

Biosorption of Ni(II), Pb(II) and Zn(II) on calcium alginate beads: equilibrium, kinetic and mechanism studies

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The biosorption process of three divalent metal ions – nickel, lead and zinc– from on calcium alginate from aqueous solution was studied, in single component systems. The biosorbent were investigated by Fourier Transform Infrared Spectroscopy. The batch mode experiments of the adsorption process were carried out as a function of pH, initial metal ions concentration, sorbent dosage and contact time. The adsorption influencing parameters for the maximum removal of metal ions were optimized. The experimental data were analyzed using the Langmuir, Freundlich, Langmuir-Freundlich, Koble-Corrigan and Redlich-Peterson models. The kinetic data of biosorption process were evaluated using pseudo-first and pseudo-second order equations. The Weber and Morris model was employed to interpret the metal ions diffusion in biosorption process.

Keywords: biosorption, heavy metal, nickel, lead, zinc, alginate.

INTRODUCTION

Heavy metal water solutions are widely used in industrial activities such as metal finishing, electroplating, painting, dyeing etc. The effluents of industrial wastewaters often contain considerable amounts of toxic and polluting heavy metals, such as Hg, Pb, Cr, Ni, Cu, Cd, Zn, etc¹. Most of heavy metal ions are highly toxic and carcinogenic even at low concentrations, about 0.1–0.3 mg/L².

Efficient removal of heavy metal from wastewaters is an important and widely studied research area. Traditional methods used for removal them from wastewaters include: chemical precipitation, membrane filtration, ion exchange, adsorption and reverse osmosis³. Due to the specific nature of industrial effluents the effective removal of metal ions from aqueous solution is both very difficult and costly process. In addition, these methods can be ineffective and also can increase contamination by creating more toxic byproducts². Furthermore, they can be inaccessible to the majority of people living in developing countries, where contamination of drinking water is dangerous to human health. Therefore, looking for new, effective and inexpensive methods for removal of heavy metals from environment is still demanded⁴.

In recent years studies on biological materials have increased significantly. It was shown that biosorption process may be a promising alternative to traditional physical and chemical methods. As biosorbents strongly binding metal ions are used both animal substance (chitin, chitosan) and plant origin (cellulose, alginate, carrageen)⁵. Alginate and chitosan gel beads have been recognized as one of the most effective biosorbents for eliminating low levels of heavy metal ions from wastewater stream.

The most important advantages of biosorption process over conventional treatment methods are low cost, high efficiency of metal removal from dilute solution, easy biosorbent regeneration and possibility of metal recovery⁶.

In this paper the equilibrium and kinetic of biosorption of Ni(II), Pb(II) and Zn(II) ions by calcium alginate beads were investigated. The influence of experimental conditions such as solution pH, effect of varying adsor-

bent dose, initial metal concentration and contact time were studied. The Langmuir, Freundlich, Langmuir-Freundlich, Koble-Corrigan and Redlich-Peterson equilibrium models, were used to evaluate the experimental data.

MATERIAL AND METHODS

Material

Sodium alginate powder and calcium chloride dehydrate ($\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$) were obtained from SIGMA-Aldrich and Chempur, respectively, and used without further purification. Metal solutions of 2000 mg/dm³ of nickel, lead and zinc were prepared from analytical grade $\text{Ni}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$, $\text{Pb}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$ and $\text{Zn}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$ (Chempur) by dissolving in distilled water. The stock solution was diluted with distilled water to the required concentration of the biosorption experiments. The solution pH was adjusted to the desired value by dilute HCl and dilute NaOH solutions at the start of the experiment.

Preparation of calcium alginate beads

Solution of 2% sodium alginate was prepared by dissolving 2 g sodium alginate (SIGMA-Aldrich) into 98 mL distilled water. Solution was keeping at a temperature of 60°C for better dissolution. The beads were formed by adding drop-wise of sodium alginate into 0.05 M CaCl_2 solution under gentle stirring. Stirring was kept during 12 h in order to stabilize the obtained beads and to remove small air bubbles generated during stirring. Beads were washed several times with distilled water to remove unreacted CaCl_2 from the beads surface. Following the washing, the beads were taken onto a filtration paper to remove excess water.

Characterization

Fourier transform infrared (FTIR) spectroscopy was used to confirm the presence of functional groups in samples of sodium alginate powder and dry calcium alginate beads. Beads composed of 2% calcium alginate

were prepared for analysis by drying at room temperature for 24 h. Each spectrum was from 4000 to 400 cm^{-1} .

Biosorption studies

Biosorption experiments were performed using 8 g of wet calcium alginate beads which were placed in opaque bottles. Then 100 mL solution containing trace metal ions was added. The bottles were shaken at 150 rpm at 30°C. All experiments, except for pH test were performed at pH 5. After shaking, gel beads were separated from the metal solution and the supernatant solution was analyzed by inductively coupled plasma atomic emission spectrometry (ICP-MS) in a Jobin Yvon type JY-24 apparatus. The biosorption capacity of the metal ions was determined by the difference in solution concentration before and after adsorption. The adsorption quantity of trace metal ions and the adsorption percentage were evaluated according to the following equations:

$$q = \frac{(C_0 - C) \cdot V}{m_{ads}} \quad (1)$$

where q is the equilibrium uptake, mg/g, C_0 is the initial metal ion concentration, mg/L, C is equilibrium metal ion concentration, mg/L, V is the volume of solution, L, and m_{ads} is the amount of gel beads, g.

Percent removal was determined using the following equation:

$$q = \frac{(C_0 - C)}{C_0} \cdot 100\% \quad (2)$$

RESULTS AND DISCUSSION

FTIR spectra

Figure 1 shows FTIR spectra of sodium alginate powder and dry calcium alginate beads. The sodium alginate FTIR spectrum showed a few significant peaks. The O-H stretching vibrations of alginate appeared around 3273 cm^{-1} . Stretching vibrations of aliphatic C-H were observed at 2925 cm^{-1} . COO- stretching is split into asymmetric and symmetric C=O vibration. The first one is found at 1590 cm^{-1} and the second one at 1410 cm^{-1} . The bands at 1295 cm^{-1} were attributed to the C-O stretching vibration. The next peak, around 1085 cm^{-1} , is related to C-O, C-C and to COC stretching vibrations. The strong and sharp peak at 1030 cm^{-1} is also assigned to C-C and to COC vibrations.

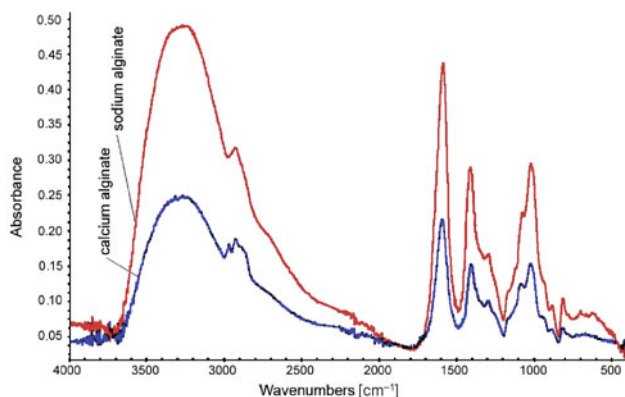


Figure 1. FTIR spectrum of calcium alginate beads and sodium alginate powder

Dry calcium alginate beads showed significant difference bands in comparison with FTIR spectrum of sodium alginate. Absorption region of stretching vibration of hydroxyl bonds in sodium alginate appeared wider than calcium alginate. This difference results from the participation of hydroxyl and carboxylate groups of alginate to the calcium ion in order to form chelating structure. Those results are similar to others obtained from alginate and brown algae with different materials^{4, 7-11}.

Initial pH effect

Heavy metal sorption is highly dependent on pH solution. Solution pH influence on the total charge of the biosorbent and on the surface metal binding sites. Moreover, the pH value affects the solubility of the metal ions in solution¹². The effect of initial solution pH for Ni(II), Pb(II) and Zn(II) biosorption capacity on alginate beads was studied at $C_0 = 60$ mg/L at 30°C. Figure 2 present the alginate biosorption capacity after 24 h duration of the removal heavy metal ions at solution pH in the ranges: 2–6 for Pb(II), 3–7 for Ni(II) and Zn(II).

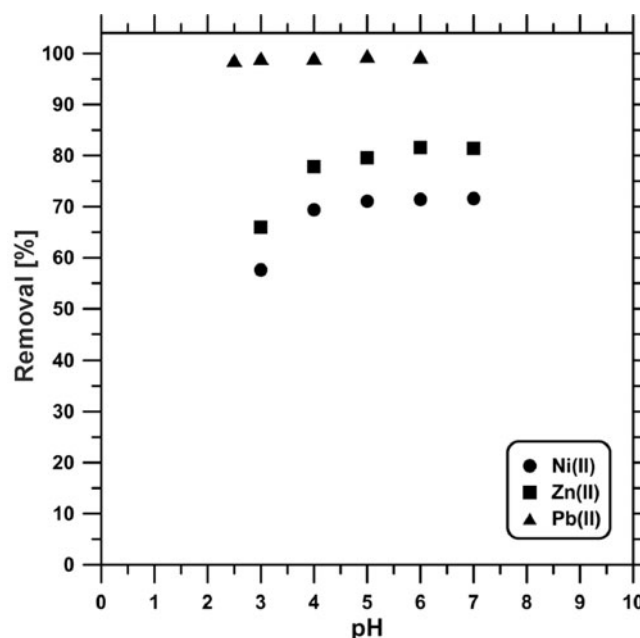


Figure 2. pH influence on heavy metal ions biosorption ($C_0 = 60$ mg/L, $m_{ads} = 8$ g/100 mL, $t = 30^\circ\text{C}$)

Investigated metal ions uptake capacity was affected by their solution pH. The uptake capacity was relatively constant for Pb(II) at solution pH 3–6, but for Ni(II) and Zn(II) still increased for solution pH from 3 to 5. This behavior is similar to other pH-dependence reported in various articles^{1, 12-16}. This suggest that alginate and alginate derivatives shares the same basic mechanism of metal ions binding. The optimal solution pH was defined as the pH value at which the sorption capacity was maximal. Thus, all subsequent biosorption experiments in this study were conducted at pH = 5.

Biosorbent dose

The effective amount of biosorbent for removal of heavy metal ions on calcium alginate was studied by varying biosorbent dose from 1 to 12 g on 100 mL of solution. The contact time and agitation speed was set at 24 h and 150 rpm, respectively. Figure 3 shows the

effect of adsorbent dose on the removal of metal ions on calcium alginate.

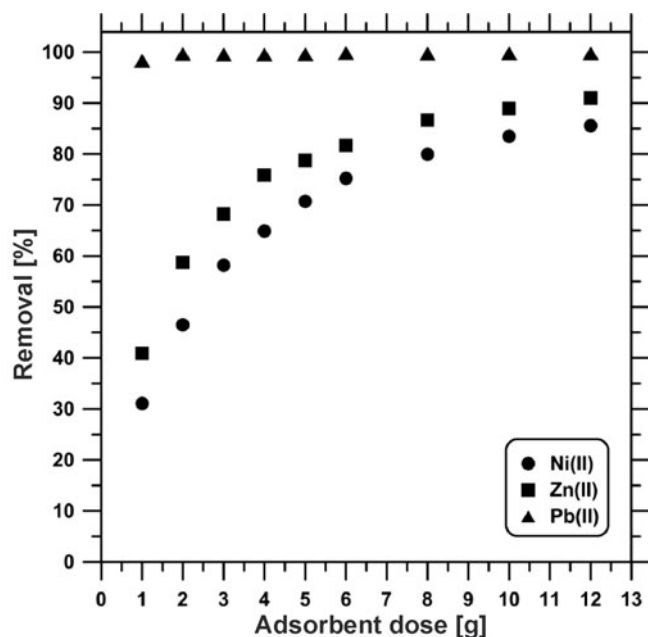


Figure 3. Adsorbent dose for various metal ions ($C_0 = 60$ mg/L, pH = 5, $t = 30^\circ\text{C}$)

It was observed that the removal of metal ions was increased with increase in adsorbent dose. The maximum removal of metal ions was observed at adsorbent dose of 8 g/100 mL so all subsequent biosorption experiments in this study were conducted with this amount of biosorbent.

Effect of contact time

The time required to achieve biosorption equilibrium was studied using Pb(II), Ni(II) and Zn(II) aqueous solutions with initial concentration of 60 mg/L at pH = 5. The contact time was varied from 1 to 300 min, and results are shown in Figure 4. The results indicated that increase in the contact time increase the metal uptake, but after achieving an equilibrium metal capacity remains constant.

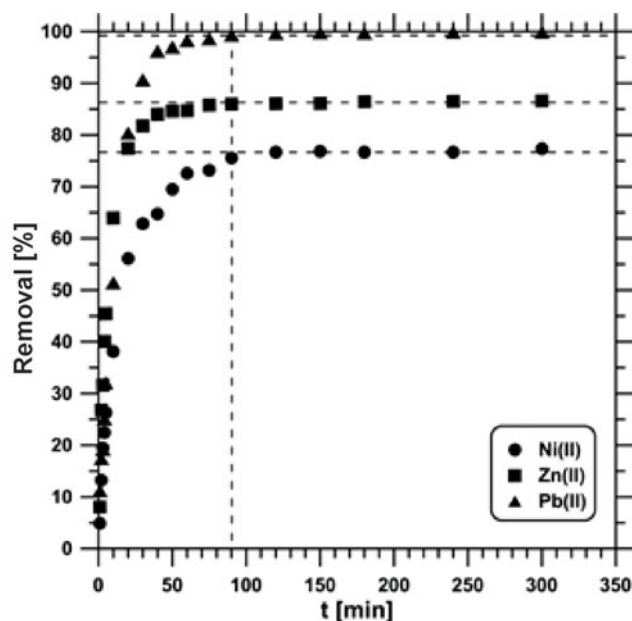


Figure 4. Effect of contact time for various metal ions ($C_0 = 60$ mg/L, pH = 5, $m_{\text{ads}} = 8$ g/100 mL, $t = 30^\circ\text{C}$)

As can be seen from above figure, the removal of metal ions involves in two stages. In first 40 min biosorption process is proceed very quickly and then slow down until equilibrium is achieved after 90 min. The maximum removal for each metal ions was reached at 90 min but experiments were carried out for a contact time of 120 minutes, to ensure that the system reaches equilibrium even at low initial metal concentration.

Sorption equilibrium study

The equilibrium isotherm is fundamental in describing the interactive behavior between solutes and biosorbent. The biosorption experiment for different initial metal concentration in the range from 10 to 1200 ppm was investigated at 30°C and solution pH = 5. The experimental data of the single-metal sorption isotherms for Pb(II), Ni(II) and Zn(II) are shown in Figure 5. These results indicate that an increase in the metal ions concentration resulted in an increase in the amount of the ions adsorbed. The sorption capacity of the calcium alginate for these metals followed the order Pb(II) > Zn(II) > Ni(II).

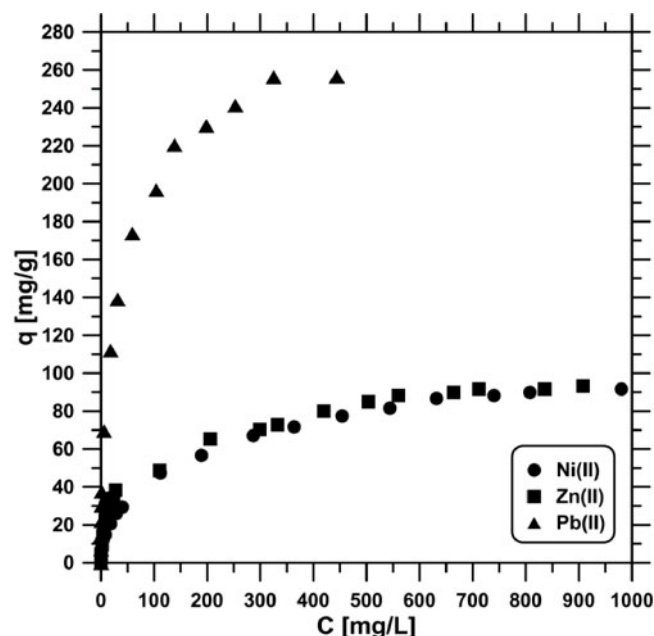


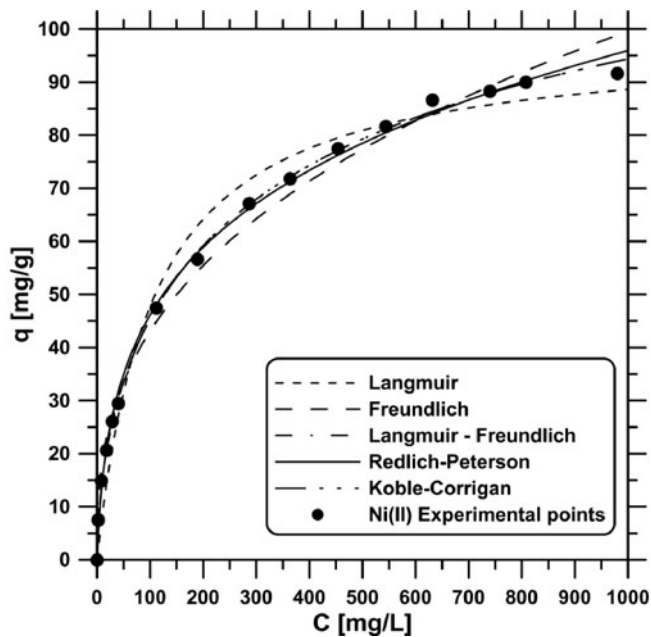
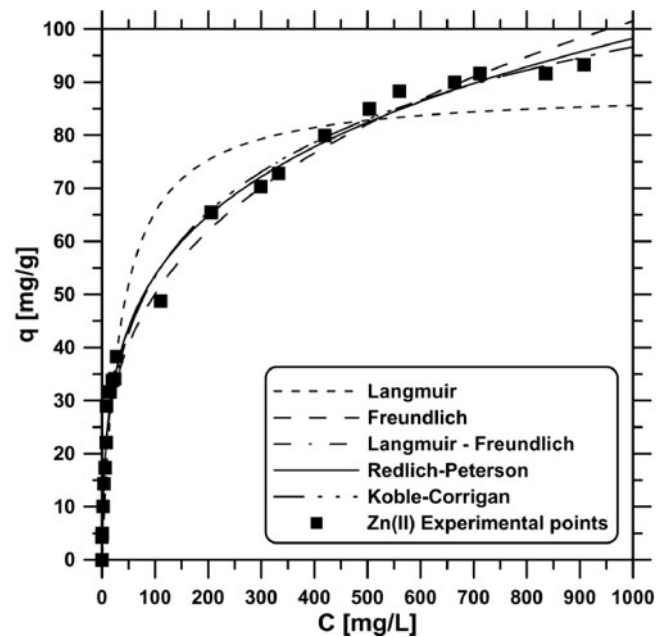
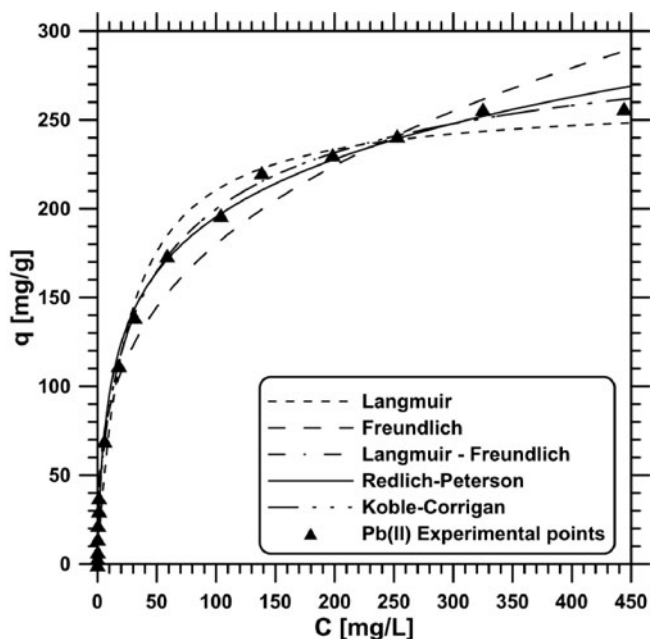
Figure 5. Adsorption isotherms of Ni(II), Pb(II) and Zn(II) on calcium alginate ($C_0 = 10$ –1200 mg/L, pH = 5, $m_{\text{ads}} = 8$ g/100 mL, $t = 30^\circ\text{C}$)

In order to describe adsorption process two- and three-parameter isotherms were used. Two-parameter Langmuir and Freundlich models are the most commonly used. However, the two-parameter models habitually showed a limit of application, therefore models with three parameters such as Langmuir-Freundlich, Koble-Corrigan and Redlich-Peterson were also applied. Equilibrium model equations used to describe adsorption process are listed in Table 1.

To find the parameters for each adsorption models, the nonlinear least square regression method was used in Statistica program. Values of the biosorption equilibrium constants, obtained from the experimental data using non-linear regression, are reported in Table 2. In Figures 6 through 8, the predicted amounts of sorption q determined using selected isotherm models were compared to the experimental values.

Table 1. Equilibrium model equations used to investigate Ni(II), Pb(II) and Zn(II) biosorption onto calcium alginate

Isotherm	Nonlinear form	Parameters	Eq.
Langmuir	$q = q_m \frac{K_L \cdot C}{1 + K_L \cdot C}$	q_m – maximum adsorption capacity [mg/g] K_L – constant related to the free energy of adsorption [L/mg]	(3)
Freundlich	$q = K_F \cdot C^{\frac{1}{n}}$	K_F – constant indicative of the relative adsorption capacity of the adsorbent [$\text{mg}^{1-(1/n)} \text{L}^{1/n} \text{g}^{-1}$] n – constant indicative of the intensity of the adsorption.	(4)
Langmuir-Freundlich	$q = q_{mLF} \frac{(K_{LF} \cdot C)^{n_{LF}}}{1 + (K_{LF} \cdot C)^{n_{LF}}}$	K_{LF} – equilibrium constant for a heterogeneous solid, n_{LF} – heterogeneity parameter, lies between 0 and 1.	(5)
Koble-Corrigan	$q = \frac{K_{KC} \cdot C^{n_{KC}}}{1 + B C^{n_{KC}}}$	K_{KC} – Koble-Corrigan isotherm constant [$\text{L}^n \text{mg}^{1-n} / \text{g}$] B – Koble-Corrigan isotherm constant [$(\text{L}/\text{mg})^n$] n_{KC} – adsorption intensity	(6)
Redlich-Peterson	$q = \frac{K_{RP} \cdot C}{1 + B C^{n_{RP}}}$	K_{RP} – Redlich-Peterson isotherm constant [L/g], B – constant having unit of [$(\text{L}/\text{mg})^n$], n_{RP} – exponent that lies between 0 and 1.	(7)

**Figure 6.** Adsorption isotherm of Ni(II) on calcium alginate using various isotherm models ($C_0 = 10$ –1200 mg/L, pH = 5, $m_{\text{ads}} = 8$ g/100 mL, $t = 30^\circ\text{C}$)**Figure 8.** Adsorption isotherm of Zn(II) on calcium alginate using various isotherm models ($C_0 = 10$ –1200 mg/L, pH = 5, $m_{\text{ads}} = 8$ g/100 mL, $t = 30^\circ\text{C}$)**Figure 7.** Adsorption isotherm of Pb(II) on calcium alginate using various isotherm models ($C_0 = 10$ –1200 mg/L, pH = 5, $m_{\text{ads}} = 8$ g/100 mL, $t = 30^\circ\text{C}$)

It can be seen that all models fit to the experimental data fairly good. The applicability of the isotherm equation to describe the adsorption process was judged by the values of average relative error δ , which were calculated using following equation:

$$\delta = \frac{1}{N} \cdot \sum_{i=1}^N \left| \frac{(q_i^{\text{exp}} - q_i^{\text{cal}})}{q_i^{\text{exp}}} \right| \cdot 100 \quad (3)$$

where q_i^{cal} , is each value of q_e predicted by the fitted model and q_i^{exp} , is each value of q_e measured experimentally, and N is the number of measurement points.

Obtained average relative errors between experimental and predicted values were presented in Table 2.

For two-parameter equations the best fitting to experimental data for Pb(II) ions was obtained using Langmuir model, while for Ni(II) and Zn(II) was obtained using Freundlich model. Low values of δ confirm the good fitting to the experimental data. The value of the constant n indicates good adsorption capacity. It is generally stated that values of n in the range from 2 to 10 represent good, from 1 to 2 moderately difficult, and less than 1 poor adsorption characteristics¹⁷. In this case

Table 2. The isotherms adsorption constants and average relative error

Model	Parameter	Ni	Pb	Zn
Langmuir	q_{max} , [mg/g]	97.93	261.89	88.65
	K , [L/mg]	0.0095	0.041	0.028
	δ , [%]	17.18	23.07	14.32
Freundlich	K [$\text{mg}^{1-(1/n)} \text{L}^{1/n} \text{g}^{-1}$]	8.07	41.89	12.21
	n	2.75	3.16	3.26
	δ , [%]	10.73	39.98	10.06
Langmuir-Freundlich	q_{max} , [mg/g]	152.60	326.23	174.18
	K , [L/mg]	0.0022	0.02	0.0016
	n	0.58	0.63	0.45
	δ , [%]	1.53	8.27	7.57
Redlich-Peterson	K , [L/mg]	2.95	31.20	10.58
	B , [L/mg]	0.17	0.35	0.58
	n	0.74	0.82	0.75
	δ , [%]	5.26	8.23	6.18
Koble-Corrigan	K [$\text{L}^n \text{mg}^{1-n} \text{g}$]	4.42	28.09	9.95
	B , [$(\text{L/mg})^n$]	0.029	0.086	0.056
	n	0.58	0.63	0.44
	δ , [%]	1.50	8.27	7.62
Number of measurement points	N	17	16	23

the value of n is greater than 2 and represents a good adsorption condition.

Among the tested three-parameter equations the best fitting to the experimental data for Ni(II) was obtained using Koble-Corrigan equation, where average relative error δ , amounts to 1.50%. For Zn(II) and Pb(II) the best fitting was obtained using the Redlich-Peterson model, where average relative error δ , amounts to 6.18% and 8.23%, respectively.

On the basis of the average relative error values (Table 2), the Langmuir-Freundlich equation also gives good fitting, but is less suitable than Koble-Corrigan and Redlich-Peterson to describe Ni(II), Pb(II) and Zn(II) biosorption process onto calcium alginate.

The results obtained using the two- and three-parameter equations show that the adsorption isotherm models fits to experimental data in the following order for Ni(II): Koble-Corrigan > Langmuir-Freundlich > Redlich-Peterson > Freundlich > Langmuir, for Zn(II): Redlich-Peterson > Langmuir-Freundlich > Koble-Corrigan > Freundlich > Langmuir, and for Pb(II): Redlich-Peterson > Langmuir-Freundlich > Koble-Corrigan > Langmuir > Freundlich.

Sorption kinetics study

In order to investigate the mechanism of sorption, the kinetic data obtained from batch studies have been

analyzed using pseudo-first (Eq. 4) and pseudo-second order (Eq. 5) models:

$$\frac{dq_t}{dt} = k_1 \cdot (q_e - q_t) \quad (4)$$

$$\frac{dq_t}{dt} = k_2 \cdot (q_e - q_t)^2 \quad (5)$$

where k_1 , k_2 are rate constants of the pseudo-first and pseudo-second order, respectively, min^{-1} , q_e is the amount of metal ions bound at equilibrium, mg/g and q_t is the amount of metal ions bound, mg/g, at time t , min.

Introducing experimental data of the q_e and q_t into Eq. 3, the plot of $\log(q_e - q_t)$ versus t should give linear relationship, indicating that the processes follows the pseudo-first order model. For the pseudo-second order model, a plot of t/q_t versus t according to the Eq. 4 should give straight line to confirm the applicability of this kinetic model. The better fitting to experimental data will show which kinetic model is adequate to describe sorption process mechanism.

Figure 9 and 10 show the fitting of the pseudo-first and pseudo-second order kinetic models, respectively, on their linear forms to the experimental biosorption data.

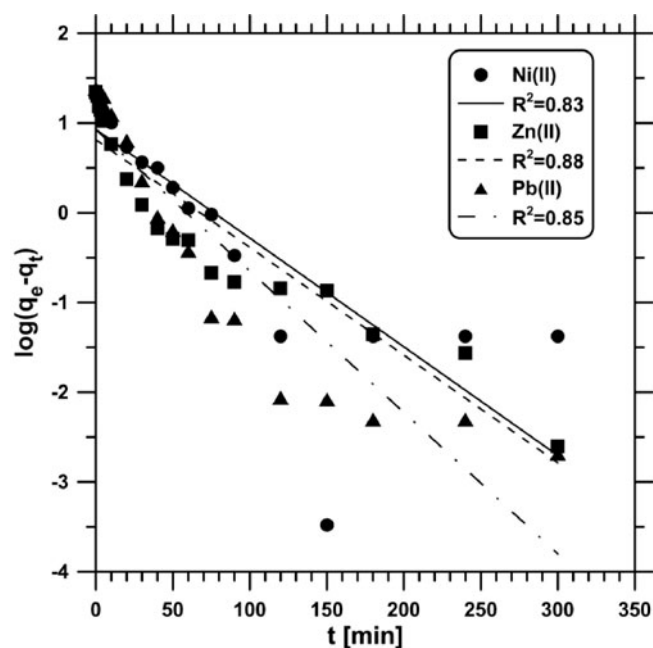


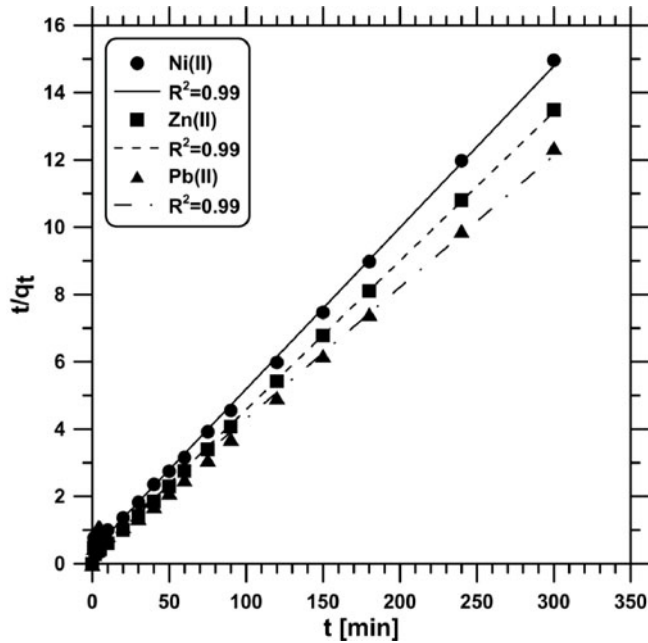
Figure 9. Pseudo-first order model fitting to the experimental results ($C_0 = 60$ mg/L, pH = 5, $m_{ads} = 8$ g/100 mL, $t = 30^\circ\text{C}$)

The value of the average relative error has been used as a criterion for the fit accuracy to the experimental data. The comparison of q_i^{exp} and the q_i^{cal} values estimated from the pseudo-first and pseudo-second order kinetic model are presented in Table 3.

The kinetic data presented in Table 3 show that, the pseudo-second order model fits to the experimental results more accurately than the pseudo-first order. Calculated q_i^{cal} values from pseudo-second order model agree well with the experimental q_i^{exp} values for all studies heavy metal ions. This indicates that the pseudo-second order mechanism is predominant and the chemisorption (ion exchange, electrostatic attractions) may be the rate-limiting step that controls the biosorption process.

Table 3. Comparison of the pseudo-first and pseudo-second order kinetic parameters

Metal	N	q_i^{exp} [mg/g]	Pseudo-first order				Pseudo-second order			
			q_i^{cal} [mg/g]	k_1 [1/min]	δ [%]	R^2	q_i^{cal} [mg/g]	k_2 [g/(min · mg)]	δ [%]	R^2
Zn(II)	3	22.24	6.49	-0.028	70.8	0.88	22.61	0.012	1.6	0.99
Ni(II)	3	20.08	8.99	-0.025	57.5	0.83	20.89	0.006	4.0	0.99
Pb(II)	3	24.25	8.43	-0.036	65.2	0.85	25.08	0.006	3.4	0.99

**Figure 10.** Pseudo-second order model fitting to the experimental results ($C_0 = 60$ mg/L, pH = 5, $m_{ads} = 8$ g/100 mL, $t = 30^\circ\text{C}$)

Diffusion process

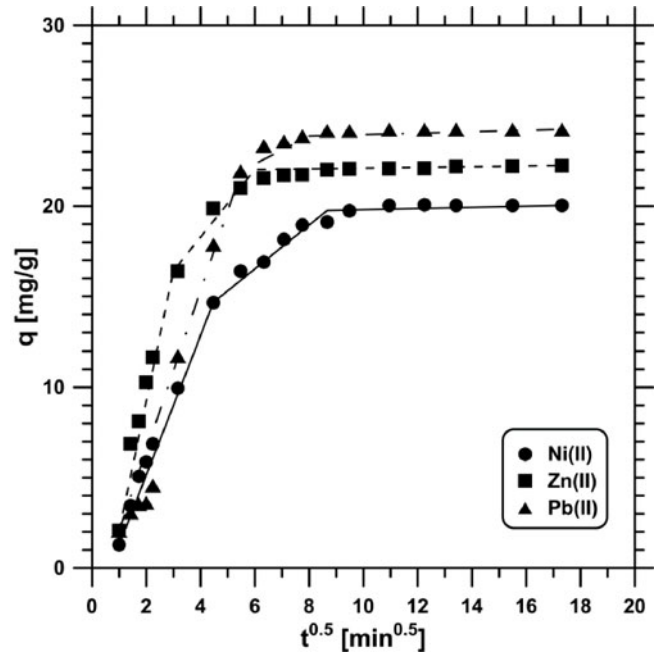
Despite the good results for the pseudo-second-order model this model does not provide information about diffusion-limited mechanism. Therefore, in order to examine the diffusion process another kinetic model was used. To explain the adsorption mechanism, the rate controlling step in the adsorption process is essential to calculate. For a solid-liquid adsorption process, the solute transfer is characterized by external or internal mass transfer¹⁸. The mechanism for removal of metal ions from the aqueous solution by the adsorbent was described by the Weber and Morris intra-particle diffusion model, which is presented as:

$$q_t = k_p \cdot t^{1/2} + C \quad (6)$$

where q_t (mg/g) is the amount of metal ions adsorbed per unit mass of the adsorbent at time t (min), C (mg/g) is a constant, and k_p (mg/g · min^{1/2}) is the intra-particle diffusion rate constant.

According to this model, if the adsorption process is controlled by the intra-particle diffusion then the plot of q_t versus $t^{1/2}$ should give a straight line which goes through the origin. If the data exhibit multi-linear plots, then two or more steps influence the adsorption process¹⁹. The intra-particle diffusion data for Pb(II), Ni(II) and Zn(II) is shown in Figure 11.

It can be seen from analyses of the Figure 11 that relationship between q and $t^{1/2}$ is not linear over the whole time range and this indicates that there are several processes affecting the adsorption. In this case, expe-

**Figure 11.** Presentation of the Intra-particle diffusion model according to Eq. (11)

perimental points for each heavy metal ions are divided into three stages.

The first, sharper portion may be considered as an external surface adsorption or faster adsorption stage. The second portion corresponds to the gradual adsorption stage, where intra-particle diffusion process was rate-limiting step. The third portion is attributed to the final equilibrium stage, where intra-particle diffusion starts to slow down due to the extremely low adsorbate concentrations in the solution.

The intra-particle diffusion constants (k_{p1} , k_{p2} , k_{p3}) were calculated from the slope q_t versus $t^{1/2}$ plot. Obtained intra-particle diffusion constants for all three stages were presented in Table 4. The results suggest that the heavy metal ions diffuse quickly among the particles at the beginning of the adsorption process, then intra-particle diffusion slow down and stabilizes.

Table 4. Comparison of the regressed diffusion parameters in each stage

Stage	Ni	Pb	Zn
k_{p1}	3.73	5.25	4.91
R_1	0.99	0.98	0.94
k_{p2}	1.27	0.37	0.32
R_2	0.98	0.99	0.82
k_{p3}	0.039	0.008	0.025
R_3	0.58	0.63	0.93
N	3	3	3

In the intermediate stage (second portion) where the adsorption is gradual, the process is controlled by intra-particle diffusion. This indicates that intra-particle diffusion is involved in Pb(II), Ni(II) and Zn(II) adsorption onto calcium alginate, but it was not the sole rate-controlling-step.

CONCLUSIONS

In this study, the calcium alginate was successfully applied for the removal of metal ions such as Ni(II), Pb(II) and Zn(II) from the aqueous solutions. The process of heavy metal ions adsorption was found to be dependent on experimental conditions, particularly the solution pH, adsorbent dose, contact time and initial metal ion concentration.

The removal of metal ions was increased with increase in solution pH. The uptake capacity was relatively constant for Pb(II) at pH = 3 to pH = 6, but for Ni(II) and Zn(II) still increased from pH = 3 to pH = 5. The maximum removal of investigated heavy metal ions was obtained at pH = 5.

The removal of metal ions by calcium alginate was found to be increased with increase in adsorbent dose. The maximum removal of metal ions was observed at adsorbent dose of 8 g/100 mL.

With regard to contact time, the removal of metal ions was increased up to the contact time of 90 minutes and remained almost constant for further time. This indicate that after this time the equilibrium state was obtained.

The sorption equilibrium was modeled using two- (Langmuir, Freundlich), and three- (Langmuir-Freundlich, Koble-Corrigan and Redlich-Peterson) parameter of isotherm equations. For two-parameter models the best fittings for Ni(II) and Zn(II) were obtained using Freundlich equation, while for Pb(II) using Langmuir equation. The best fitting for three- parameters models was obtained using Koble-Corrigan isotherm for Ni(II) sorption process, while for Pb(II) and Zn(II) the best fittings were obtained using Redlich-Peterson isotherm.

Kinetics data from Ni(II), Pb(II) and Zn(II) sorption on wet alginate beads were better described by the pseudo-second order equation, than by first-order one. It suggest that the chemical adsorption mechanism takes place.

Diffusion studies show that biosorption process was not only controlled by intra-particle diffusion, but there are several processes affecting the adsorption.

In summary, the results of this study suggest that calcium alginate beads can be used as an effective adsorbent to removal of metal ions from the wastewaters.

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