Equilibrium Study of Adsorption of Cobalt ions from Wastewater using Saudi Roasted Date Pits

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Abstract: Date pits from Al-Qassim region, Saudi Arabia were collected, roasted and characterized for the adsorption of cobalt ions from wastewater. Also, the effect of pH of solution and different temperatures on the adsorption of cobalt ions by roasted date pits were studied. The adsorption capacity of roasted date pits decreased with an increase in the temperature of adsorption systems. The Langmuir, Freundlich, Redlich-Peterson and Thoth models were applied. It was found that, the Langmuir and Redlich-Peterson models explained the experimental data very well at different temperatures. The mean maximum adsorption capacity of roasted date pits for Co ions was 6.28 mg g⁻¹ at 20°C and 4.11 mg g⁻¹ at 80°C. Overall, the adsorption phenomena of Co ions is an exothermic and non-spontaneous process.

Key words: Cobalt ions, Saudi roasted date pits, adsorption, wastewater, Langmuir, Freundlich, Redlich-Peterson, Thoth, exothermic process

INTRODUCTION

Cobalt (Co) is a heavy metal and belongs to a special group of trace elements which has been shown to create definite health hazards if taken by plants and found above the recommended permissible limits in wastewater. Its main contaminant sources in wastewater are electroplating, catalytic processes, Ceramic and alloys industries (Brezonik, 1974; Patterson and Passino, 1987; Emsley, 1992). Many serious human health problems such as heart failure, thyroid and liver damaging and asthma-like allergy are associated with it if the concentration in the wastewater is above the permissible limits, whereas, the permissible level in irrigation water is 0.05 mg L⁻¹ and in water for livestock is 1 mg L⁻¹ (Demirbas, 2003).

Currently, different treatment techniques such as membrane process, chemical precipitation, ion exchange process and adsorption are in use for the removal of some heavy metal ions like Cobalt from wastewater (Patterson, 1985). Majority of these techniques are expensive especially in term of the capital costs (Demirbas, 2003). Therefore, using roasted date pits powder as a low cost adsorbent in the adsorption process for the removal of cobalt ions from wastewater is good technique.

Previously much work has been accomplished on the adsorption of heavy metal ions by date pits and activated carbon derived from date pits (El-Hendawy, 2009; Awwad et al., 2008; Al-Multaseb et al., 2008; Abdulkarim and Al-Rub, 2004; Banat et al., 2002, 2003). El-Hendawy (2009) investigated the adsorption of lead and cadmium ions from wastewater on activated carbon from date pits in Egypt. He concluded that the adsorption of lead and cadmium ions from wastewater was dependent on pH of the solution and the modification of the surface chemistry of the adsorbent. The date pits from Egypt were activated by steam and by ferric chloride (Awwad et al., 2008). The carbon dosage, pH, initial concentration and
temperature affected the adsorption capacity of the activated carbon derived from date pits for various heavy metals such as Pb⁺, Cd²⁺, Fe³⁺ and Sr²⁺. Also, it was found that the adsorption is affected by the presence of some anions, NO₃⁻, CO₃²⁻, SO₄²⁻ and EDTA in solution due to antagonistic phenomenon.

A comparison study was carried between activated carbon derived from date pits and the commercial activated carbon on the adsorption of aluminum ion from wastewater (Al-Muhtaseb et al., 2008). They concluded that adsorption of aluminum ion at low concentration and low pH (pH = 4) was better by date pits activated carbon than the commercial activated carbon. The adsorption of lead ions from wastewater on date pits activated carbon and modified activated carbon from date pits was studied by Abdulkarim and Al-Rub (2004). They did not observe any increase in the adsorption of lead ions by the modified activated carbon. However, the adsorption of lead ions increased by increasing the pH and the initial lead concentrations. The kinetic study showed that the adsorption of lead ions on these adsorbents followed the pseudo-second order equation. Also, from equilibrium studies, they found that, Langmuir and Freundlich models fitted the experimental data well.

The cadmium (Cd) ion adsorption from wastewater on date pits and activated carbon derived from date pits was investigated by Banat et al. (2003). They studied the effect of pH, initial concentration and temperature on the adsorption of cadmium on the date pits. After kinetic studied, they concluded that the experimental data can be described by the pseudo-second order model. Banat et al. (2002) investigated the adsorption of copper and zinc ions from wastewater on date pits and activated carbon derived from date pits. They found that adsorption of copper and zinc ions on date pits was higher than on activated carbon derived from date pits. They also reported that the adsorption of these ions (Cu and Zn) increased with an increase of pH but decreased by increasing the temperature.

The literature survey indicated that no research is carried on Saudi roasted date pits for the adsorption of cobalt ions from wastewater. Therefore, it is imperative to investigate the adsorption of cobalt ions from wastewater using Saudi roasted date pits at different temperatures and pH of solution and also to test the validity of various isotherm models.

MATERIALS AND METHODS

Materials

Saudi roasted date pits from Qassim Region, Saudi Arabia were used as adsorbent. The date pits were roasted at 130°C for 4 h and then ground into powder by Willy Mill.

The adsorbate was cobalt ions solution prepared from cobalt (II) nitrate purified LR (Co(NO₃)₂) and supplied by VWR International SAS 201, Rue Camot- F- 94126, Sous Bois.

Physical and Chemical Characteristics of Saudi Roasted Date Pits

The chemical composition of Saudi roasted date pits was done by XRF (Table 1). The physical parameters such as the total surface area, pore diameter and pore volume of

<table>
<thead>
<tr>
<th>Elements</th>
<th>Composition (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ca</td>
<td>28.02</td>
</tr>
<tr>
<td>K</td>
<td>56.77</td>
</tr>
<tr>
<td>S</td>
<td>11.52</td>
</tr>
<tr>
<td>Trace of other elements (Mg, Ti, Mn, etc.)</td>
<td>3.69</td>
</tr>
</tbody>
</table>

Table 1: Some selected chemical elements of Saudi roasted date pits by XRF
Table 2: Surface area and pore characteristics of Saudi roasted date pits

<table>
<thead>
<tr>
<th>Element</th>
<th>Saudi roasted date pits</th>
</tr>
</thead>
<tbody>
<tr>
<td>BHJ adsorption cumulative surface area of pores between 17,000 Å and 3000,000 Å diameter (nm² g⁻¹)</td>
<td>0.151</td>
</tr>
<tr>
<td>BHJ adsorption average pore diameter (Å)</td>
<td>349.165</td>
</tr>
<tr>
<td>BHJ adsorption cumulative volume of pores between 17,000 Å and 3000,000 Å diameter (cm³ g⁻¹)</td>
<td>0.001320</td>
</tr>
</tbody>
</table>

Table 3: Some main functional groups in Saudi roasted date pits

<table>
<thead>
<tr>
<th>Observed band (cm⁻¹)</th>
<th>Functional group</th>
<th>Contributors</th>
</tr>
</thead>
<tbody>
<tr>
<td>2996</td>
<td>C-H</td>
<td>Alkane</td>
</tr>
<tr>
<td>1743</td>
<td>C=O</td>
<td>Aldehyde, ketone, esters</td>
</tr>
<tr>
<td>1130</td>
<td>C-O</td>
<td>Alcohol, ester, amide</td>
</tr>
</tbody>
</table>

Fig. 1: FT-IR spectra of Saudi roasted date pits

Saudi roasted date pits were determined by the surface area analyzer (Table 2). The FT-IR of Saudi date pits is shown in Fig. 1 and Table 3.

Equilibrium Experiments

Equilibrium isotherms of Saudi roasted date pits were determined by placing a constant mass (1 g) of roasted date pits in 50 mL cobalt ions solution in 250 mL capacity conical flasks on a thermostat-controlled shaker. For each isotherm run, the cobalt ion solution concentrations ranged from 50-900 mg L⁻¹. The particle size of the adsorbent was 0.25 mm for the isotherm experiment and the solution temperature ranged between 20 to 80°C. A preliminary test run for the equilibrium isotherm experiment showed that the adsorption process reached state of equilibrium after 40 min. However, the actual equilibrium experiments were run for 90 min to ensure that the adsorption process achieved the state of equilibrium. After that, the samples were filtered using filter papers, then diluted and the absorbance was measured by atomic absorption spectroscopy. Later on, the absorbance of samples was converted to concentrations using the calibration curve of cobalt ions already stored in the atomic absorption spectroscopy. The amount of cobalt ions adsorption on the roasted date pits was calculated from the mass balance equation on the batch reactor as follows:

\[
q_e = \frac{V(C_i - C_f)}{M} \tag{1}
\]

3
where, \( M \) is Saudi roasted date pits mass in g, \( V \) is volume of the solution in liter, \( q_e \) is the amount of adsorption mg g\(^{-1}\), \( C_i \) is the initial solution concentration of cobalt ions, mg L\(^{-1}\) and \( C_e \) is the concentration of the cobalt ions at equilibrium, mg L\(^{-1}\). The amount of cobalt ions adsorbed on Saudi roasted date pits versus the cobalt ions concentration was plotted to obtain the equilibrium adsorption isotherm curves.

**RESULTS AND DISCUSSION**

**Equilibrium Time for Co ion Adsorption**

The time required for the state of equilibrium for the adsorption of cobalt ions on Saudi roasted date pits was determined (Fig. 2). It was observed that the adsorption process attained the state of equilibrium in about 40 min time period, but the experiment was run for 90 min to ensure that the adsorption process reached to a complete state of equilibrium.

**Effect of pH on Co ion Adsorption**

The effect of changing pH of the adsorption process on the adsorption of cobalt ions on roasted date pits was studied (Fig. 3). The pH of the system ranged from 1 to 7 which was adjusted by NaOH (0.25 M) to increase the pH and with HCl (0.25 M) to decrease the pH. The amount of Co ion adsorption was low at low pH (pH = 2) and showed increases with pH ranging between 2 to 5. Above pH 5, the increase in the rate of adsorption was slow. This

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Fig. 2: Equilibrium time for adsorption of cobalt ions on Saudi roasted date pits

Fig. 3: Effect of pH on adsorption of cobalt ions on Saudi roasted date pits
change in metal ion adsorption behavior could be attributed to the change in the charge on the functional groups. Because, the Saudi roasted date pits contain many chemical functional groups (Table 3) such as carboxylic groups. The FT-IR spectrum for Saudi roasted date pits agree with the results of other researchers (El-Hendawy, 2006; Bouchelta et al., 2008). As such, the pH of solution affects the charge on the functional groups. The functional groups such as carboxylate are protonated at low pH and become repulsive towards metal ions (Banat et al., 2003). As the pH increased, deprotonation of the functional groups might have occurred and become available for metal ion binding. The metal ions has attraction force with the negative charge on the functional groups of the date pits, such as carboxylate at alkaline solution when the pH of solution was high.

**Effect of Temperature on Adsorption**

The adsorption capacity of Saudi roasted date pits decreased with increasing temperature (Fig. 4) thus, indicating that the adsorption of the cobalt ions on roasted date pits is an exothermic process. Therefore, increasing the temperature of the system for the adsorption of cobalt ions by the roasted date pits was unfavorable. Similar views were reported by Banat et al. (2002, 2003).

**Analysis of Equilibrium Experimental Results**

Four equilibrium isotherm models namely Langmuir, Freundlich, Redlich-Peterson isotherm and Toth models were used. The equilibrium constant parameters were obtained by fitting the equilibrium isotherm models with the equilibrium experimental data by using Nonlinear regression method (i.e., finfunsearch function from MATLAB). These equilibrium parameters can be used for modeling the adsorption of cobalt ions by roasted date pits in a batch and fixed bed adsorbers.

**Langmuir Isotherm Mode**

The Langmuir isotherm model assumes that a monolayer of cobalt ions is adsorbed on the roasted date pits particle and is also used to estimate the maximum adsorption capacity (Mckay, 1996). The Langmuir isotherm equation is as follows:

\[
q_e = \frac{K q_m C_e}{1 + b C_e}
\]

(2)

Fig. 4: Equilibrium isotherm for the adsorption of cobalt ions on roasted date pits at different temperatures
The equilibrium parameters, $K$ and $b$, can be determined by using the non-linear regression method with Eq. 2.

Data in Fig. 5-8 show the non-linear relationship between $Ce$ and $q_e$ at different temperatures (i.e. $T= 20, 40, 60, 80^\circ C$). The equilibrium constants $K$ and $b$ were estimated by nonlinear regression method (Table 4). As shown in Fig. 5-8, the Langmuir model fits the experimental data apparently very well. The dimensionless equilibrium parameter, $R$, was calculated to determine if the adsorption process of cobalt ions by the Saudi roasted date pits is favorable or unfavorable by using the following equation (El-Geundi et al., 2005).

$$R = \frac{1}{1+bc_0}$$  \hspace{1cm} (3)

where, $b$ is the Langmuir constant and $c_0$ is the initial concentration of cobalt ions. The dimensionless equilibrium parameter values for cobalt ions adsorbed on the roasted date pits.

**Fig. 5:** Comparison between the experimental data and calculated data from isotherm models for adsorption of cobalt ions on Saudi roasted date pits at 20°C

**Fig. 6:** Comparison between the experimental data and calculated data from isotherm models for adsorption of cobalt ions on Saudi roasted date pits at 40°C
were determined (Table 4). The values of the dimensionless equilibrium parameters were between $0 < R < 1$. This range indicated that the adsorption process is favorable (El-Geundi et al., 2005). Therefore, it was noticed that the adsorption process of cobalt ions on the roasted date pits is favorable.

**Freundlich Isotherm Model**

The Freundlich isotherm model was utilized to describe equilibrium adsorption experimental data for heterogeneous surface. The Freundlich model is as follows:
Table 5: Freundlich equilibrium parameters for the cobalt ions adsorption of roasted date pits at different temperatures

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>K_f (L g⁻¹)</th>
<th>n (-)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>0.0273</td>
<td>3.4019</td>
</tr>
<tr>
<td>40</td>
<td>0.2001</td>
<td>1.9680</td>
</tr>
<tr>
<td>60</td>
<td>0.1238</td>
<td>1.7857</td>
</tr>
<tr>
<td>80</td>
<td>0.0735</td>
<td>1.6250</td>
</tr>
</tbody>
</table>

\[ q_e = K_f C_e^\frac{1}{n} \]  
(4)

The equilibrium parameters, \( K_f \) and \( n \), can be calculated by using the non-linear regression method with Eq. 4. The adsorption of cobalt ions on the Saudi roasted date pits is favorable when the values of \( n \) are greater than one (El-Geundi, 1990). Figures 5-8 show the non-linear relationship between \( C_e \) and \( q_e \) at different temperatures i.e., 20, 40, 60 and 80°C. The equilibrium constants were estimated by nonlinear regression method (Table 5). As shown in Fig. 5-8, the Freundlich model also correlates the experimental data well.

Redlich-Peterson Isotherm Model

The Redlich-Peterson Model overcomes one of the disadvantages of the Freundlich Model i.e., it does not reduce to Henry’s law at low concentrations. The Redlich-Peterson model also reduces to Langmuir equation when \( \beta = 1 \). Since, the Redlich-Peterson model has a heterogeneity parameter (\( \beta \)), hence, it is used to describe the equilibrium data on heterogeneous surface (Mckay, 1996). The Redlich-Peterson model is written in the following form:

\[ q_e = \frac{K_a C_e}{1 + a_0 C_e^\beta} \]  
(5)

where, \( 0 \leq \beta \leq 1.0 \)

Using the non-linear regression method of Eq. 5, the equilibrium constants, \( K_a \), \( a_0 \) and \( \beta \) can be determined. Figures 5-8 show the relationship between \( q_e \) and \( C_e \) for different temperature i.e., \( T = 20, 40, 60 \) and 80°C. The equilibrium constants were estimated by nonlinear regression method (Table 6). The consistency of the experimental data with the nonlinear regression showed that the Redlich-Peterson isotherm model is an applicable model to fit the experimental data.

Toth Isotherm Model

The fourth model used was Toth model. The Toth model can be written as follows (Unaobonah et al., 2007):

\[ q_e = \frac{K_t C_e}{(1 + (b C_e)^t)} \]  
(6)

The Toth parameters \( K_t \), \( b \) and \( t \) were obtained using the non-linear regression technique of equation 6.

Figures 5-8 show the relationship between \( q_e \) and \( C_e \) for different temperatures i.e., \( T = 20, 40, 60 \) and 80°C. The equilibrium parameters \( K_t \), \( b \) and \( t \) were calculated by non-linear regression technique (Table 7). As shown in Fig. 5-8, the Toth equation fits the data well.
Table 6: Redlich-Peterson equilibrium parameters for the adsorption of cobalt ions on Saudi roasted date pits at different temperatures

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>K_p (L g⁻¹)</th>
<th>a_d (L mg⁻¹)</th>
<th>b_t (L mg⁻¹)</th>
<th>β (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>0.0223</td>
<td>0.0153</td>
<td>0.9795</td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>0.0289</td>
<td>0.0060</td>
<td>0.9306</td>
<td></td>
</tr>
<tr>
<td>60</td>
<td>0.0227</td>
<td>0.0086</td>
<td>0.8533</td>
<td></td>
</tr>
<tr>
<td>80</td>
<td>0.0163</td>
<td>0.0122</td>
<td>0.7568</td>
<td></td>
</tr>
</tbody>
</table>

Table 7: Toth equilibrium parameters for the adsorption of cobalt ions by Saudi roasted date pits at different temperatures

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>K_p (L g⁻¹)</th>
<th>b_t (L mg⁻¹)</th>
<th>t (-)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>0.4296</td>
<td>0.0417</td>
<td>0.4285</td>
</tr>
<tr>
<td>40</td>
<td>0.2987</td>
<td>0.0063</td>
<td>0.2444</td>
</tr>
<tr>
<td>60</td>
<td>0.2886</td>
<td>0.0084</td>
<td>0.2443</td>
</tr>
<tr>
<td>80</td>
<td>0.2989</td>
<td>0.0114</td>
<td>0.2446</td>
</tr>
</tbody>
</table>

Table 8: Thermodynamic parameters for the adsorption of cobalt ions on roasted date pits

<table>
<thead>
<tr>
<th>T (K)</th>
<th>K_p</th>
<th>1/T (1/K)</th>
<th>ln K_p</th>
<th>ΔH (KJ/mol)</th>
<th>ΔS (KJ/mol·K)</th>
<th>ΔG (KJ/mol)</th>
</tr>
</thead>
<tbody>
<tr>
<td>293</td>
<td>0.16392</td>
<td>0.003413</td>
<td>-1.80838</td>
<td>-6.714</td>
<td>-0.03795</td>
<td>4.4052</td>
</tr>
<tr>
<td>313</td>
<td>0.13498</td>
<td>0.003195</td>
<td>-2.00263</td>
<td>-6.714</td>
<td>-0.03811</td>
<td>5.2114</td>
</tr>
<tr>
<td>333</td>
<td>0.12</td>
<td>0.003003</td>
<td>-2.12026</td>
<td>-6.714</td>
<td>-0.03779</td>
<td>5.870</td>
</tr>
<tr>
<td>353</td>
<td>0.10129</td>
<td>0.002833</td>
<td>-2.28777</td>
<td>-6.714</td>
<td>-0.03806</td>
<td>6.720</td>
</tr>
</tbody>
</table>

Fig. 9: Relationship between ln K_p vs. 1/T

**Estimation of Thermodynamic Parameters**

The enthalpy change (ΔH), Gibbs free energy change (ΔG) and entropy change (ΔS) were calculated as follows.

The enthalpy change (ΔH) was calculated using the following equation (Ruixia et al., 2004).

\[
\ln K_p = \ln K_{p0} + \frac{-\Delta H}{RT}
\]  

A plot of ln K_p versus [1/T] gives the enthalpy change (ΔH) for the adsorption process (Fig. 9). The enthalpy change (ΔH) was obtained from the slope of the linear form as shown in Fig. 9 and Table 8.

The standard Gibbs free energy change (ΔG) was calculated using following Gibbs equation (Ruixia et al., 2004).

\[
\Delta G = -RT\ln K_p
\]
where, \( R \) is the gas constant, \( T \) is the absolute temperature and \( K_d \) is a constant. The \( K_d \) is the dimensionless equilibrium constant and was calculated as follows (Namasivayam and Ranganathan, 1994).

\[
K_d = \frac{C_{so}}{C_{se}}
\]  

(9)

where, \( C_{so} \) is the amount of cobalt ions adsorbed by the roasted date pits per liter of cobalt ions solution at equilibrium (mg L\(^{-1}\)) and \( C_{se} \) is the cobalt ions concentration in the solution at equilibrium (mg L\(^{-1}\)). The reference states were defined on the basis of amount of cobalt ions adsorbed on roasted date pits (mg g\(^{-1}\)) and cobalt ions concentration in the solution (mg L\(^{-1}\)).

The entropy change (\( \Delta S \)) was calculated using the following Gibbs-Helmholtz equation (Ruixia et al., 2004).

\[
\Delta S = \frac{\Delta H - \Delta G}{T}
\]

(10)

The results in Table 8 indicate that the value of the enthalpy is negative which means that the adsorption is exothermic. Also, the values of standard Gibbs free energy are positive thus gives an indication of a non-spontaneous process (Demirbas, 2003; Orumwense, 1996). The value of the entropy is negative where the system turn out to be less random at the interface of the roasted date pits-cobalt ions solution during the adsorption of cobalt ions on roasted date pits (Qadeer and Khalid, 2005).

**Evaluation of Goodness of the Fitting**

The results from the models (Langmuir, Freundlich, Redlich-Peterson and Toth) and the experiments were compared and plotted (Fig. 5-8). The coefficient of determination (\( R^2 \)) with Chi-square method (\( \chi^2 \)) were calculated to evaluate the best fit between the theoretical results from the models and experimental results. The coefficient of determination (\( R^2 \)) is normally used to evaluate the goodness of the fit. The Chi-square method (\( \chi^2 \)) was applied to estimate the agreement between the data from the models and the equilibrium experiments. The Chi-square (\( \chi^2 \)) equation is written as follows.

\[
\chi^2 = \frac{1}{N} \sum_{i=1}^{N} \left( \frac{q_{exp} - q_{calc}}{q_{calc}} \right)^2
\]

(11)

where, \( N \) is the number of data points, \( q_{exp} \) the experimental amount of cobalt ions adsorption on the roasted date pits and \( q_{calc} \) the calculated amount of cobalt ions adsorption on the roasted date pits for a given data point i. In the case of Chi-square method (\( \chi^2 \)), the \( \chi^2 \) has a small value, the results from the model were close to the result of the equilibrium experiment and vice versa.

The (\( R^2 \)) values and Chi-square method (\( \chi^2 \)) are presented (Table 9). The (\( R^2 \)) and Chi-square method (\( \chi^2 \)) show the best model to fit the experimental results. It was found that the Langmuir and Redlich-Peterson models confirmed the best correlation with the experimental data at different temperatures.
Table 9: Comparison of (R^2) and (\chi^2) for Langmuir, Freundlich, Redlich-Peterson and Toth Models

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Langmuir R^2</th>
<th>\chi^2</th>
<th>Freundlich R^2</th>
<th>\chi^2</th>
<th>Redlich-Peterson R^2</th>
<th>\chi^2</th>
<th>Toth R^2</th>
<th>\chi^2</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>0.9759</td>
<td>0.1044</td>
<td>0.9052</td>
<td>0.4970</td>
<td>0.9751</td>
<td>0.1039</td>
<td>0.9552</td>
<td>0.2196</td>
</tr>
<tr>
<td>40</td>
<td>0.9278</td>
<td>0.4794</td>
<td>0.8898</td>
<td>0.6973</td>
<td>0.9250</td>
<td>0.4800</td>
<td>0.9010</td>
<td>0.6668</td>
</tr>
<tr>
<td>60</td>
<td>0.9572</td>
<td>0.3160</td>
<td>0.9270</td>
<td>0.4947</td>
<td>0.9526</td>
<td>0.3374</td>
<td>0.9116</td>
<td>0.6668</td>
</tr>
<tr>
<td>80</td>
<td>0.9379</td>
<td>0.3184</td>
<td>0.9160</td>
<td>0.3121</td>
<td>0.9303</td>
<td>0.3038</td>
<td>0.8563</td>
<td>0.7325</td>
</tr>
</tbody>
</table>

CONCLUSIONS

The maximum adsorption capacity of the Saudi roasted date pits for Cobalt ions decreased with an increase in the solution temperature. This suggested that the adsorption process is an exothermic process. It was found that the Langmuir and Redlich-Peterson isotherm models agreed with the experimental data as the Chi-square for Langmuir and Redlich-Peterson was less than the values of Chi-square both for the Freundlich and Toth models. Also, the coefficient of determination (R^2) values for Langmuir and Redlich-Peterson were higher than those obtained both for the Freundlich and Toth models.

It was observed that the nature of the adsorption process of cobalt ions on Saudi roasted date pits is favorable based on the values of dimensionless equilibrium parameters. The negative value of ΔH showed that the adsorption process of cobalt ions on Saudi roasted date pits is an exothermic process. The values of ΔG were positive for cobalt ions adsorbed on Saudi Roasted date pits and showed that the adsorption process of cobalt ions on Saudi Roasted date pits was non-spontaneous.

NOMENCLATURE

M = Roasted date pits mass (g)
V = Volume of the solution (L)
q_e = The amount of adsorption (mg g\(^{-1}\))
C_0 = Initial solution concentration of cobalt ions (mg L\(^{-1}\))
C_e = Concentration of the cobalt ions at equilibrium (mg L\(^{-1}\))
K = Equilibrium parameter of Langmuir model (L g\(^{-1}\))
b = Equilibrium parameter of Langmuir model (L mg\(^{-1}\))
\bar{R} = The dimensionless equilibrium parameter (-)
K_f = Equilibrium parameter of Freundlich model (L g\(^{-1}\))
n = Equilibrium parameter of Freundlich model (-)
K_r = Equilibrium parameter of Redlich-Peterson model (L g\(^{-1}\))
α_m = Equilibrium parameter of Redlich-Peterson model (L mg\(^{-1}\))
K_t = Equilibrium parameter of Toth model (L g\(^{-1}\))
bt = Equilibrium parameter of Toth model (L mg\(^{-1}\))
t = Heterogeneity parameter of Toth model (-)
R = The gas constant (8.314 J/mol.K)
T = The absolute temperature (K)

Greek Symbols

\beta is heterogeneity parameter of Redlich-Peterson model (-)

REFERENCES


