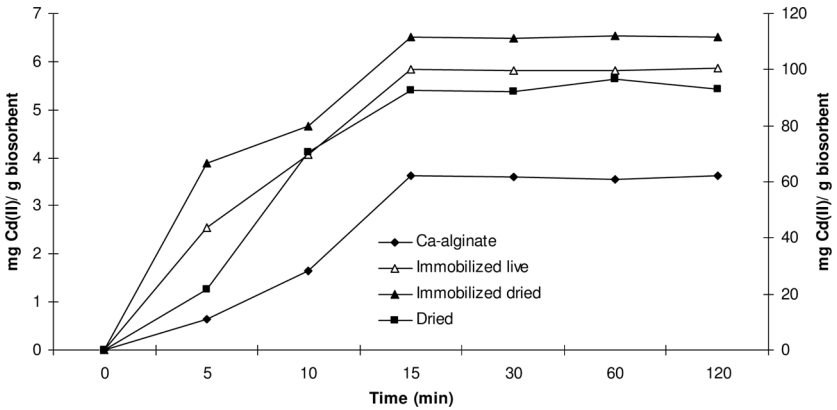

Figure 3. Effect of contact time on the biosorption isotherm of dried biomass, immobilized dried and immobilized live cells of *Synechocystis* sp. for Cd(II) ions (C_0, 100 mg/L; pH, 7.0, temperature, 25°C). y axis at right side is belong to dried biomass.

cell walls (adsorption) and to other external surfaces. This process is generally considered as a rapid process, taking place within a few minutes (38). The rapid metal sorption is also highly desirable for the successful deployment of the biosorbents for practical applications (2).

Effect of Initial Concentration of Cd(II) on Biosorption

Biosorption for Cd(II) ions of all the tested biomass forms were presented as a function of the initial concentration of Cd(II) ions between 50 and 300 mg/L (Fig. 4). Biosorption of all the tested biomass forms increased up to the initial concentration of 250 mg/L by increasing initial concentration of cadmium ions. Between 250 and 300 mg/L of Cd(II), biosorption was about constant for each form. The maximum amount of biosorbed Cd(II) ions on the dried, immobilized dried biomass, immobilized live biomass and plain Ca-alginate beads was found as 75.7, 4.9, 4.3, and 3.9 mg/g, respectively. The biosorption amount of free dried biomass of *Synechocystis* sp. was about 15, 17, and 19 times higher than those of the each immobilized dried biomass, immobilized live biomass, and plain Ca-alginate beads, respectively. Viability of the living immobilized *Synechocystis* sp. was not changed. An increase in the biosorption capacity of free dried biomass may be due to the biosorptive characteristics of the cell wall constitutes of biomass of *Synechocystis* sp. On the other hand, the low biosorption capacity obtained for both immobilized forms compared to free biomass of *Synechocystis* sp. may be due to the

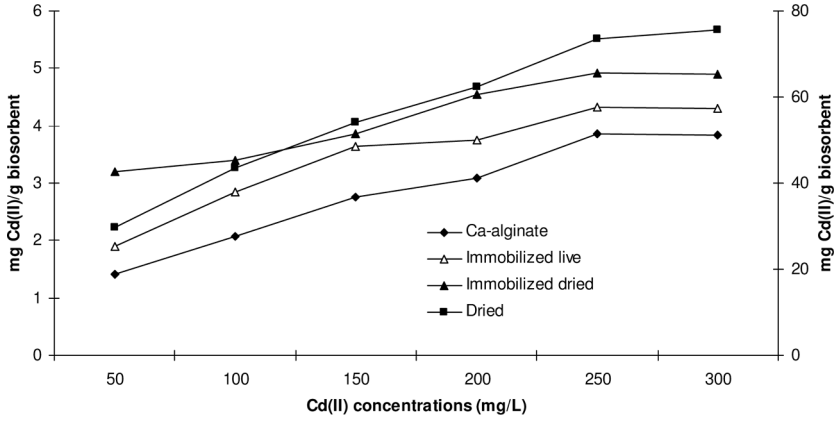

Figure 4. Biosorption isotherm of dried biomass, immobilized dried and immobilized live cells of *Synechocystis* sp. for Cd(II) ions (pH, 7.0; temperature, 25°C, 60 min). y axis at right side is belong to dried biomass.

formation of non-effective functional groups belonging to cell wall by immobilization. This is a significant achievement in the development of immobilized biosorbent systems over the currently used gel-immobilized biosorbent systems where a significant decrease in amount of metal sorption has been reported in comparison with free cells (39,40). The reduction in the ratio of metal uptake by the gel-immobilized biosorbent have been projected to be due to limitations in the movement of metal ions, or the masking of active sites on the biosorbent (41). Moreover, part of the cell surface might be shielded by the gel matrix and thus would not be available for metal binding (39).

Langmuir and Freundlich Adsorption Isotherms

The Langmuir and Freundlich isotherm model below is commonly used to describe the sorption of metals onto microbial surface.

Linearized Langmuir equation (42) was given below:

$$\frac{C}{q} = \frac{1}{Q_{max}b} + \frac{1}{Q_{max}}C \tag{3}$$

Where, Q_{max} (mg/g) is the maximum amount of the Cd(II) per unit mass of biosorbent to form a complete monolayer coverage on the surface bound, C (mg/L) is the equilibrium concentration of Cd(II), q (mg/g) is the amount of Cd(II) adsorbed per unit mass of biosorbent at equilibrium, and b (L/mg) is the Langmuir constant related to the affinity of binding sites. From the Eq. (3) a linearized plot of (C/q) versus C is obtained and values of Langmuir constants (Q_{max} and b) are calculated from the slopes and intercepts of the plots. The coefficient *b* in Langmuir equation is a measure of the stability of the complex formed between metal ions and adsorbent under specified experimental conditions.

The Freundlich equation was given below:

$$q = K_F(C)^{1/n} \tag{4}$$

$$\log q = \log K_F + (1/n \log C) \tag{5}$$

Where, K_F and n are the Freundlich constants, the characteristics of the system. K_F and n are the indicators of the adsorption capacity and adsorption intensity, respectively. The ability of the Freundlich model to fit the experimental data was examined. For this case, the plot of log C versus log q was employed to generate the intercept value of K_F and the slope of n. As can be seen from Table 1, for all the tested biosorbents, sufficient n values were obtained for sufficient separation.

Table 1. Langmuir and Freundlich constants and correlation coefficients of isotherm models for the biosorption of Cd(II) ions from aqueous solutions

Form of *Synechocystis* sp.	Langmuir constants			Freundlich constants		
	Q_{max} (mg/g)	b (L/mg)	R^2	K_F	n	R^2
Dried biomass	109.89	0.007	0.979	2.04	1.29	0.971
Immobilized dried	5.90	0.016	0.978	1.37	0.03	0.987
Immobilized live	5.81	0.010	0.990	1.87	0.92	0.974
Plain Ca-alginate	5.71	0.010	0.934	1.94	1.20	0.968

However, higher K_F value was obtained for free dried biomass than that of other biomass forms which corresponding the higher adsorption capacity.

Desorption and Reusability of Biosorbent

Higher biosorption capacity of a biosorbent is generally required in the wastewater treatment. However, it is also required that it can be regenerated and used again. Therefore, the stability and potential reusability of the biosorbents should be investigated. The stability and potential reusability of the cyanobacterial forms were assessed by monitoring the change in the recoveries of Cd(II) ions through several adsorption-elution cycles.

More than 90% of the adsorbed Cd(II) ions were desorbed from the biosorbents. Metal sorption by the biomass decreased slightly after each successive cycle. Furthermore, the present study shows that 38%, 23%, 43%, and 30% decrease in sorption of Cd(II) by the dried, immobilized dried, immobilized live biomasses, and Ca-alginate was occurred after five sorption/desorption cycles, respectively. Such a decline occurs because acids deteriorate biomass and may dissolve certain polysaccharides that may contain metal binding sites (44). The regeneration of cyanobacterial biomass showed that the biosorption–desorption process using the dried biomass, immobilized dried, and immobilized live *Synechocystis* sp. and plain Ca-alginate beads was reversible process.

Comparison with other Biosorbents

A wide range of biosorbents have been studied worldwide for Cd(II) removal from various media. In order to demonstrate the validity of proposed method, biosorption potential of dried biomass, immobilized dried and immobilized live *Synechocystis* sp. must be compared with other biosorbents used for this purpose. A number of biosorbents has been

investigated for Cd removal (45,46). The Cd binding capacity was reported in the literatures for different algae. For *Synechococcus*, biosorption capacities of both free and immobilized biomass about 50 mg/g (47). Katırcıoglu et al. found that the cadmium binding capacity of free and immobilized *Oscillatoria* Cd binding was about 30 mg/g (7). The highest Cd binding capacity was reported by Chojnacka et al. for *Spirulina* sp. as 159 mg/g (48). Cd binding capacity of *Lyngbya taylorii* and *Ascophyllum nodosum* was found as 283.2 mg/g (49) and 215 mg/g (50), respectively.

CONCLUSION

Biosorption performance of dried, immobilized dried and immobilized live *Synechocystis* sp. biomass was studied for the removal of Cd(II) ions from aqueous solutions. Biosorption was found to be dependent on pH, the contact time, and the temperature. The rate of biosorption was very high and equilibrium was almost reached at about 15 min for Cd(II) ion for dried biomass. Equilibrium biosorption of cadmium ions by *Synechocystis* sp. biomass forms follows typical adsorption isotherms and fits both Langmuir and Freundlich isotherms. The experimental results show that dried biomass yielded a higher biosorption capacity for Cd(II) than that of immobilized dried, immobilized live *Synechocystis* sp. and plain Ca-alginate beads. It may be inferred from here that immobilization may cause diffusional limitations for the Cd(II) ions and may decreased the Cd(II) sorption. The results of this study indicated that the dried *Synechocystis* sp. biomass was suitable for the removal and recovery of Cd(II) from wastewater. The dried biomass of *Synechocystis* sp. can be regenerated using 0.1 mol/L HCl up to 90% recovery and moreover, can be repeatedly used in successive biosorption/desorption cycles to remove Cd(II) ions from aqueous solutions. With the advantage of high metal biosorption capacity, the dried biomass of *Synechocystis* sp. has the potential to be used as an efficient and economic biosorbent material for the removal of cadmium from aqueous phase. Cell wall characterization of the dried biomass belonging to *Synechocystis* sp. may be done for carboxyl groups and also, different immobilization agents may be used to compare the biosorption capacity of different biomass of *Synechocystis* sp. for future studies.

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