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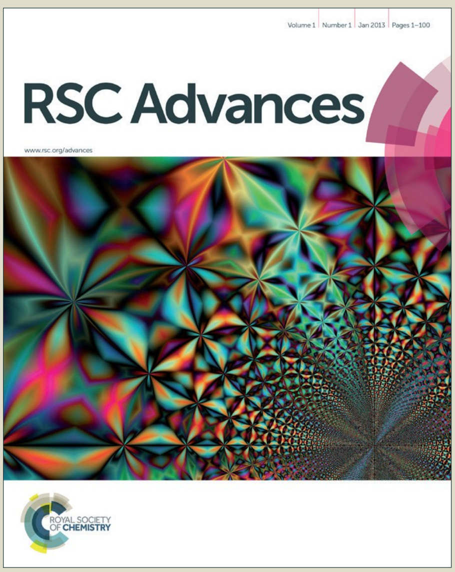

Optimizing the biosorption of Bi^{3+} ions by *Streptomyces rimosus* using experimental design and applicability in kinetics and isotherms modeling

Mohammad Reza Fathi[a], Hamid Reza Noormohamadi [a], Mehrorang Ghaedi [*b] and Gholam Reza Ghezelbash [*c]

[a] *Department of Chemistry, College of Science, Shahid Chamran University, 6135743337, Ahvaz, Iran*
[b] *Chemistry Department, Yasouj University, Yasouj 75918-74831, Iran.*
[c] *Biology Department, Faculty of Science, Shahid Chamran University of Ahvaz, 61357-831351, Iran*

Abstract

This investigation seeks to analyze bismuth biosorption onto *Streptomyces rimosus* in solutions following optimization by using Box-Behnken Design (BBD). Based on efficient method, three significant parameters including pH, temperature, and initial bismuth (Bi^{3+}) concentration in a batch system were studied by using Design of Experiment (DOE). Central composite second order response surface methodology (RSM) accomplishes construction of model biosorption (R %) and operating condition. Using this statistical–mathematical method leads to obtain a second-order equation for the bismuth removal. The regression equation was obtained by using Design Expert 7.0 software. The numerical optimization shows great biosorption percentage (>97%) at pH 8.0, 30ºC, and 30 mg L^{-1} for bismuth. The quadratic models exhibited higher R^2 values, significant p-values, and insignificant lack-of-fit *p-values* that all confirm high adequacy for predicting the response. Both mathematical empirical models due to their high correlation coefficients (R^2) of 0.9997 are suitable for predicting biosorption trend bismuth solution. The closeness of predicted values and experimental value also support this conclusion. The pseudo-second order kinetic model adequately described the kinetic data. The Langmuir isotherm model described the process of Bi^{3+} uptake better than the other models. The maximum biosorption capacity of the biosorbent was found to be 38.91 mg g^{-1} for bismuth biosorption. The possible interactions between biosorbents and bismuth were also evaluated by Fourier transform infrared (FT-IR) spectroscopy analysis.

Keywords: Biosorption; Bi^{3+}; Design of experiments; Equilibrium isotherm; Kinetic; *Streptomyces rimosus*.

* Corresponding author at: Tel.: +98 741 2223048; fax: +98 741 2223048.
E-mail address: m_ghaedi@mail.yu.ac.ir; m_ghaedi@yahoo.com (M. Ghaedi)
* Corresponding author at: Tel.: +98 611 3331045
E-mail address: gh.r.ghezelbash@gmail.com (G. R. Ghezelbash)

1. Introduction

Environmental problems associated with heavy metals are very difficult to be solved in contrast to organic Matters because incineration or biodegradation can transform the latter. [1] As a fact, most of heavy metals have toxic Effects on living organisms when transcending a certain concentration. Besides, some heavy metals are being Subject to bioaccumulation and may pose a risk to human health when transferred to the food chain. [2] Bismuth and its compounds have been used in many variance areas such as cosmetic products, lubricatingoils, medicines, pigments, electronics, semiconductors, alloys industry and in recycling of uranium nuclear fuels. [3, 4] Neuropathology, osteoarthropathy, nephropathy and hepatitis have been ascribed to bismuth compounds as toxic effects on humans. [5] Therefore, bismuth species are included in the list of potential toxins. [6-8] The Conventional processes such as ion-exchange; electrolysis and biosorption for heavy metal removal often are neither effective nor economical. [9, 10] Hence there is a great need for an alternative technique, which is both economical and efficient. Biosorption is an innovative technology and has distinct preferences over conventional methods being currently employed. [11] As an alternative to traditional methods, its promising results are now being considered for application by the scientific community. Biosorption is either metabolism independent, such as physical or chemical biosorption onto the cell wall, or metabolism depended, such as transport, internal compartmentalization, and extra cellular precipitation by metabolites. Biosorption has other advantages over conventional treatment methods as low cost, a minimal amount of chemical and biological sludge and the potentiality of biosorbent regeneration and metal recovery.[9] Microorganisms can adjust and grow under divers extreme conditions of pH, temperature and nutrient availability, as well as high metal concentrations. [12-15]

Generally, microbial biomasses have evolved various measures to respond to heavy metal stress via processes such as transport across the cell membrane, biosorption to cell walls, entrapment in extracellular capsules, as well as precipitation and transformation of metals. [16-18] Recent investigations by various biosorbents groups have shown the impressive biosorption capacities for a range of heavy metal ions. But no information are available for bismuth (Bi^{3+}) biosorption from aqueous solutions by microorganism until now.

The design and efficient operation of biosorption processes require equilibrium data for using in kinetic and mass transfer models. These models can then be used to predict the performance of the biosorption contact processes under a range of operating conditions. [19]

The purpose of this study was to investigate the biosorption characteristics of bismuth (Bi^{3+}) ions on Streptomyces rimosus. The effects of operating parameters such as pH, temperature, and initial metal ion on the biosorption of bismuth (Bi^{3+}) ions were analyzed using RSM.

2. Experimental

2.1. Biosorbent preparation

At first, *Streptomyces rimosus* obtained from the Iranian Research Organization for Science and Technology (IROST) was cultured on Trypaic Soy Broth (TSB) and incubated for 24 h in 30 ºC .then,1 colony was dissolved in a 100 mL Erlenmeyer flask containing 25 mL of TSB and placed on rotator shaker for 24 h in 30 ºC in order to grow bacteria. [20-22]

2.2. Materials and apparatus

Determination of the metal ions in sample was carried out by the GBC model Avanta flame atomic absorption spectrometer (Sidney, Australia) fitted with bismuth hollow cathode lamps and air acetylene flame. The infrared spectra were obtained using a Bomem FT-IR spectrophotometer (Canada) to identify the functional groups. pH adjustments were carried out by the Metrohm pH-meter model 827 (Herisau, Switzerland). Response surface analysis was performed by the Design-Expert® Software (Version 7.0, Stat-Ease Inc., USA). The significances of all terms in the polynomial equation were analyzed statistically by computing the F-value at a probability (p) of 0.05. The Stock Bi^{3+} solution of 1000 mg L^{-1} which was prepared by bismuth nitrate penta-hydrate (Merck, Germany). Then, the solution was sterilized by autoclaving at a pressure of 1.5 atoms and a temperature of 121ºC for 30 min

2.3. Batch biosorption studies

In the batch biosorption experiments 1mL of bacteria solution was added to 25 mL of each bismuth solution with shaking rate of 150 rpm, equilibrium was reached after 48h, the required pH value of the solutions was adjusted with 0.1 mol L^{-1} HCl or NaOH solutions. [20-23] Samples were taken at given time intervals and were centrifuged at 6000 rpm, in order to isolate and measure dry weight absorbent. Then, the filtered supernatant was used to determine bismuth concentration with atomic absorption spectrophotometer.

The amount of Biosorption onto bacterial biomass were determined from the difference between the Bi added to the solution and the Bi^{3+} remaining in the solution after 48 h. Blank samples were also examined to ensure no biosorption had taken place on the walls of the apparatus used. Each experiment was repeated three times to confirm the results. The Bi^{3+} uptake was calculated by using the following Eq:[24]

$$q_e = \frac{(C_i - C_e)V}{m} \qquad (1)$$

Where q_e denotes the specific metal biosorption (mg g^{-1}), C_i and C_e are the initial and final Bi^{3+} concentration (mg L^{-1}) in the solution, respectively. V is the volume of aqueous solution (L) and m is dry weight of biomass for biosorption (g).

2.4. *Design of experiment study of operational parameters*

RSM is a useful technique for development and optimization of biosorption process. [25] The main advantages of RSM are the reduced numbers of experimental trials needed to evaluate multiple parameters and their interactions and it is useful for developing, improving, and optimizing process. [26, 27] By careful design of experiments, the objective is to optimize a response (output variable) which is influenced by several independent variables (input variables). [28] An experiment is a series of tests, or the runs, in which changes are made in the input variables in order to identify the reasons for changes in the output response. [29, 30] One of the most popular design of experiment applied in RSM technique is Box Behnken design (BBD). [31]

In the present study, three parameters (initial bismuth concentration, pH and Temperature) were studied using BBD model with three levels in the experimental design model, metal ion concentration (20-40 mg L^{-1}), pH (7.0-9.0) and temperature (25-35ºC), were taken as input variables. Bi^{3+} by the biosorbent was taken as the response of the system. The experimental design matrix derived from the BBD model is shown in Table 1. Bismuth adsorbed (mg L^{-1}) by the biosorbent indifferent experimental conditions based on the experimental design matrix was estimated, the results of which have also been included in the same table.

The data were subjected to analysis of variance and the coefficient of regression (R^2) was calculated to find out the advantageous fit of the model. The quality of the fit of quadratic model was determined from correlation coefficient (R^2) value adjusted coefficient of determination (R_{adj}^2) which is a criterion to express quality of fitting. The e F-value (Fisher variation ratio), probability value (Prob> F), standard deviation (SD), coefficient of variation (CV %) and adequate precision (AP) are criteria for judgment about quality and applicability of model. [32]

3. Results and discussion

3.1. *Effect of contact time*

As the biosorption process proceeds, the sorbed solute tends to desorb back into the solution. Eventually, the rates of biosorption and desorption will attain an equilibrium state. When the system reaches the sorption equilibrium, no further net biosorption occurs. The effect of contact time at greatest contribution on removal percentage at 30 mg L^{-1} of bismuth on their biosorption onto the bacteria is presented in Fig. 1. When Bismuth was adsorbed in the first 16–18 h, further time did not increase biosorption rate and reached equilibrium around 48 h.

3.2. *Statistical analysis*

The results of BBD experiments for studying the effects of three independent variables along with the predicted mean and observed responses were shown in Table 1.The application of RSM gave the level of Bi^{3+} biosorption as the function of the initial solution pH (A),Temperature (B) and initial Bi^{3+}

concentration (C),.Based on multiple regression analysis, second-order quadratic polynomial equation for predicted response Y (R% Bi^{3+}), in terms of coded as well actual values which is expressed as:

$$y = 97.6 - 10.4A - 8.3B - 7.1C + 7.3AB + 3.5AC + 3.8BC - 36.6A^2 - 44.1B^2 - 29.4C^2 \quad (2)$$

Where y is the removal rate of Bi^{3+}, A, B and C are the independent variables. *F*-statistic and *P-value* were used to determine the significance of each coefficient. The F-statistic of the model was 26200 corresponding to *P-value* (less than 0.0001), which indicated that the model was adequate. The "*lack of fit F-value*" of 0.2049 proves low contribution of lack of fit compare to pure error that non-directly suggest suitability and efficiency of model for well representation of experimental data (Table 2). The model R^2 of 0.9997 suggests sample variation of 99.97% for biosorption is ascribed to the independent variables and only 0.03% of the total variation is not described by the model. The adjusted R^2 (0.9999) was sufficiently high to indicate the significance of the model. It has been suggested that R^2 should be at least 80% for a good fit of a mode. [33] Quadratic model was selected for model development as suggested by the software (Table 3). The lower coefficient of variation (CV%) value is an adequate indication of precision and reliability of the experiments. [26, 34] A low CV% of 1-1.5% suggests a good precision and higher reliability of the models for predicting experimental results. Adequate precision indicates the signal to noise ratio greater than 4 and proves its suitability. [35] A ratio 440.0 for Bi^{3+} confirms adequate signal.

Fig. 2a presents the plot of the actual values of biosorption of Bi^{3+}vs. predicted values using the model. Based on Fig. 2a, the suitable fitness between experimental data and predicted values could be revealed. The plot of studentized residual versus run number (Fig. 2b) shows that residuals were scattered randomly around ±2.00, which indicated a minimal deviation at the fitted value from the observed value.

3.3. Interactive effects of two variables

The combined effect of pH and temperature (Fig. 3a) reveal that the biosorption efficiency improved following raising pH from 6.0 to 7.0 that is probably due to the negative surface charge of black cumin at high pH values that following electrostatic interactions via biosorption through different mechanism adsorbed bismuth. The low biosorption in acidic solutions is related to competition between hydrogen and dyes for biosorbent active sites. At high temperatures, the sorbed bismuth amount decreased with raising temperature. The increase in uptake with decreasing temperature is due to large value of diffusion coefficient and sorbate transport enhancement within the pores of the sorbent. The decrease in biosorption at lower temperature (cooler media) is related to weakening of adsorptive forces between the active sites of the adsorbents and adsorbate species and also between the adjacent molecules of the adsorbed phase. On the other hand, according to Arrhenius equation at lower temperature a decrease in mass transfer and diffusion coefficient was observed. As can be seen from Fig. 3a the maximum dyes biosorption was obtained at pH 8.0 and temperature of 30 ºC.

3.4. Optimization of operational parameters using Desirability Functions (DF)

Numerical optimization is based on selection of desired goal for each factor and response. A minimum and a maximum level had to be provided for each parameter admitted in this study, while curvature of the response surfaces curve and their combination with desirability function sometimes lead to appearance of some maximum. Starting from various points in the design, improved the chances of detecting the "best" local maximum. [36, 37] A multiple response method was applied for optimization of any combination of three factors like pH (7.0-9.0) and initial bismuth concentration (20-40 mg L^{-1}) based on achievement of conditions for reaching the best ideal response (100%). Fig.4 shows a ramp desirability that was generated from 10 optimum points via numerical optimization. The best local maximum was found to be at pH of 8.0, temperature of 30 ºC, and initial Bi^{3+} concentration of 30 mg L^{-1} a desirability value of 1.00 indicates that the estimated function can well represent the experimental model and desired conditions.

3.5. Fourier transform infrared (FT-IR) spectroscopic study

In order to identify which functional groups might be involved in bismuth biosorption, a FT-IR study was carried out. Fig.5 shows The IR spectrum of metal-free and metal-loaded biomass, of bottom to top respectively and displaying a number of absorption peaks and indicating the complex nature of the biomass examined. Table 5 shows assignment of the main characteristic absorption bands for each of four structures. The FTIR analysis results showed the peak intensity changed in response to dosing with heavy metals. .Table 3 and Fig. 5 showed the changes in the intensity of bands at different regions that are related to functional groups of –OH, NH,–CN, –CH and –CO on the bacterial cell walls. Thus, it is concluded that these groups play an important role in uptake of bismuth.

3.6. Energy dispersive analysis of X-rays (EDAX)

Fig. 6a depicts EDAX spectra of *Streptomyces rimosus* and Bi-*Streptomyces rimosus* . The bismuth peak present in the EDAX spectrum of the bismuth sorbed *Streptomyces rimosus* composite depicted in Fig. 6b confirms the biosorption of bismuth. The quantitative elemental composition of biosorbent after metal ion sorption is listed in the respective figure.

3.7. Effect of initial bismuth concentration

The initial metal concentration provides an important driving force to overcome the diffusive mass transfer resistance of all molecules between the sorbate and sorbent.[9] Therefore, in the present study, the initial concentration of bismuth was varied from 10 to 100 mg L^{-1} at 30ºC and pH =8.0. As illustrated in Fig. 7, Percentage (%) removal of Bi^{3+} has been found to be higher at lower concentration of bismuth solution (30 mg L^{-1}); a maximum bismuth removal of 97.60% has been obtained for *Streptomyces rimosus* biomass.

3.8. Determination of biosorption isotherms

Biosorption isotherms best describe the equilibrium behavior. An isotherm is a plot of amount of solute adsorbed per unit amount of adsorbent against the corresponding equilibrium concentration in the solution phase keeping temperature constant. Vital conclusion can be drawn from these isotherms, which are useful in designing of biosorption systems. [38] In order to determine the biosorption isotherms, batch experiments were performed in aqueous solution with initial bismuth concentration ranging between 5 and 120 mgL^{-1}. This latter solution was prepared by using a stock solution. Experiments were conducted for each bacteria strain at pH = 8.0 under magnetic stirring. In any run, the pH was measured, controlled and corrected to pH= 8.0 with 0.1 mol L^{-1} HCl and/or NaOH. After 48 h, 2 mL of the suspension were taken and centrifuged at 9000 rpm. The supernatant was analyzed by atomic biosorption to compute the equilibrium bismuth concentration. The kinetics parameters in this study are given in Table 4. The experimental data had a better fit to the pseudo-second-order kinetic model than the pseudo-first-order kinetic model, based on the R^2 values presented in Table 4. The theoretical q_{cal} values for bismuth were very close to the experimental q_{exp} values. This suggests that the biosorption data were well represented by pseudo-second-order kinetics. It was concluded that the biosorption mechanism involved chemisorptions between adsorbate and the adsorbent. [39]

3.8.1. Langmuir isotherm

Langmuir isotherm is obtained from a kinetic derivation of equilibrium between adsorbed and desorbed molecules.[40] This gives

$$\frac{C_e}{q_e} = \frac{1}{Q_m k_L} + \frac{C_e}{Q_m} \qquad (3)$$

where q_e (mg g^{-1}) is the equilibrium biosorption capacity denoted as adsorbent mass per weight unit of solid adsorbate, C_e (mg L^{-1}) is the equilibrium adsorbate concentration remained in solution and Q_m (mg g^{-1}) and K_L are the biosorption equilibrium constant related to the binding energy. One of the major characteristics of this model is the dimensionless separation factor, $R_L = 1/(1 + K_L C_0)$ that points out whether the biosorption process is favorable ($0 < R_L < 1$), unfavorable ($R_L > 1$), linear ($R_L = 1$) or irreversible ($R_L = 0$). The model parameters were obtained from the linear relation between C_e/q_e and C_e (Table 4). [41]

3.8.2. Freundlich isotherm

This isotherm is derived from empirical consideration and expressed as

$$\ln q_e = \ln K_F + \left(\frac{1}{n}\right)\ln C_e \qquad (4)$$

Where, K_F is the Freundlich constant, which is a measure of biosorption capacity or fundamental effectiveness of the adsorbent. It is directly related to the standard free energy change, and n is an empirical constant related to heterogeneity of the adsorbent surface. Thus a plot between log q_e and log C_e is a straight line. Values of K_F and 1/n are calculated from plotting of graph between log q_e and log C_e. A high K_F and high 'n' values are indicative of high biosorption throughout the concentration range. A low K_F and high 'n' values indicate low biosorption throughout the studied concentration range. A low 'n' value Indicates high biosorption at strong solute concentration.

3.9. Determination of biosorption kinetics

The Lagergren's first-order and pseudo-second-order models were used to test biosorption kinetics data to investigate the mechanism of biosorption. The Lagergren pseudo-first-order model (Eq. (5)) and pseudo-second-order model (Eq. (6)) equations are: [42, 43]

$$1/q_t = k_1/(q_{e1}t) + 1/q_{e1} \qquad (5)$$

$$t/q_t = 1/(k_2 q_{e2}^2) + t/q_{e2} \qquad (6)$$

Where q_e and q_t are the amounts of bismuth adsorbed by the adsorbent at equilibrium and at time t (mg g^{-1}), respectively; k_1 and k_2 are the pseudo-first-order and pseudo-second-order constants (min^{-1}), respectively; and t is the biosorption time. The kinetics parameters in the single and binary systems are given in Table 5. The experimental data had a better fit to the pseudo-second-order kinetic model than the pseudo-first-order kinetic model, based on the R^2 values presented in Table 5. The theoretical q_{cal} values for bismuth biosorption were very close to the experimental q_{exp} values. This suggests that the biosorption data were well represented by pseudo-second-order kinetics. It was concluded that the biosorption behaviors of bismuth were better described by the pseudo-second-order kinetic model, which suggests that the biosorption mechanism involved chemisorptions between adsorbate and the adsorbent. [39, 44]

4. Conclusion

A bacterial biosorbent was an effective biosorbent for removal of Bi^{3+} from water solution. Response surface methodology as less labor intensive and time-consuming approaches was used to optimize effect of variables. RSM approach based on BBD efficiency was judged according to fitness of polynomial equation, the model adequacy, lack-of-fit (LOF), *P-values*, *F-values* and subsequent replication at optimum point suggested by model. The optimum biosorption conditions were determined as initial pH 8.0; 30 ºC; 48 h and initial concentration of 30 mg L^{-1} Bi^{3+}. The FTIR spectroscopic analysis confirmed that biosorbent functional groups on the biosorbent are main reactive sited to accomplish biosorption. It was also found that the biosorption process followed the Langmuir isotherm model with the highest value of correlation coefficients (>0.980) and the biosorption capacity being estimated to be 38.91 mg g^{-1} .The pseudo-first order and pseudo-second order models were applied to the experimental data in order to kinetically describe the removal mechanism of bismuth, with the second one showing the best fit with the experimental kinetic biosorption data (R^2 = 0.999).

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Table. 1. Matrix for the BBD.

		Levels				
Factors		Low (-1)	Central (0)	High (+1)	-α	+α
X_1:pH		6.00	7.00	8.00	5.00	9.00
X_2: temperature (ºC)		20.00	25.00	30.00	15.00	35.00
X_3: Bi^{3+} concentration (mg L^{-1})		10.00	15.00	20.00	5.00	25.00

Factors				R% Bi^{3+}	
Run	X_1	X_2	X_3	Actual[a]	Predicted[b]
1 (F)	9.00	30.00	20.00	24.60	23.96
2 (F)	7.00	30.00	20.00	52.50	43.70
3 (F)	8.00	30.00	30.00	97.70	46.93
4 (F)	9.00	30.00	40.00	17.50	64.30
5 (F)	9.00	25.00	30.00	7.400	71.63
6 (F)	9.00	35.00	30.00	5.600	57.50
7 (F)	8.00	35.00	40.00	12.40	83.63
8 (F)	8.00	25.00	20.00	43.70	74.79
9 (F)	7.00	35.00	30.00	11.50	16.68
10 (F)	8.00	35.00	20.00	18.90	44.70
11 (F)	7.00	30.00	40.00	31.60	22.35
12 (F)	8.00	30.00	30.00	97.40	74.30
13 (F)	8.00	30.00	30.00	97.60	53.25
14 (F)	8.00	25.00	40.00	21.30	70.13
15 (F)	7.00	25.00	30.00	42.60	65.10

[a] Experimental values of response.
[b] Predicted values of response by RSM proposed model.
F: Factorial point
A: Axial point
C: Center point

Table. 2. Analysis of variance (ANOVA) for BBD.

Factor	SS[a]	Df[b]	MS[c]	F-value	P-value	Status
Model	15530	9	1725	26200	< 0.0001	*
X_1	863.2	1	863.2	13110	< 0.0001	*
X_2	554.4	1	554.4	8422	< 0.0001	*
X_3	404.7	1	404.7	6147	< 0.0001	*
X_1X_2	214.6	1	214.6	3260	< 0.0001	*
X_1X_3	47.61	1	47.61	723.2	< 0.0001	*
X_2X_3	63.2	1	63.2	960	< 0.0001	*
X_1^2	4962	1	4962	75370	< 0.0001	*
X_2^2	7192	1	7192	109200	< 0.0001	*
X_3^2	3182	1	3182	48340	< 0.0001	*
Residual	0.3292	5	0.06583			
Lack-of-Fit	0.2825	3	0.09417	4.036	0.2049	**
Pure Error	0.04667	2	0.02333			
Total	15530	14				

[a]Sequential sums of squares
[b] Degrees of freedom
[c]mean sums of squares
*significant
**not significant

Table. 3.FTIR Spectra analysis

Before biosorption (cm^{-1})	After biosorption (cm^{-1})	Functional groups
3430.28	3442.1	O-H, N-H
2920.2	2920.2	C-H
2845.3	1652.7	C-H
1625.4	1646.3	-COO, C-O
1401.2	1401.2	COO-
1118.21	1046.45	-C-O, C-N

Table. 4. Isotherm constant parameters and correlation coefficients calculated for the biosorption of bismuth onto *Streptomyces rimosus*.

Isotherm	Parameters	Bi^{3+}
Langmuir	Qm ($mg.g^{-1}$)	38.93
	K_L ($L\ mg^{-1}$)	1. 01
	R^2	0.9944
	R_L	0.047-0.012
Freundlich	1/n	0.1266
	K_F($L\ mg^{-1}$)	4. 037
	R^2	0.8009

Table. 5. Kinetic parameters for the biosorption of bismuth using *streptomyses rimosus*.

Model	Parameters	Values
Pseudo- First-order- kinetic	k_1 (min^{-1})	0.1566
	q_e (calc) (mg g^{-1})	4.431
	R^2	0.8282
Pseudo-second-order-kinetic	k_2 (min^{-1})	0.00047
	q_e(calc) (mg g^{-1})	13.489
	R^2	0.9999
	h (mg $g^{-1}min^{-1}$)	0.0855
Experimental Data	q_{eq} (exp) (mg g^{-1})	12.837

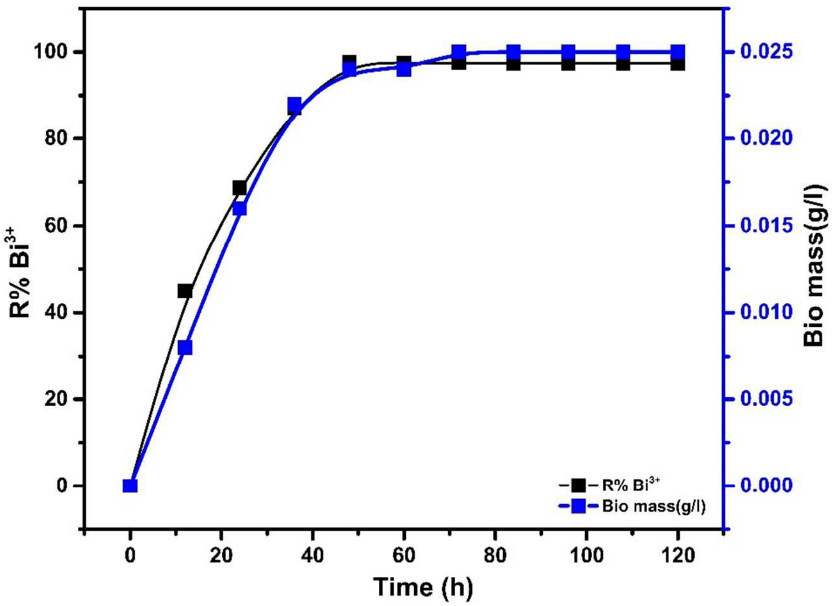

Fig. 1. Effect of contact time on Bi^{3+} biosorption on *streptomyces rimosus* (pH =5.5,T = 25 ºC, C_0=30 mg L^{-1}).

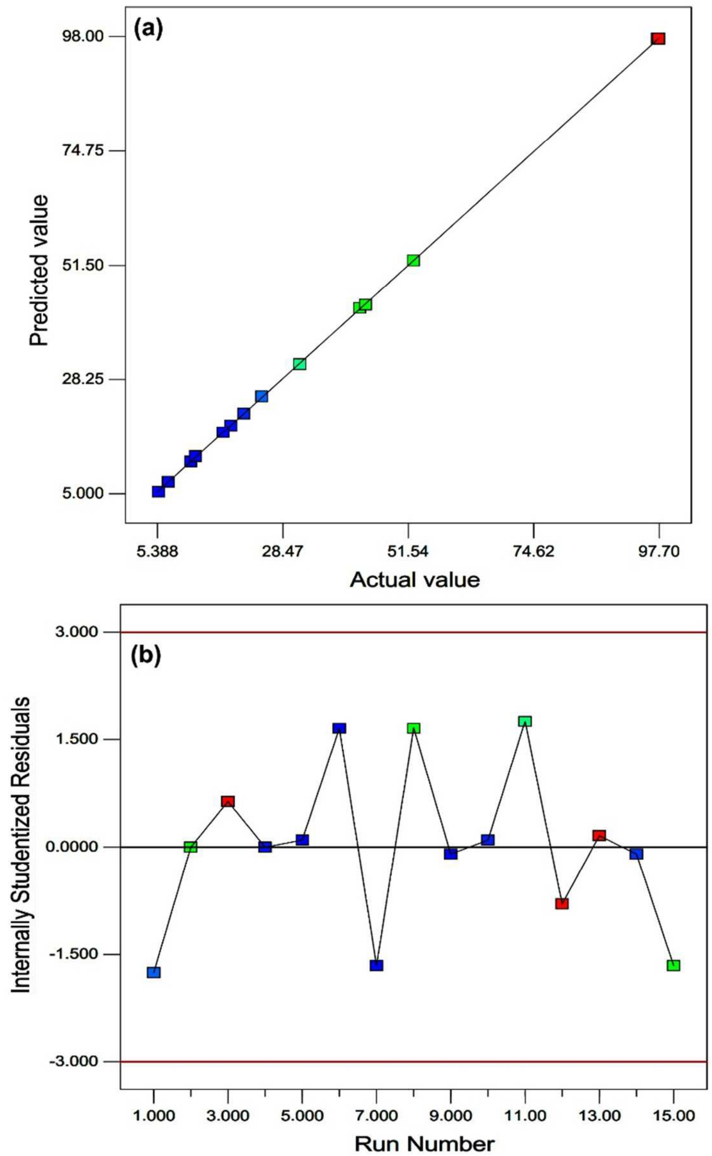

Fig. 2.a) Correlation of actual and predicted percent biosorption and b) the studentized residuals vs. run number plot for biosorption of Bi^{3+}.

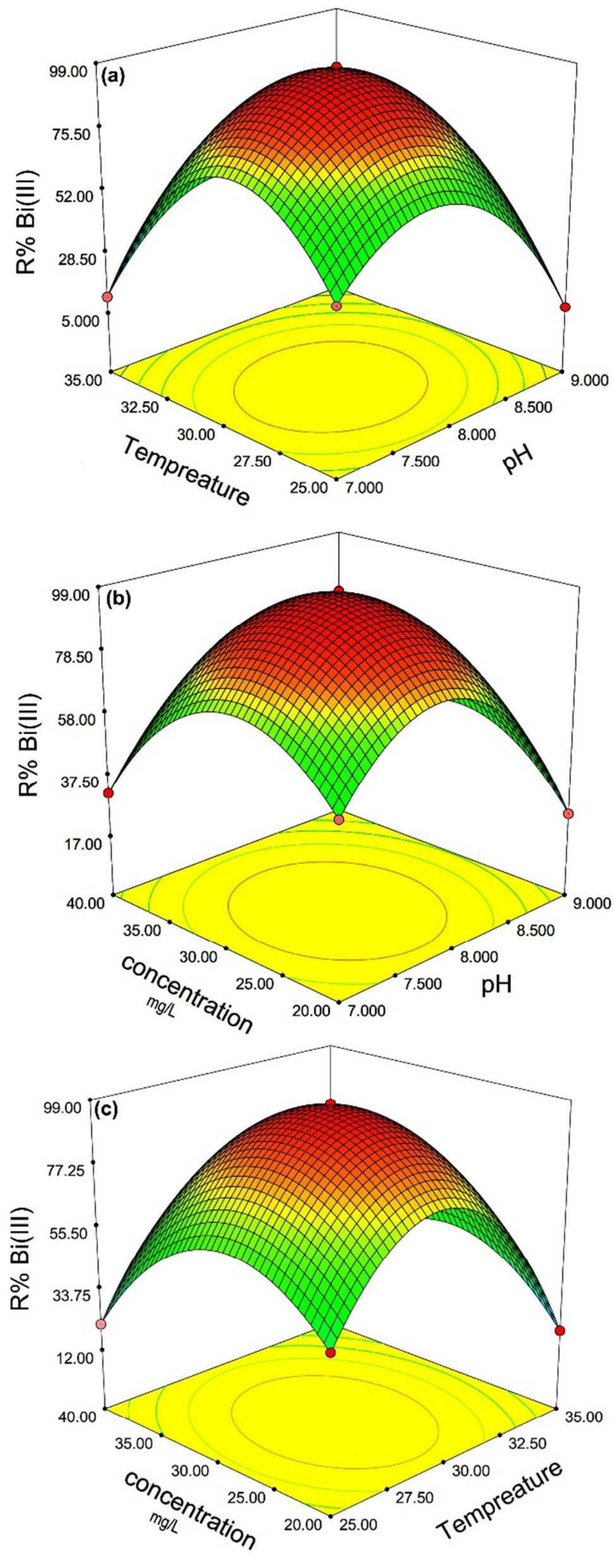

Fig. 3. 3D surface plots of the biosorption Bi^{3+}ions versus two independent factors: (a) pH-temperature, (B) initial ion concentration – pH and (C) initial ion concentration - temperature.

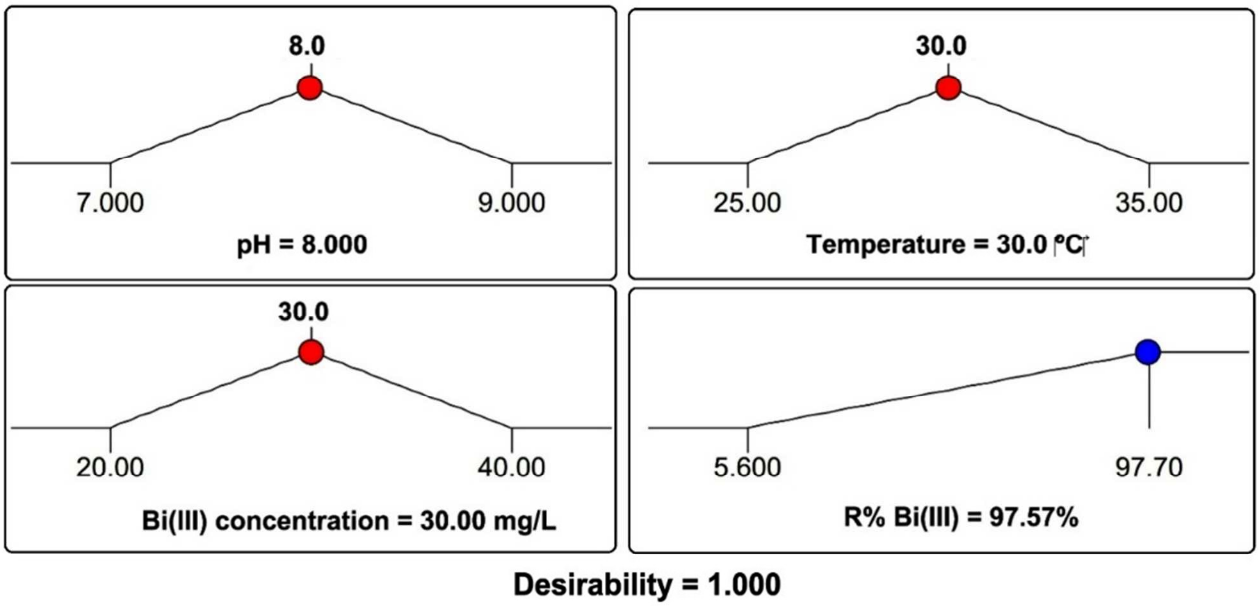

Fig. 4. Desirability ramp for numerical optimization of three goals, namely the pH, temperature, initial Bi^{3+} concentration and Bi^{3+}removal.

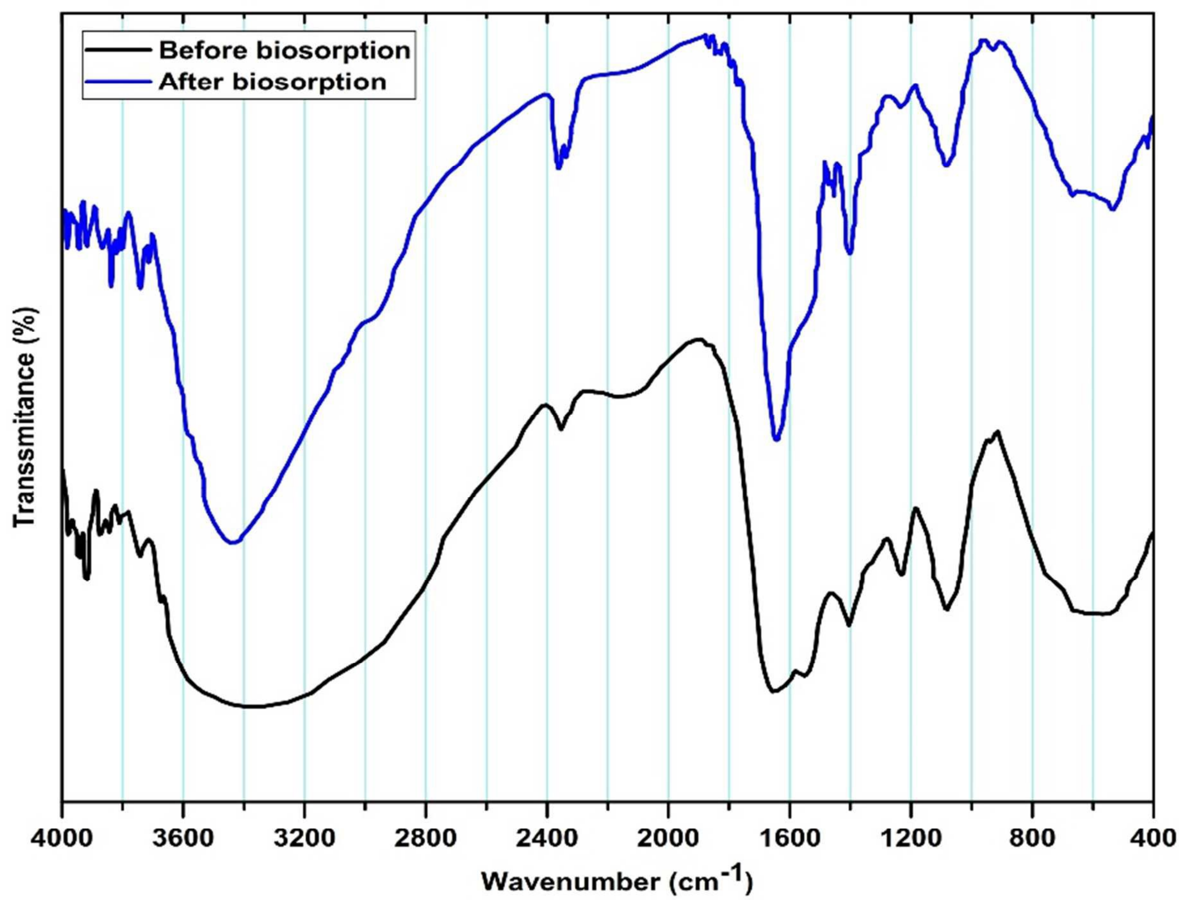

Fig. 5. FTIR spectra of *streptomyses rimosus* for biosorption of Bi^{3+}ions: before and after biosorption.

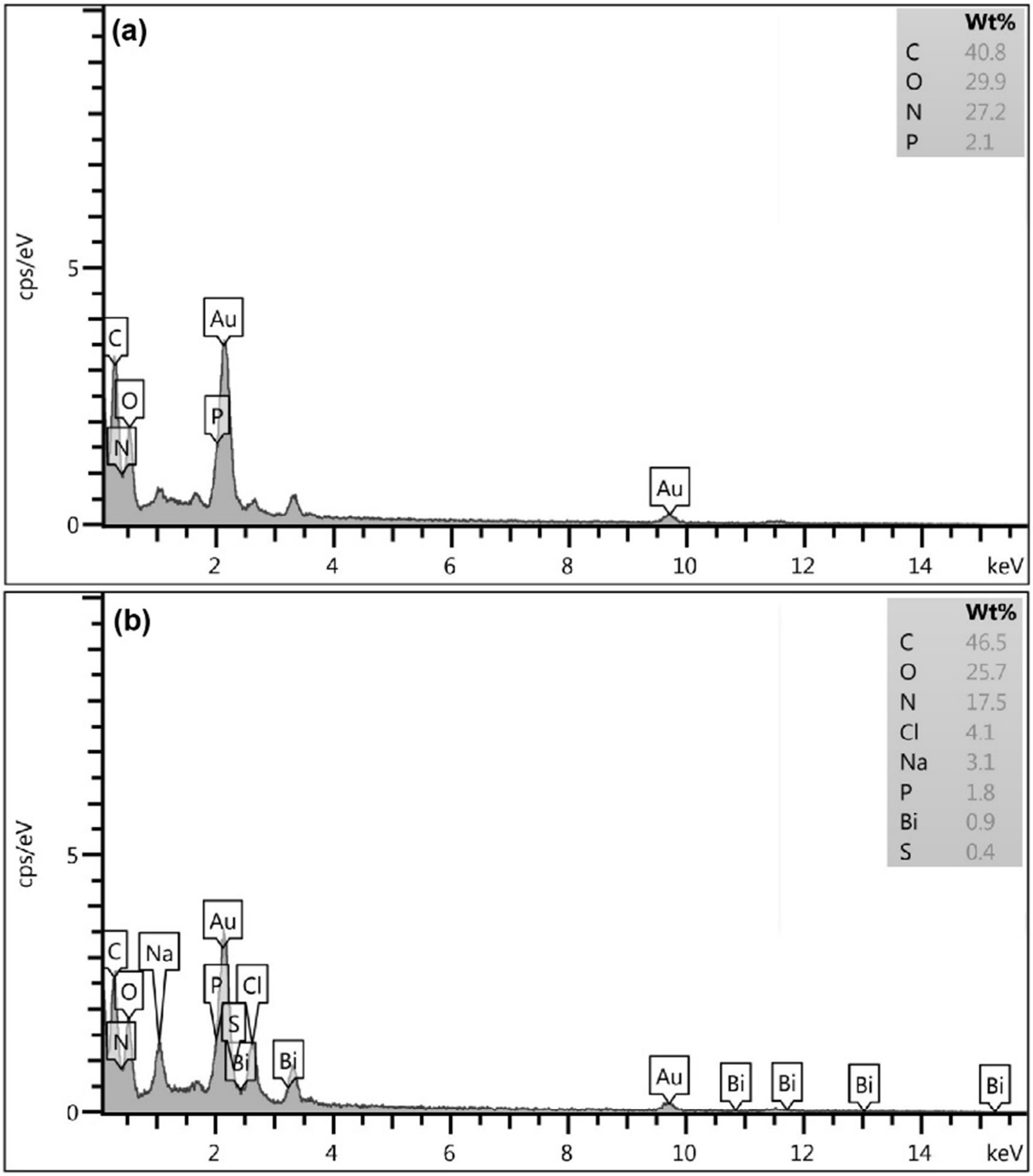

Fig. 6. EDAX spectra of *streptomyces rimosus*: (a) in the absence of bismuth and (b) after bismuth biosorption (C_0 = 30 mg L^{-1}).

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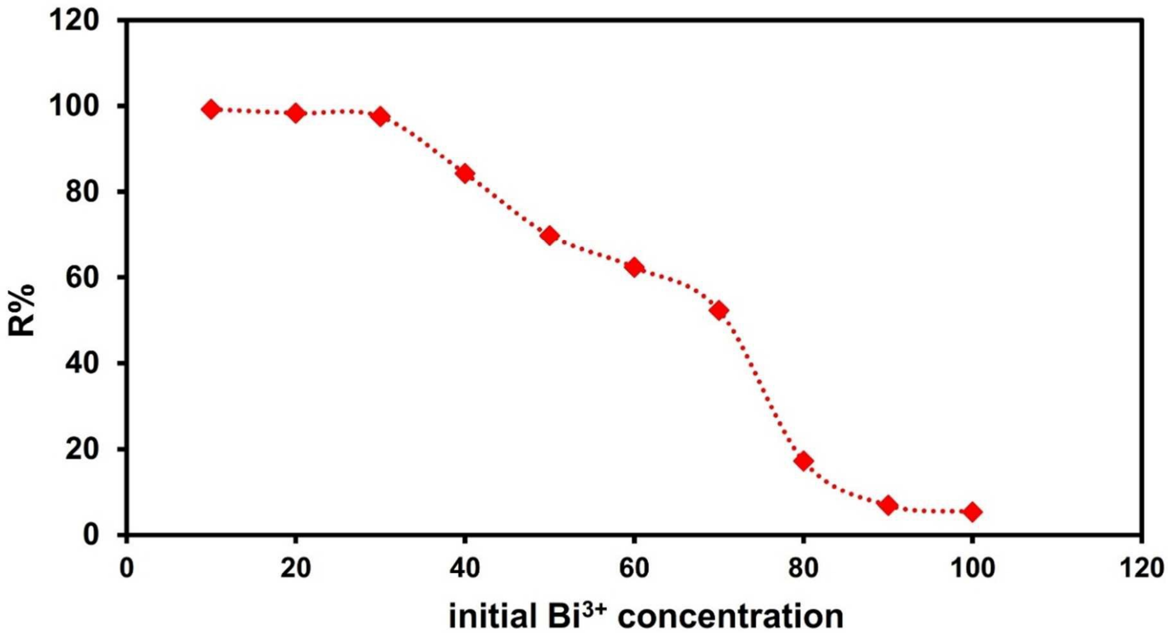
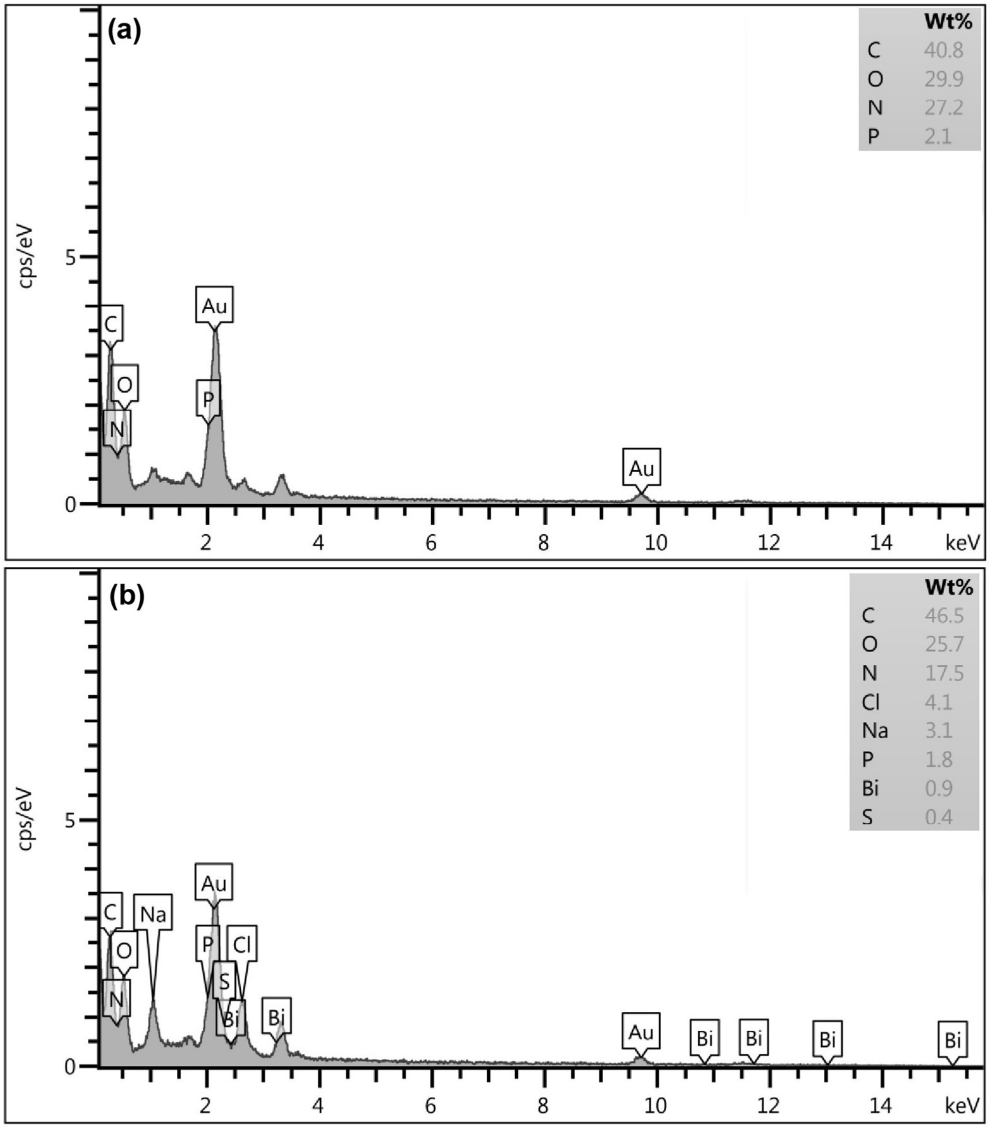


694 **Fig. 7.** Influence of initial Bi^{3+} concentration on removal efficiency and biosorption capacity of
695 *streptomyces rimosus* (contact time =48 h, temperature =30 ºC and pH =8.0).
696



147x167mm (300 x 300 DPI)