Chapter 10

Biosorption of Cadmium by Mangrove-Derived Cyanobacteria (*Gloeocapsa sp ARKK3*)

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Abstract

Dried microbial biomass of *Gloeocapsa* sp. *Trichoderma,* and *Thrustochytrids* used as bioadsorbent for the removal of cadmium in the artificial sewage. Among the three species the maximum adsorption recorded in *Gloeocapsa* sp. biomass. For the augmentation of cadmium removal in sewage, adsorption process conditions was statistically optimized by the method of response surface methodology (RSM) and adsorption kinetics also studied. The important factors of temperature, pH, adsorbent dosage and processing time were selected for optimization, and it was done with 30 experimental cycles derived from centre composite design (CCD). The statistical optimization reveled that optimized condition for cadmium removal was pH 9, temperature 40ºC, adsorbent dosage 0.6 mg.l^{-1} and 60 minutes. Finally in this condition was experimentally proved with yield of cadmium removal of 92.9 % under statistically optimized condition. In the case of the adsorption kinetic *Gloeocapsa* sp. biomass showed a significant adsorption capacity of qmax-56.96 (mg.g^{-1}). The present study concluded that the microbial dried biomass derived from marine *Gloeocapsa* sp. was a potent source for the removal of the cadmium in the sewage waste water.

Keywords: Cyanobacteria; biosorption; *Gloeocapsa* sp.; cadmium removal; Kinetic studies.

Introduction

Heavy metals and metal ions contamination is an environmental threat. The electronic and metal industries are directly discarding their waste in to the environment without proper treatment, which is containing high level of toxic cadmium and directly act as toxic to the environment (Connell et al., 2008;

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Dhananjay Kumar and Gaur, 2014). Mohan and Sreelakshmi (2008) has been proved their experimentally, the cadmium is not a biodegradable and it only accumulate in living organisms and animals and human body through food chain. The many numbers of mechanisms are used to remove heavy metals, including cadmium, from waste water. The methods used are filtration, chemical precipitation, electrochemical treatment, oxidation/reduction, ion exchange, membrane technology, reverse osmosis, and evaporation recovery. However, most of the methods are expensive, inefficient, labor-intensive, and non selective in treatment process (Chen et al., 2008; Tang et al., 2008). Many types of the plants are used on phytoremidiation of heavy metals and to degrade and detoxify contaminants (Garbisu et al., 2001). The high quantities of heavy metal can be accumulated by plant species and they are known as hyper-accumulators (Brooks et al., 2001). However, there are several disadvantages that limit the use of phytoremediation. This makes the detoxification process much more time consuming than the other methods. Phytoremediation is not feasible for rapid heavy metal sewage treatment. On the other hand, biosorption is considered to be an economic, eco-friendly and efficient option to solve the problem of heavy metal pollution. Many scientists devote to finding good biosorbents which possess both the high biosorption ability and high biomass yield. Hence, the aim of present tested the efficiency of three group of microbial derived biomass (adsorbent) on removal of cadmium and optimized the condition by using response surface methodology.

Materials and Methods

Isolation of marine microbes from mangrove environment

Three groups of microorganisms selected for removal of cadmium *Gloeocapsa* sp. *Trichoderma* sp. and *Thurstochytrids* sp. They were isolated from mangrove soil samples of Pichavaram mangrove forest east coast of India (Lat. 11° 29’ 21.9-28.3” N; Long. 79° 46’ 27.2-57.3” E) and cultured in laboratory condition (Anburaj,2011; Anburaj et al.,2011; Dhananjay Kumar and Gaur, 2014). This resulted in the production of dried microbial biomass. Primary screening of cadmium adsorption was done by inoculating the microbial biomass in artificially prepared sewage water and then harvested after attaining considerable growth. The potential bio adsorbent was analyzed in the harvested biomass and analyzing the accumulation of cadmium by using inductively coupled plasma mass spectrometry (Perkinelmer-optima 2400dv). This revealed that Cyanobacterial biomass *Gloeocapsa* sp. ARKK3 (JQ040263) is efficient in the cadmium removal in sewage solution. Therefore this species was taken for further augmentation cadmium removal, the kinetic studies and optimizing process conditions for the maximum bio removal of cadmium was done by using response surface methodology (RSM). The pure strain of *Gloeocapsa* sp was maintained at 24±1°C on SN medium (Rippika et al., 1981a). For experimental purposes, *Gloeocapsa* sp. was used by aseptically transferring to the 100ml SN medium in 250mL Erlenmeyer flasks. The flasks were incubated at 24±1^{o}C under static conditions with intermittent shaking (Waterbury, 2006; Anburaj, 2011; Anburaj et al., 2011; Anburaj et al., 2012). The biomass harvested after twenty four days was washed thoroughly with deionized distilled water and dried at 70^{o}C in a hot air oven for 24 h. Quantification of the biomass was done by dry weight. Care was taken to keep the particle size of biomass uniform, by grinding into powder and sieving through in a 150-mesh sieve. The biomass was stored in a desiccator until used for cadmium biosorption study (Goswami et al., 2015; Yu zin et al., 2016).

Preparation of the adsorbate stock solution

The cadmium stock solution (1000 mg L-1) of was prepared in 1000mL deionized - distilled water by dissolving 1g of cadmium chloride (AR grade, Hi Media, Mumbai, India). The desired pH of working solution was prepared based on experimental condition by adding 1M HCl or NaOH. The change in the working solution due to the addition of HCl or NaOH was negligible. Fresh dilutions were used for each experiment.

Batch biosorption experiments

To investigate the effects of experimental conditions such as pH, temperature, biosorbent dosage and the adsorptions processing time on cadmium removal was optimized for augmentation of cadmium removal in aqueous solution. The biosorption experiments were performed in 250mL Erlenmeyer flasks by agitating specified amount of adsorbent in 100mL of cadmium solution of desired concentration at varying pH in an environmental orbital incubating shaker (Labline Shaking incubator lab Equipment, India) with a contact time of 120min. The optimum pH for the biosorption of cadmium was investigated by equilibrating the biomass (0.6g/l) and cadmium solution (100mL of 37.72mg L-1) in the pH range of 6.0-11.0. The effect of temperature was studied by incubating the biosorbent with cadmium solution (37.72 mg L-1) at 20 - 60°C at a difference of 10°C. The effect of biosorbent dosage on biosorption of cadmium was investigated by employing biomass concentrations of 0.2, 0.4, 0.6, 0.8, and 1g L^{-1}. In all the experiments, at the end of the desired contact time, the residual cadmium concentration in the sewage solution was determined after filtering the samples using Whatman No. 1 filter paper. The filtrate were analyzed for residual cadmium concentration using inductively coupled plasma system ICP- Optical Emission Spectrophotometer by using the instrument Optima 2100DV and quantified against known standards. The cadmium solution without the biosorbent was used as control. The Kinetic and isotherm method was carried out followed by the optimization conditions of cadmium removal by using central composite design of response surface methodology.

Kinetic studies

Batch experiments were conducted for optimum adsorbent dosage and equilibrium time. The amount of adsorbed cadmium was calculated using Equation (1) by the difference of initial and residual amount of cadmium in solution divided by the mass of adsorbent. The removal efficiency, R_e (determined as the cadmium removal percentage relative to initial concentration) using Equation (2) of the system, was calculated as:

$$q_e = [Co-Ce)/ M] \quad X \; V \qquad \text{-------------------------------- (1)}$$

$$R_e = [(Co-Ce) /Co] \; X \; 100 \qquad \text{-------------------------------- (2)}$$

Where, q_e (mg/g) is the amount of the cadmium adsorbed per unit dried biomass of *Gloeocapsa*. C_0 and C_e are the initial and equilibrium (or at any time) ion concentration (mg/L), respectively, V is the volume in liter of solution and M is the dried biomass of the *Gloeocapsa* (g).

Batch isotherms studies

After determining the optimum pH, temperature and equilibrium time, isotherm studies were conducted by varying the concentration of dried microbial biomass *Gloeocapsa*. Different concentration of dried biomass of *Gloeocapsa* (0.2, 0.4, 0.6, 0.8, and 1 g L^{-1}) was used and added the 0.6 g/l of dried biomass and 37.18 mg/L of cadmium in solution in 100ml aqueous solution for 60 min. The initial pH of the cadmium solutions was adjusted to an optimum value of pH 9 with NaOH or HCl.

Experimental setup by RSM

A central composite design, which includes all important factor combinations, is a powerful tool for understanding interaction combined effect of the selected parameters on the cadmium removal. The experiments with different pH, adsorbent dosage, temperature, and processing time were engaged concurrently covering the variety of variables for the removal of cadmium in the central composite design. In order to describe the effects of pH, adsorbent dosage, temperature, and processing time on percentage of cadmium removal batch experiments were conducted. The coded values of the process parameters were determined by the following equation 3.

$$Y = \beta_0 + \Sigma_i \beta_i X_i + \Sigma_i \beta_{ii} X_i^2 + \Sigma_{ij} \beta_{ij} X_i X_j \text{ ---------------------------------- (3)}$$

Where Yi is the predicted response, X_iX_j are independent variables, β_0 is the offset term, β_i is the i^{th} linear coefficient, bii is the i^{th} quadratic coefficient, and β_{ij} is the ij^{th} interaction coefficient. The range and levels of individual variables were given in Table 10.1. The experiment design is given in Table 10.2 along with experimental and predicted responses. However, in this study, the independent variables were coded as X_1, X_2, X_3 and X_4. Thus, the second order polynomial equation can be presented as follows equation 4:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_{11} X_1^2 + \beta_{22} X_2^2 + \beta_{33} X_3^2 + \beta_{44} X_4^2 + \beta_{12} X_1X_2 + \beta_{13}X_1X_3 + \beta_{14} X_1X_4 + \beta_{23} X_2X_3 + \beta_{24} X_2X_4 + \beta_{34} X_3X_4 \text{ ------------------------ (4)}$$

A statistical program package Design Expert 8.0.6, was used for regression analysis of the data obtained and to estimate the coefficient of the regression equation. The equations were validated by the statistical tests called the ANOVA analysis. The significance of each term in the equation is to estimate the goodness of fit in each case. Response surfaces were drawn to determine the individual and interactive effects of test variable on percentage removal of cadmium. The optimal values of the test variables were first obtained in coded units and then converted to the uncoded units.

Results

Kinetic and isotherm experiments

Isotherm and kinetic evaluations were conducted in this segment of the study. Kinetic studies were done under optimized conditions at constant pH of 9.0 with known cadmium concentration of 37.18 mg L^-1 and adsorbent concentration of 0.6g L^-1 at 40°C. Samples were taken at every 30min intervals over a period of 120min for test of the residual cadmium concentration in the aqueous solution. The kinetic modeling of cadmium biosorption process was studied using time dependent removal of cadmium under optimized conditions using first and second-order kinetic equation models and adsorption isotherm (Anburaj et al., 2011).

Adsorption kinetics

Kinetics of cadmium removal is clearly explained in the literature using first-order and second-order kinetic models. The adsorption of cadmium is analyzed using Lagergran rate equation. The first order Lagergran model is equation (5).

$$dq_t / Dt = k_1 (q_e – q_t) \text{ ------------------------- (5)}$$

Where, qt is the amount of cadmium adsorbed on the adsorbent at time t (min) and k1 (1/min) is the rate constant of first order adsorption. The incorporated form of the above equation with the State line conditions t = 0 to >0 (q = 0 to >0) and then rearranged to obtain the following time dependence function equation (6),

$$\text{Log}(q_e - q_t) = \log q_e - (k_1/2.303)\, t \text{ ------------------------- (6)}$$

Where qe is the amount of cadmium adsorbed at equilibrium. The qe and rate constant (k1) were calculated from the slope of the plots of log (qe −qt) versus time (t) (Figure.1). It was found that the calculated qe value do not agrees with the experimental qe values. The second order kinetic model is expressed as equation (7) (Namasivayam and Kavitha, 2002; Vasudevan et al., 2011; Anburaj et al., 2011).

$$(dq_t/ Dt) = k_1 (q_e^2 - q_t^2) \text{ ------------------------- (7)}$$

Where k_2 is the rate constant of second order adsorption. The integrated form of Eq. (6) with the boundary condition t = 0 to >0 (q=0 to >0) is

$$t/ q_t = [(1/ k_2 q_e^2) + (1/t)]\, t \text{ --------------------------- (8)}$$

Eq. (8) can be rearranged and linearized as,

$$h = k_2 q_e^2 \text{ ---------------------------- (9)}$$

The plot t/qt versus time (t) (Fig. 2) shows the straight line. The second order kinetic values of qe and k_2 were calculated from the slope and intercept of the plots t/qt versus t. Table 10.3 depicts the computed results obtained from first and second order kinetic model. The calculated qe values well agree with the experimental qe values for second order kinetics model better than the first order kinetics model for adsorption capacity of adsorbent. These results indicate that the adsorption system belongs to the both kinetic model of first second order kinetics.

Adsorption Isotherm

The equilibrium adsorption isotherm is important on the adsorption studies (Wang et al., 2005; Anburaj et al., 2011). In this study were selected the Langmuir isotherm for cadmium removal. The Langmuir adsorption isotherms assumes that adsorption takes place at specific homogeneous sites within the adsorbent and has found successful application to many sorption process of monolayer adsorption. The Langmuir adsorption isotherm can be written as:

$$q_e = (q_m b c_e) / (1+bc_e) \text{ ---------------------- (10)}$$

The Langmuir parameters were obtained by fitting the experimental data to the linearized equation derived from Eq. (10):

$$C_e/Qe = (1 /bqm)+ (C_e/qm) \text{ ---------------------- (11)}$$

$$1/q_e = [(1/bq_m) \times (1/ q_m) + (1/q_m)] \text{ ----------------------(12)}$$

Where, qe is the adsorbent amount (mg/g) of the Cadmium, Ce is the equilibrium concentration of the Cadmium in solution (mg/L), qm is the monolayer adsorption capacity (mg/g) and b is the constant related to the free energy of adsorption (L/mg). Based on Eq. (11) and Eq. (12) the isotherms were fitted to the adsorption data obtained. The Langmuir adsorption exponents for Eq. (11) and Eq. (12), the qm and b are determined from the linear plots of Ce/qe versus Ce and 1/qe versus 1/Ce and calculated correlation coefficients for these isotherms, are shown in Table 10.4. The values of the Langmuir constant were calculated from the slopes and intercepts of the plots. The magnitude of Langmuir constant b was small (0.412L/mg) and the adsorption capacity qm was determined as 2.401mg/g.

Optimization studies by statistical experimental design

Optimization experiments were followed by the centre composite design and a quadratic model was obtained. Analysis of variance (ANOVA) of the regression model was carried out to find the significance of the main effects and interacting effects of parameters on the biosorption process. While the main effects temperature (ºC), pH, dried microbial biomass *Gloeocapsa* dose (adsorbent) (mg/l) and Processing time (min)) were significant (P <0.0001), and interacting factor were not statistically significant at 95% confidence limits. The negative effect of factors A, B, C and D in regression equation indicates that a reduction in removal efficiency occurs at high level of these factors and that the first-order effects of temperature, pH, *Gloeocapsa* dried biomass dose and processing time were significant while their respective second-order effects were not significant (P >0.05). The model was found to be highly significant, as is evident from the Fisher's F-test with a very low probability value (P >0.0001), shown in Table 10.5. The integrity of the model was checked by the determination coefficient R^2 and multiple correlation coefficientsR^2. The value of adjusted R^2 (0.8157) suggests that only 19% of the total variations in the metal removal response could not be explained by the model. The value of R^2 (0.9171) obtained in the present case indicates good correlation between the experimental and predicted values of the response. A plot of the standard errors in biosorption of the metal as a function of temperature and pH is shown in Fig. 3. The shape of the standard error plot was not only found to fit on the design but also the polynomial showed low and flat errors exhibiting circular contours and symmetrical shape around the centroid, representing ideal condition. Standard error value increased at the centroid as well as away from the optimization point. The standard error value around the centroid is 0.434, which is the best value. Response surface plot was used to determine percentage removal of cadmium in combined and interactive effects temperature, pH, *Gloeocapsa* dried biomass dose and adsorption processing time (Fig. 4a-f). Removal of cadmium by *Gloeocapsa* dried biomass dose was increased as the temperature increased from 0 to 30ºC. There was maximum adsorption of cadmium on the biosorbent at pH 9, temperature 40ºC, adsorbent dosage 0.6 mg/l and adsorption processing time was 60minute (Fig.5) but above cadmium removal declined.

Discussion

The cadmium removal from aqueous solution and their kinetics was tested. The optimization of cadmium removal was carried out with help of central composite design. It revealed the optimum condition for the removal of cadmium using the *Gloeocapsa* sp dried microbial biomass at temperature 40ºC, pH 9, adsorbent dosage (0.6mg/l), and adsorption processing time 60 minute (Fig.10). Various bio adsorbent dosages were tested and the bio adsorption of cadmium was found to be maximum at 0.6mg/l. The biosorption capacity decreased with the increasing dosage. Similar results were observed when other biomasses were employed as biosorbents to remove heavy metals, such as lead, cadmium and zinc biosorption by *Citrobacter* strain MCMB-181 (Puranik and Paknikar,1999; Anburaj et al., 2011; Goswami et al., 2015; Yu zin et al., 2016), biosorption of cadmium by black gram husk *C. arientinum* (Saeed et al., 2003) and cadmium removal by a byproduct of *L. edodes* (Cheen et al., 2003; Dhananjay Kumar and Gaur, 2014). The number of binding sites available for adsorption was determined by the dose of biomass added to the solution. A higher biosorption capacity at a lower dosage could be attributed to an increased ratio of metal to biosorbent, which decreases upon an increase in dosage (Puranik and Paknikar,1999; Anburaj, 2011; Anburaj et al., 2011). Cadmium does not exhibit significant changes of chemical form in aqueous solutions from pH 7 to 11. We decided to use a pH range from 7 to 11 for this experiment in order to determine the cadmium removal ability of *Gloeocapsa* dried biomass over the widest possible pH range because the *Gloeocapsa* sp is derived from marine environment. Adsorption was very low at pH 7, but the metal was well adsorbed in the pH range from 8-9, indicating that *Gloeocapsa* sp can be used for cadmium removal over a range of pH 8-9 the similar report already documented with Cyanobacterium *T. tenuis* at pH- 4-8 (Inthorn et al., 1996; Anburaj et al., 2012) . The kinetic study showed the maximum adsorption capacity of *Gloeocapsa* sp biomass with the 56.96qmax (mg/g). In that comparing present work qmax value with other researchers the maximum cadmium removal capacity is reported *Spirulina platensis* with 196 *qmax* (Solisio et al., 2007; Anburaj et al., 2011; Dhananjay Kumar and Gaur, 2014) and minimum is *Arthrobacter globifirmis* with qmax value of 0.2 Scott and Palmer (Scott and Palmer, 1988; Anburaj et al., 2011; Anburaj et al., 2012; Dhananjay Kumar and Gaur, 2014; Goswami et al., 2015; Yu zin et al., 2016) comparing with micro algae and Cyanobacterium the present work was quiet ideal for the removal of cadmium.

Conclusion

The dried microbial biomass of marine cyanobacterium (*Gloeocapsa* sp. ARKK3) for biosorption of cadmium from aqueous solution was tested. The dried biomass of *Gloeocapsa* sp not only exhibits high biomass yield but also shows excellent biosorption efficiency percent of cadmium removal. The efficiency was even superior to that reported with fresh Cyanobacterium biomass for removal of the cadmium. By applying centre composite design for the optimization experiments and under statistically optimized condition it was exhibited the maximum cadmium removal of 92.9%. High percentage of cadmium removal in the aqueous solutions suggests that the Cyanobacterium of *Gloeocapsa* sp dried biomass could be applied in bioremediation of cadmium in contaminated wastewaters of several industries, the present approach ensures utilization of marine derived microbial biomass as the potent and an environment friendly for bioremoval of cadmium in polluted wastewaters.

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Table 10.1 Experimental range and levels of independent process variables

Factor	Range and Coded value				
	-2	-1	0	1	2
Temperature (ºC)	20	30	40	50	60
Ph	7	8	9	10	11
Adsorbent Dosage (mg/l)	0.2	0.4	0.6	0.8	1
Processing time (min)	0	30	60	90	120

Adsorbent- Dried microbial biomass of *Gloeocapsa*

Table 10.2 Central composite design matrix for the experimental design and predicted responses for cadmium removal

Standard Order	Temperature (ºC)	pH	Adsorbent Dosage (mg/l)	Processing time (min)	Cadmium removal (%)	
					Experimental	Predicted
1	20	7	0.2	0	1.6423	15.31286
2	60	7	0.2	0	1.7838	11.5325
3	20	11	0.2	0	3.9613	17.85147
4	60	11	0.2	0	3.3545	13.77161
5	20	7	1	0	6.5815	14.17412
6	60	7	1	0	9.5589	18.57196
7	20	11	1	0	12.332	15.69848
8	60	11	1	0	12.26	19.79682
9	20	7	0.2	120	42.1824	38.62112
10	60	7	0.2	120	30.8107	36.03101
11	20	11	0.2	120	40.2539	39.82763
12	60	11	0.2	120	40.5551	36.93802
13	20	7	1	120	62.0941	60.26378
14	60	7	1	120	75.7665	65.85187
15	20	11	1	120	66.2292	60.45603
16	60	11	1	120	70.8284	65.74463
17	0	9	0.6	60	37.6278	30.44458
18	80	9	0.6	60	37.3319	31.95281
19	40	5	0.6	60	37.0898	28.40146
20	40	13	0.6	60	34.7068	30.83283
21	40	9	-0.2	60	25.5406	9.150658
22	40	9	1.4	60	32.9909	36.81853
23	40	9	0.6	-60	45.5191	14.18251
24	40	9	0.6	180	64.6643	83.43858
25	40	9	0.6	60	92.3023	92.37808
26	40	9	0.6	60	92.1076	92.37808
27	40	9	0.6	60	92.9527	92.37808
28	40	9	0.6	60	92.808	92.37808
29	40	9	0.6	60	91.9177	92.37808
30	40	9	0.6	60	92.1802	92.37808

Table 10.3 Lagergren constants, Pseudo second-order rate constants constants for cadmium

Cadmium mg/l	Lagergren constants					
	qexp	K_1 X 10^{-3}	R^2	Qe	K_2 X10^{-3}	R^2
37.18	34.32	0.011	0.77	90	1.66	1

Table 10.4 Langmuir isotherm constant for adsorption of cadmium by *Gloeocapsa* sp.

Langmuir isotherm parameters	C_e/q_e	1/qe
qm (mg/g)	56.96	56.96
b (L/mg)	22.78	22.78
R2	1	1

Table 10.5 Analysis of variance table (ANOVA) for response surface methodology of main effects and interacting effects of parameters in quadratic model.

Source	Sum of Squares	Df	Mean Square	F- Value	p-value Prob > F
Model	26511.77	14	1893.698	10.16649	< 0.0001****
A-Temperature (ºC)	3.412152	1	3.412152	21.018318	0.0001***
B-pH	8.867316	1	8.867316	15.047605	0.0002***
C-Adsorbent Dosage (mg/l)	1148.266	1	1148.266	16.164576	0.0253*
D-Processing time (min)	7194.604	1	7194.604	38.62491	< 0.0001***
AB	0.0897	1	0.0897	0.000482	0.9828 NS
AC	66.88296	1	66.88296	0.359067	0.5580 NS
AD	1.416695	1	1.416695	0.007606	0.9317 NS
BC	1.028703	1	1.028703	0.005523	0.9417 NS
BD	1.77449	1	1.77449	0.009527	0.9235 NS
CD	518.9922	1	518.9922	2.786259	0.1158 NS
A^2	6416.431	1	6416.431	34.44722	< 0.0001***
B^2	6752.461	1	6752.461	36.25123	< 0.0001***
C^2	8255.069	1	8255.069	44.31812	< 0.0001***
D^2	3253.938	1	3253.938	17.46908	0.0008***
Residual	2794.027	15	186.2685		
Lack of Fit	2793.182	10	279.3182	16.52	< 0.8561 NS
Pure Error	0.845028	5	0.169006		
Cor Total	29305.79	29			

Statistically significant *** (P <0.0001), *(P< 0.05), NS Non-significant

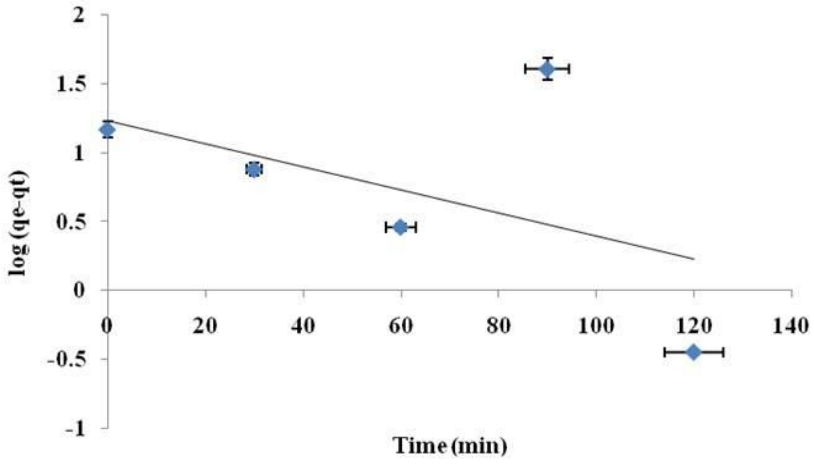

Figure 10.1 Kinetics analysis of cadmium adsorption by linear plots of pseudo first-order rate equations

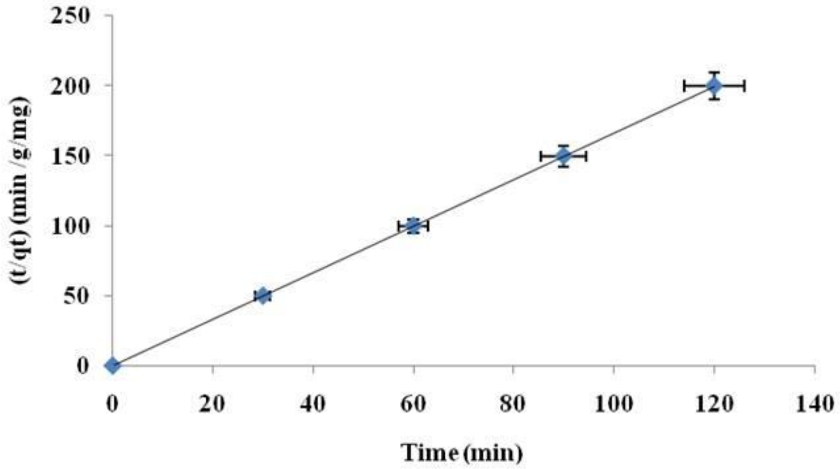

Figure 10.2 Kinetics analysis of cadmium adsorption by linear plots of pseudo second-order rate equations

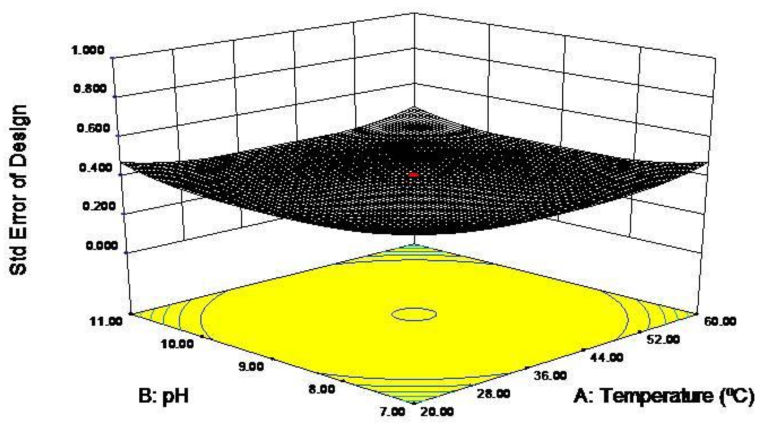

Figure 10.3 Three-dimensional standard error plot for biosorption of cadmium by *Gloeocapsa*

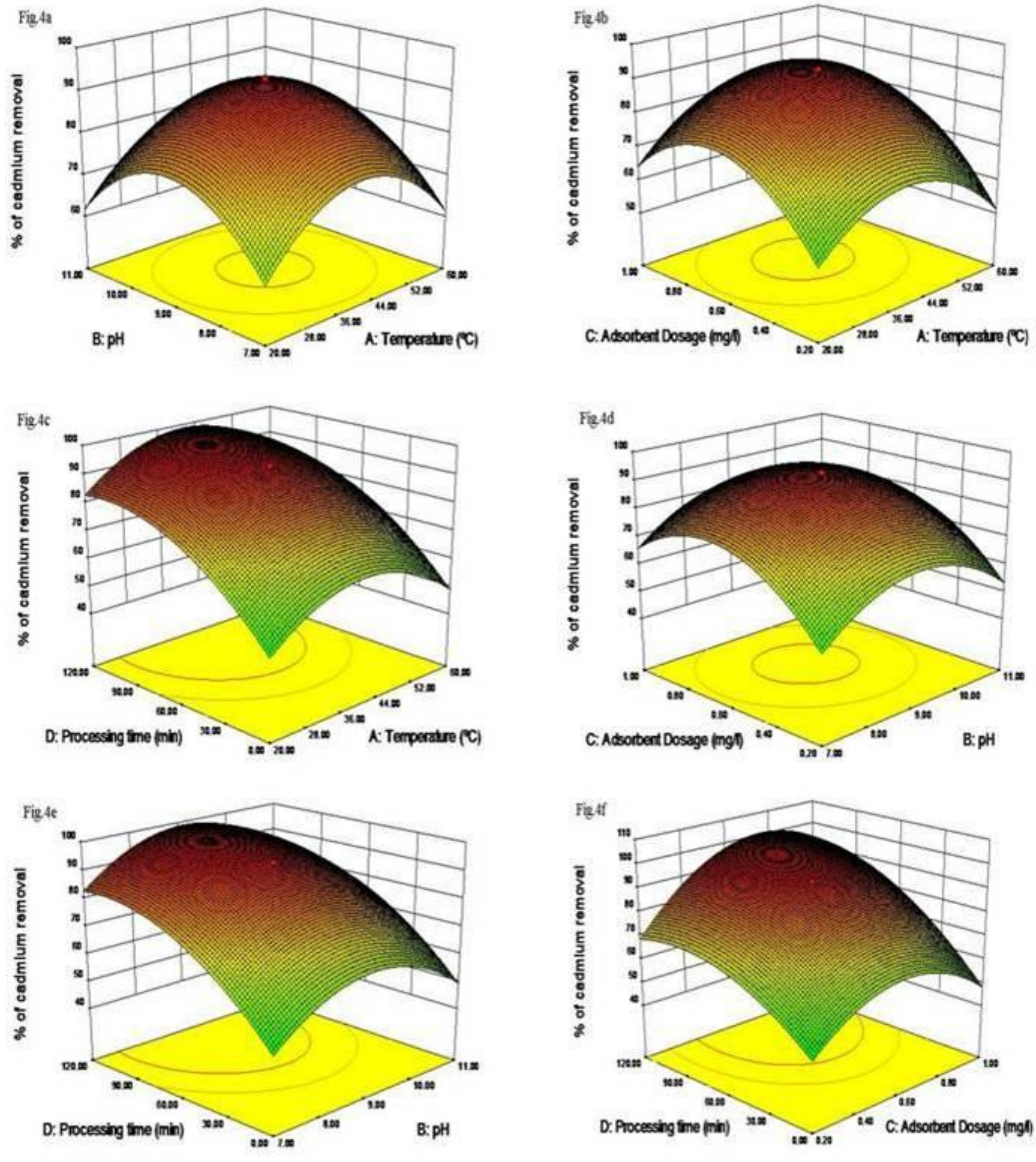

Figure 10.4 Three-dimensional response surface plot for the (a) Effect of temperature and pH, (b) Effect of temperature and adsorbent dosage (mg/l), (c) Effect of temperature and processing time, (d) Effect of pH and adsorbent dosage, (e) Effect of pH and processing time and (f) Effect of adsorbent dosage and processing time, on biosorption of cadmium by *Gloeocapsa* sp.

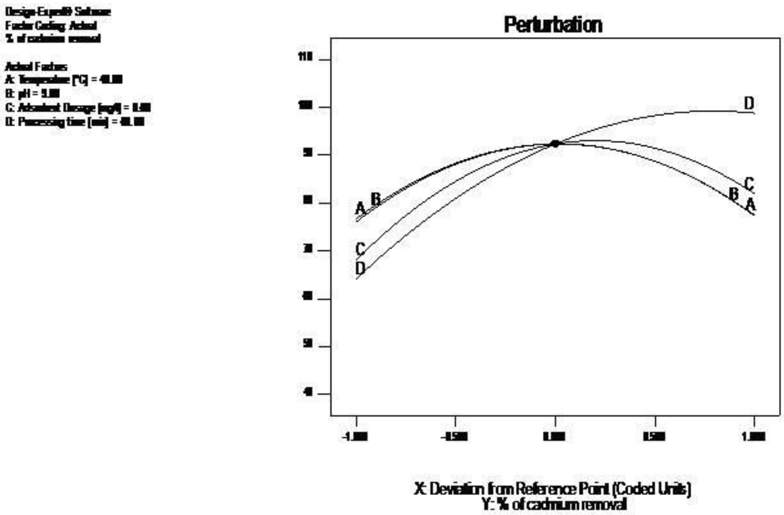

Figure 10.5 Perturbation of main and interactive effect of parameters influenced their optimal condition of cadmium removal by *Gloeocapsa* sp.