Equilibrium and kinetic studies of Pb (II) biosorption from aqueous solution using shrimp peel

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ABSTRACT: Heavy metals are non-degradable in the environment and can be harmful to a variety of living species. So, the removal of these metals from waters and wastewaters is important in terms of protection of public health and environment. Biosorption is one of methods for removing these metals. In this study, biosorption of lead ion from the aqueous solution using shrimp peel species of Vanami has been investigated. For this purpose, effect of effective parameters such as pH, concentration of adsorbent, contact time for adsorbent and solution, initial concentration of metal ion and agitation speed on the adsorption process were studied. The best efficiency for adsorption of Pb ions by shrimp peel is determined 98 % obtaining at temperature, pH, contact time, the concentration of adsorbent, initial concentration of Pb ions and agitation speed 30°C, 6, 130 min, 5 g/L, 60 mg/L and 200 rpm, respectively. To study the equilibrium behavior of adsorbents, several equations such as Longmuir, Freundlich, Temkin, were used. Also, pseudo-first order, pseudo-second order kinematic models, particle penetration, liquid film penetration, Elovich and Ritchie second-order models were used for consideration of kinetic behaviors of experimental data.

Key words: Biosorption, Equilibrium study, Kinetic study, Isotherm, Lead ions

INTRODUCTION

Heavy metals are non-degradable in the environment and can be harmful to a variety of living species. For that reason, the removal of these metals from waters and wastewaters is important in terms of protection of public health and environment (Ünlü and Ersoz, 2006; Bailey et al., 1999; Li et al., 2007).

The major sources of heavy metals (Zn, Cu, Cr, Pb, …) and cyanide pollutants which contribute greatly to the pollution load of the receiving water bodies and therefore increase the environmental risks. The undesirable effects of these hazardous chemicals can be avoided by treatment of their wastewater prior to discharge (Srivastava et al., 2006). Lead (Pb) is one of the major environmental pollutants because of its presence in automobile fuel and subsequent emission into the atmosphere in the exhaust gases (Özcan et al., 2005). Lead (pb), one of the three most toxic heavy metals, has long-term potential negative impacts on anemia, encephalopathy, hepatitis and nephritic syndrome (Cloquet et al., 2006). Lead (II) ions have been associated with death and disease in humans, birds, and animals (Stephen et al., 2005; Tunali et al., 2006). The lead (II) ions concentrations were approximately the range of 200–500 mg dm⁻³ in industrial wastewaters, according to water quality standards, this value is very high and must be reduced to a value of 0.10–0.05 mg dm⁻³ (Stephen et al., 2005).

The heavy metal levels in wastewater, drinking water, and water used for agriculture should be decreased to the maximum permissible concentration. Several methods have been used over the years on the elimination of these metal ions present in industrial wastewaters and soils. The usual methods for removal of heavy metal ions from aqueous solutions can be ordered as chemical precipitation, ion-exchange, solvent extraction, ultrafiltration, electro dialysis, reverse osmosis, and adsorption (Srivastava et al., 2006; Özcan et al., 2005; Cloquet et al., 2006; Ake et al., 2001; Pamukoglu et al., 2006). However, these methods are either inefficient or expensive when heavy metals exist in low concentrations. Additionally, these methods may also risk the generation of secondary wastes, which are difficult to treat (Cloquet et al., 2006). Consequently, it is urgent to find new technologies or materials for removing heavy metal ions from wastewater. Biosorption utilizes the ability of certain materials to accumulate heavy metals from aqueous solutions by either metabolically mediated or physico-chemical pathways of uptake. The most prominent features of biosorption
are the use of low cost and highly efficient biomass materials to adsorb heavy metals even present at very low concentrations. Various types of biomass, including bacteria, yeast, fungi, and algae, have been investigated with the aim of finding more efficient and cost-effective metal-removal biosorbent (Cloquet et al., 2006; Şölener et al., 2008; Jianlong et al., 2001; Dubey et al., 2005). The majority of adsorption investigations were conducted in the batch mode.

In recent years, low cost biosorptions such as residual biomass of agricultural (Malkoc and Nuhoglu, 2005), wood materials (Hanif et al., 2007), rice straw (Ajmal et al., 2003), orange peel (Li et al., 2008), olive stone (Kula et al., 2008; Fiol et al., 2006), agricultural waste sugar beet pulp (Aksu and İşoğlu, 2005), sunflower wastes (Zhang and Banks, 2006) and marine algae (Kaewsarn, 2002; Kaewsarn and Yu, 2001; Jalali et al., 2002; Herrero et al., 2006) have been used for removal of heavy metals.

The main aim of this research was to determine the potentiality and adsorption capacity of shrimp peel as bio-adsorbent for removal of pb from aqueous solutions. For this purpose, effect of several parameters such as pH, temperature, adsorbent concentration and initial concentration amount of pb in the solution on the adsorption of Lead ions were studied. Also, kinetic and equilibrium behavior of bio-adsorbent were studied.

MATERIALS AND METHODS

Materials
Shrimp peels were prepared from Fisheries Company of Bushehr city (Iran) and after washing and separation of the waste, stored in the plastic pockets at 4 °C. Sodium hydroxide, chloridric acid and lead nitrate were purchased from Merck Company (Germany). To prepare the solutions containing lead, twice distilled water was used in all experiments.

The surface characterization of shrimp peels
200 g of shrimp peel was washed with distilled water and after separating its waste materials, it was dried in oven at 105 °C for 3 h. The dried shrimp peel was powdered by mill (Moulinex model) and was passed through sieve No. 25. The shrimp powder prepared was poured into plastic bags made of polyethylene and was stored at 4 °C in refrigerator. Scanning electron microscopy (SEM) (Model Hitachi JSM-6700F) was also used to study the surface characteristics of adsorbent after and before adsorption. For this purpose, the adsorbent surface was covered with a layer of gold in vacuum and then study the surface area of adsorbent by microscope. The surface of shrimp peel before and after adsorption of Pb ions are shown in Fig. 1. As shown in these images, many cavities with different sizes are seen on the surface of shrimp peel.

Stock solutions
A stock solution of lead (II) ions used in this work was prepared by dissolving of Pb (NO₃)₂ into deionized distilled water. Other concentrations were prepared from stock solution by dilution varied between 10 and 60 mg/L and the solution pH was adjusted to be desired values with 1 mol/L HCl and 1 mol/L NaOH. Fresh dilutions were used for each experiment. All the chemicals used were in the analytical grade.

Experimental procedure
All batch experiments were carried out in an Erlenmeyer flask with 250 mL and 100 mL working volume containing lead solution with different concentrations between 10 to 60 mg/L. The pH of samples was between 2-10 which were adjusted with sodium hydroxide and hydrochloric acid before addition of biosorbent. Biosorbent (1.5 g) was then added to solutions and mixed by magnet stirrer with different speed from 0 to 200 rpm at temperature of 30 °C and different times of 5 to 130 min. After the considered time, the solution was
filtered through whatman filter paper and the biosorbent was separated from solutions. To measure the concentration of Pb (II) ion in solution, the atomic absorption spectrometry (plus Spectr AA-10 Model, Varian Company) was used.

In all experiments, the percent adsorption of pb ion (% R) and adsorption capacity (mg/g) were calculated as follow:

\[
R(\%) = \left( \frac{C_i - C_e}{C_i} \right) \times 100
\]

\[
q_e = \left( \frac{C_i - C_e}{W} \right) \times V
\]

Where \(C_i\), \(C_e\), \(V\), \(M\), \(R\) and \(q_e\) are initial concentration, equilibrium concentration of lead ion (mg/L), the volume of solution (L), the weight of used adsorbent (g), percent of adsorbed ion and adsorption capacity per gram of adsorbent used (mg/g), respectively.

**Adsorption isotherm models**

Adsorption isotherms are indicated relation between adsorbent and solution at equilibrium time (Wang et al., 2007). Three important isotherm models were selected in this study, which are namely the Langmuir, Freundlich and Temkin isotherm models. These models were applied to establish the relationship between the amount of Pb (II) adsorbed onto shrimp peel and its equilibrium concentration in aqueous solution. These models are described as followed:

**Langmuir isotherm**

Langmuir adsorption isotherm is applied to equilibrium adsorption assuming monolayer adsorption onto a surface with a finite number of identical sites and is formulated as below (Li et al., 2007; Febrianto et al., 2009; Sud et al., 2008; Ho et al., 2002; Fourest and Roux, 1992; Lonmuir, 1916; Lonmuir, 1917; Longmuir, 1918).

\[
q_e = \frac{q_{max} K_L C_e}{(1 + K_L C_e)}
\]

This equation is non-linear form of Longmuir isotherm and must be linear as equations (4-7) (Ho, 2006; Ho and Olomaja, 2006):

\[
q_e = q_{max} + \frac{1}{K_L q_{max}} C_e
\]

\[
q_e = K_L q_{max} - \frac{1}{K_L} q_e C_e
\]

\[
q_e = K_L q_{max} C_e
\]

\[
R_L = \frac{1}{1 + K_L C_0}
\]

Where \(C_0\) is equilibrium concentration of the metal (mg/L) and \(q_e\) is the amount of the metal adsorbed (mg) by per unit of the adsorbent (g). \(K_L\) and \(q_{max}\) are the energy of adsorption (L/g) and Langmuir constant relating adsorption capacity (mg/g), respectively. These constants are evaluated from slope and intercept of the linear plots of \(C_e/q_e\) versus \(C_e\), respectively.

Based on the further analysis of Langmuir equation, the dimensionless parameter of the equilibrium or adsorption intensity (\(R_L\)) can be expressed by

\[
R_L = \frac{1}{1 + K_L C_0}
\]

Where \(C_0\) (mg/L) is the initial amount of adsorbate. The \(R_L\) parameter is considered as more reliable indicator of the adsorption. There are four probabilities for the \(R_L\) value: (i) for favorable adsorption, \(0 < R_L < 1\), (ii) for unfavorable adsorption, \(R_L >1\), (iii) for linear adsorption, \(R_L = 1\), and (iv) for irreversible adsorption, \(R_L =0\) (Li et al., 2007).

**Freundlich isotherm**

The adsorption data obtained were then fitted to the Freundlich adsorption isotherm. The Freundlich isotherm is applicable to highly heterogeneous surfaces, and an adsorption isotherm lacking a plateau indicates a multi-layer adsorption. The non-linear form of this equation is as below:

\[
q_e = K_f C_e^{1/n}
\]

This equation is expressed in linear form by the following equation:

\[
L_{nq_e} = L_n K_f + 1/n \ln C_e
\]

Where \(q_e\) is equilibrium adsorption capacity (mg/g), \(C_e\) is the equilibrium concentration of the adsorbate in solution, \(K_f\) and \(n\) are constants related to the adsorption process such as adsorption capacity and intensity respectively. These constants are determined from the intercept and slope of linear plot of \(L_n q_e\) versus \(L_n C_e\), respectively.
Temkin model
Temkin suggested that due to the indirect adsorbate/adsorbent interaction, the heat of adsorption of all the molecules in the layer would decrease linearly with coverage. The linear form of Temkin isotherm can be written as:

$$q_{eq} = B \ln A_+ B \ln C_{eq}$$  \hspace{1cm} (11)

Where $B = RT/b$, $T$ is temperature in Kelvin and $R$ is the universal gas constant. The constant $B$ is related to heat of adsorption, $C_{eq}$ equilibrium concentration of the adsorbate.

Adsorption kinetic models
In an attempt to present the kinetic equation representing adsorption of Pb (II) onto shrimp peel, six kinds of kinetic models were used to test the experimental data. These models are included pseudo-first order, pseudo-second-order equation, the Elovich kinetic, Intraparticle diffusion, liquid film diffusion and Ritchie second order models. These models can be expressed as follows:

Pseudo-first order equation
The pseudo-first order equation is in the following form:

$$\log(q_e - q_t) = \log q_e - (K_1/2.303)t$$  \hspace{1cm} (12)

Where $q_e$, $q$, and $K_1$ are the amount of sorbed lead (II) ions on the biosorbent at the equilibrium (mg/g), the amount of sorbed lead (II) ions on the biosorbent at any time (mg/g), and the rate constant (1/min), respectively. The adsorption rate constant $K_1$, can be determined experimentally by plotting of $\ln(q_e - q_t)$ versus $t$.

Pseudo-second order model
The pseudo-second order model can be expressed as (Ho and McKay, 2000):

$$t/q_t = (1/K_2 q_e^2) + t/q_e$$  \hspace{1cm} (13)

Where $K_2$ (g/mg min) is the rate constant of the pseudo-second order equation, $q_e$ (mg/g) is the maximum adsorption capacity, and $q_t$ (mg/g) is the amount of adsorption at time $t$ (min). The rate of initial adsorption is determined as followed (Ho, 2004; Sarı and Tuzen, 2009):

$$H = Kq_e^2$$  \hspace{1cm} (14)

The amount of $q_e$ and $K_2$ are determined from the intercept and slope of linear plot of $t/q_t$ versus $t$.

The Elovich model
The Elovich equation is of general application to chemisorption kinetics. The equation has been applied satisfactorily to some chemisorption processes and has been found to cover a wide range of slow adsorption rates. The same equation is often valid for systems in which the adsorbing surface is heterogeneous, and is formulated as:

$$\frac{dq}{dt} = \alpha e^{-\beta q}$$  \hspace{1cm} (15)

Integrating this equation for the boundary conditions, gives:

$$q_e = \beta \ln(\alpha \beta + \beta \ln t)$$  \hspace{1cm} (16)

Where $\alpha$ (mg/g min) is the initial adsorption rate and $\beta$ is related to the extent of surface coverage and the activation energy involved in chemisorption (g/mg).

Intraparticle diffusion equation
The intraparticle diffusion model is also presented by the following equation (Weber and Morris, 1962):

$$q_e = K_{int} t^{1/2}$$  \hspace{1cm} (17)

Where $K_{int}$ is the intraparticle diffusion rate constant (mg g$^{-1}$ min$^{-1/2}$). If intraparticle diffusion is involved in the adsorption process, then the plot of square root of time against the uptake ($q_t$) would result in a linear relationship and the intraparticle diffusion would be the controlling step if this line passes through the origin.

Liquid film diffusion model
The liquid film diffusion model is presented by the following equation (Gupta and Bhattacharyya, 2006):

$$\ln(1-F) = K_d t$$  \hspace{1cm} (18)

Where $K_d$ is the external mass transfer coefficient (min$^{-1}$). A linear plot of $\ln(1-F)$ vs $t$, whereby $F=q_t/q_e$, with zero intercept would suggest that the kinetics of the adsorption process is controlled by diffusion through the liquid film surrounding the solid adsorbent.

Ritchie second order model
Kinetic model type of Ritchie second order is as followed (Cheung et al., 2001):
\[
\frac{q_e - q_t}{q_e} = 1 + K_2 t
\]  \hspace{1cm} (19)

Where \( q_t, q_e \) and \( K_2 \) are their usual meanings. The values of \( K_2 \) were calculated from the plots of \( q_e/(q_e - q_t) \) vs. \( t \).

**RESULTS AND DISCUSSION**

**Effect of agitation speed**

Stirring the solution for its turbulence is an important factor on adsorption process and due to the more contact between adsorbent and desired ions (Dotto and Pinto, 2011). In this study, the effect of agitation speed on removal efficiency of lead was studied by varying speed of agitation from 0 to 300 rpm. Effect of mixing rate on the efficiency of adsorption is showed in figure 2. As shown in this figure, the maximum adsorption efficiency was obtained 94.3 % at mixing rate 200 rpm. First the adsorption efficiency increases with increasing agitation speed of 200 rpm and between 200-300 rpm adsorption efficiency decreased and was 93 % which can be for breaking new connections between metal ions and adsorbent at high mixing speed (Argun et al., 2007).

![Figure 2. Effect of mixing rate on the efficiency of lead adsorption (Conditions: Temperature= 30°C, contact time= 80 min, adsorption dose= 3 g/l, initial concentration of lead= 60 mg/L and pH= 6)](image)

**Effect of pH**

One of the more important factors affecting biosorption of metal ions is acidity of solution. This parameter directly related with competition ability of hydrogen ions with metal ions to active sites on the biosorbent surface. The initial pH of aqueous solution is an important parameter in controlling adsorption (Chen et al., 2001). In this study, effect of pH in the range of 2-10 was investigated on the biosorption of lead ions by means of bioadsorbent prepared with shrimp peel which is showed in Fig. 3. According to the figure, there was an increase in biosorption efficiency with increasing pH from 2.0 to 6.0 because the number of active sites on the bioadsorbent increases with increasing pH. As the pH increases the amount of hydrogen ions in the solution are decreased and the amount of hydroxide ions are increased which these ions have oppositely charge with lead ions and if they place on the active sites of adsorbent, they can adsorb lead ions. At pH greater than 6, adsorption efficiency was decreased because hydroxide ions increases in solution and these ions compete with lead ions for being on the active sites of bioadsorbent. Also, at high pH hydroxide ions formed complex with lead ions and due to the deposition of lead ions and thus prevent the formation of these ions on the active sites of adsorbent. The best efficiency of biosorption was determined 94.3 % at pH 6.

![Figure 3. Effect of pH on the efficiency of lead adsorption (Conditions: Temperature= 30°C, contact time= 8 min, adsorption dose= 3 g/l, initial concentration of lead= 60 mg/L and pH= 6)](image)
Effect of initial concentration of lead ions

In batch adsorption processes, the initial metal ion concentration of metal ions in the solution plays a key role as a driving force to overcome the mass transfer resistance between the solution and solid phases (Rafatullah et al., 2009). Effect of initial concentration of lead on adsorption percent and adsorption capacity of gram dry adsorbent in pH of 6, amount of biosorbent of 5 g/L, Temperature of 30 °C, mixing rate of 200 rpm and different times of 0-130 min are shown in Figures 4. As shown in this figure, adsorption efficiency increased by increasing initial ion concentration. At the beginning of the process, lead ions were adsorbed more quickly was the results of more active sites of adsorbent. Over time, the active sites of adsorbent will occupy by lead ions and adsorption efficiency will decrease that these results are clear in the figure.

Effect of adsorbent concentration

The effect of adsorbent concentration was investigated by adding five doses (1, 2, 3, 4 and 5 g/lit) for each set of experiments at 30 °C and pH 6. Results are shown in Figures. 5. The percent removal of lead was found to increase with an increase in the mass of shrimp peel. According to the Fig. 5, the removal efficiency of lead ions increased by increasing the amount of adsorbent and the maximum rate of ion removal was obtained 70 % for 1 g/l of adsorbent after 130 min. A highest lead removal was 98 % at the adsorbent dose of 5 g/l. By increasing the concentration of adsorbent, the number of active sites for adsorption of lead ions increases.

Adsorption isotherms

Adsorption isotherms describe the equilibrium relationships between adsorbent and adsorbate. Three adsorption isotherms were used to fit the equilibrium data namely, Langmuir, Freundlich and Temkin. The equilibrium data obtained for the adsorption of Pb(II) onto shrimp peel were tabulated in Table 1 for all equilibrium isotherms. Linear relationship between 1/qe versus 1/Ce in Longmuir isotherm model for adsorption of lead ions by means of shrimp peel is shown in Fig. 6. K_L and q_max can be calculated from this figure. Equilibrium constant (K_L) and maximum adsorption capacity (q_max) for Longmuir model are determined 0.4587 L/g and 24.331 mg/g, respectively. Correlation coefficient (R^2) for the adsorption of Pb ions at 30 °C determined
0.6094. $R_L$ value for the ions adsorption of Lead, was determined 0.035 which states that the lead ions adsorption by the shrimp peel is desirable ($0<R_L<1$).

Freundlich isotherm model is another empirical relationship, can be used as a criterion for describing the equilibrium behavior of adsorbent. Fig. 7 shows the relation between $q_e$ versus $\ln C_e$ for this model. According to the Fig. 7, values of $n$ and $K_f$ determine from slope and intercept, respectively which for adsorption of Pb (II) ions using shrimp peel are obtained 2.3651 and 7.8256. The value of $n$ indicated the adsorption process was desirable and physical (Murugesan et al., 2011). Also, correlation coefficient ($R^2$) for the adsorption of lead ions determined 0.6391.

Temkin isotherm model was another model which used in this study. The relation linear between $q_e$ and $\ln C_e$ for this model is shown in Fig. 8. Constants of Temkin model are $B$ and $A_T$ which were determined from slope and intercept of this figure and calculated 8.9644 and 1.316, respectively. Correlation coefficient ($R^2$) for this model was also determined 0.485 which showed this model had less ability to describe the behavior of adsorption process than other models.

<table>
<thead>
<tr>
<th>Isotherm</th>
<th>Parameters</th>
<th>Value</th>
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<td>$K_L$</td>
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<td>$A_T$</td>
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Table 1. Langmuir, Freundlich, Temkin isotherm parameters and correlation coefficients for the adsorption of lead onto shrimp peel at different adsorbent doses.

![Figure 6. Langmuir adsorption isotherm plots for the adsorption of metal ion](image)

![Figure 7. Freundlich adsorption isotherm plots for the adsorption of metal ion](image)
Adsorption kinetics

Kinetic studies are significant for any kind of biosorption processes. Adsorption kinetics not only describes the adsorption mechanism of metals on adsorbents but also describe the metal adsorption rate which controls the contact time of metals at the solid-liquid interface (Wang et al., 2007). The adsorption mechanism depends on the physical and chemical characteristics of adsorbent and adsorbate, pH of medium, temperature, contact time and aids and mass transport process. Kinetics studies were conducted at non adjusted pH condition with four initial copper concentrations. The data were fitted with different kinetics equation namely pseudo first order, pseudo second order, Elovich and Reichenberg kinetics models. Parameters and constants of pseudo-first order, pseudo-second order and Elovich kinetic models for different concentration of Pb ions are reported in Table 2. The values obtained of $R^2$ for different initial concentrations of lead indicate that the pseudo-first-order model can be convenient and powerful model to describe the kinetic behaviour of lead adsorption onto shrimp peel. The linear relation among $\log (q_e - q_t)$ and $t$ for different concentration of ion concentrations are shown in Fig. 10. Figure 11 also show the linear relation between $t/q_t$ and $t$ for different concentration.

According to the obtained results and $R^2$ for Elovich model, it can be said that this model is capable of describing the kinetic behavior of bioadsorbent (shrimp peel). Figure 13 showed linear relation between $q_t$ and $\ln t$ for concentrations of lead that have more $R^2$. Figure 14 also showed linear relation between $\ln (1-F)$ and $t$ for concentrations of lead.

Constants of liquid film diffusion, particle diffusion and Ritchie second order models are reported in Table 2. According to the reported data and $R^2$, film diffusion and Ritchie second order models provided a good correlation to describe the biosorption of Pb (II) onto shrimp peel in contrast to intra particle diffusion model.
Figure 11. Pseudo-second order plot for adsorption of Pb (II) ion (T=30 °C, PH=9, dose=5gr/L, agitation rate=200rpm)

Figure 12. Linear relation between q_t and Ln t of Alovich model for adsorption of Pb (II) ion from aqueous solution. Temperature, pH, agitation rate and concentration of biosorption in all experiments were 30 °C, 9, 200 rpm and 5 g/l, respectively.

Figure 13. Linear relation between q_t and t^{0.5} of intraparticle diffusion model at different concentrations. In all experiments, temperature, pH, agitation rate and initial concentration of pb were 30 °C, 9, 200 rpm and 5 g/l, respectively.
Figure 14. Linear relation between Ln (1-F) and time of liquid diffusion model. In all experiments, temperature, pH, agitation rate and initial concentration of Pb (II) were 30 °C, 9, 200 rpm and 5 g/l, respectively.

Table 2. Kinetic parameters obtained from pseudo-first-order, pseudo-second-order, Elovich, intraparticle diffusion, liquid film diffusion and Ritchie second order models for Pb (II) biosorption onto shrimp peel at different adsorbate concentration

<table>
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<th>Adsorbate concentration (mg/L)</th>
<th>Kinetic Model</th>
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<td>15.015</td>
<td>11.682</td>
<td>9.68</td>
<td>11.99</td>
</tr>
<tr>
<td></td>
<td>( R^2 )</td>
<td>0.9386</td>
<td>0.9655</td>
<td>0.8119</td>
<td>0.8019</td>
<td>0.8606</td>
<td>0.9414</td>
</tr>
<tr>
<td></td>
<td>intraparticle diffusion model</td>
<td>0.0045</td>
<td>0.0172</td>
<td>0.0205</td>
<td>0.0259</td>
<td>0.0322</td>
<td>0.0267</td>
</tr>
<tr>
<td></td>
<td>( R^2 )</td>
<td>0.7942</td>
<td>0.8599</td>
<td>0.6385</td>
<td>0.6105</td>
<td>0.6929</td>
<td>0.8014</td>
</tr>
<tr>
<td></td>
<td>liquid film diffusion model</td>
<td>0.0562</td>
<td>0.0484</td>
<td>0.0362</td>
<td>0.104</td>
<td>0.0547</td>
<td>0.0399</td>
</tr>
<tr>
<td></td>
<td>( R^2 )</td>
<td>0.9919</td>
<td>0.9931</td>
<td>0.794</td>
<td>0.9802</td>
<td>0.9642</td>
<td>0.9802</td>
</tr>
<tr>
<td></td>
<td>Ritchie second order</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>( K_2 )</td>
<td>0.5337</td>
<td>1.1231</td>
<td>0.5732</td>
<td>2.6728</td>
<td>2.5031</td>
<td>1.2506</td>
</tr>
<tr>
<td></td>
<td>( R^2 )</td>
<td>0.9574</td>
<td>0.87722</td>
<td>0.9834</td>
<td>0.9225</td>
<td>0.9112</td>
<td>0.94</td>
</tr>
</tbody>
</table>

It is clear from these results that the \( R^2 \) values are high. In addition, the theoretical \( q_{e,\text{cal}} \) values were closer to the experimental \( q_{e,\text{exp}} \) values (Table 2). In the view of these results, it can be said that the pseudo-second-order kinetic model provided a good correlation for the biosorption of Pb (II) onto shrimp peel in contrast to another models.

**CONCLUSION**

In the present work, bio-adsorbent prepared from shrimp peel species *Vanami* was used to adsorb and remove the Pb (II) ions from aqueous solutions. To do so, effective parameters on adsorption were investigated and it was found that the adsorption depends strongly on the initial pH and amount of adsorption is significantly increased by increasing pH from 2 to 9. The maximum amount of adsorption was obtained 98 % by 5 g/l of bioadsorbent. Additionally, several kinetic and equilibrium models were used for investigating the behavior of the process. Due to the ability of the shrimp peel to remove lead ions from aqueous solutions and also due to features such as being biocompatible, biodegradable, renewable and, etc. can be used from this material (shrimp peel) as bioadsorbent to remove the heavy metals from wastewater and aqueous solutions.
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References:


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