ISOTHERM AND KINETIC MODELLING OF ADSORPTION OF Cr(VI) ONTO ACTIVATED ZINGIBER OFFICINALE SKIN POWDER

J. Jose Hepzin Alis¹, Dr. M. Jayarajan²

¹Research Scholar, Department of Chemistry & Research Centre, Annai Velankanni College, Tholayavattam
Affiliated to Manonmaniam Sundaranar University, Abishekapatti, Tirunelveli, Tamil Nadu, India
²Associate Professor, Department of Chemistry Research Centre, Annai Velankanni college, Tholayaattam India

ABSTRACT

Activated carbon are very effective adsorbent due to their high surface area and pore volume. It is mainly used to removes metal ions from aqueous solutions. The batch study indicated that initial pH of aqueous solution affect metal ion removal while the removal efficiency decreased with increasing initial concentration, it increased with increasing adsorbent concentration. Equilibrium data were obtained by testing the adsorption data using seven different isotherm models: Langmuir, Freundlich, Dubinin – Rabushkevich (D-R), Temkin, BET, R-P isotherm and Harkin Jura isotherm models.

It was found that the adsorption of metals correlated well with langumir isotherm and Redlich Peterson isotherm model. The adsorption followed physisorption process. The results of Kinetic models showed that the pseudo first order Kinetic model was found to correlate the experimental data were. The study provided an effective use of zingiber officinale skin as a valuable source of adsorbent for the removal of chromium ions from aqueous solution. This study could add economic value to zingiber officinale skin powder, reduce disposal problems and offer an economic source of AC to the AC users.

Keywords: Zingiber officinale skin activated carbon-Adsorption isotherm.

1. Introduction

The world is moving towards water wars our water sources are polluted, wasted and misused. The main source of water contamination include industrialization, like chemical industries, petrochemical, metal plating, leather tanning, textile, etc. The waste water streams being let out from industries carry huge amount of various toxic substances. Although there has been some discussion on alternatives and water saving Technologies. A number of treatment technologies are available with varying degree of success to remove metals from aqueous solution, however, most of these treatment process are costly and in some cases they generate secondary waste by product. Ultimately, an effective and low cost treatment tecnology for the removal of metal ions includes the use of activated carbon. The design of an adsorption process and analysis require the adsorption equilibrium which is the most important piece of information needed for a proper understanding of an adsorption process (Vasanthand and Sivaneson, 2006). The Migration of pollutant(s) in aqueous media and subsequent development of containment measures have resulted in the use of adsorption among other technics (Ayawei et al.; 2005). The various adsorption isotherm equations have been used to study the nature of adsorption such as, Langmuir, Freundlich, Tempkin, D-R isotherm, BET, R-P isotherm and Harkin-Jura isotherm models. Adsorption kinetics is the measure of the adsorption uptake with respect to time at a constant pressure or concentration and is employed to measure the diffusion of adsorption in the pore. (Science directi.com). The rate of adsorption is given by adsorption kinetics in terms of order of the constant. (Mohammed Amran et al 2011). This adsorption rate is essential to decide the type or the best suited adsorbate. One is the adsorption capacity and the other is the rate of adsorption. The aim of this work is to study equilibrium and Kinetics of adsorption of and Cr(VI) onto activated carbon. Seven isotherm models where used to analyse the
experimental data. The Kinetic experimental data were tested for two kinetic equations, pseudo first order and pseudo second-order equations.

2. Equilibrium Isotherm Studies;
The analysis of the adsorption isotherms data or important to study the adsorption capacity of adsorption, also it is important in developing accurate data that could be used for adsorption design purpose. In the present study seven adsorption isotherm were utilised: Langmuir, Freundlich, Tempkin, D-R isotherm, BET, R-P isotherm and Harkin-Jura isotherm models. Langmuir method was adopted for analyzing adsorption equilibrium of metal onto activated carbon material. For this, the linear form of Langmuir isotherm is described by

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

plot of \( \frac{C_e}{q_e} \) against \( C_e \) is shown in Figure 5. The maximum adsorption capacity \( Q_o \) and adsorption intensity \( (K_L) \) were determined from the slope and intercept, respectively where \( q_e \) is the monolayer adsorption capacity of adsorbent \( mg/g \), 'Ce' is the equilibrium concentration \( g/l \), \( Q_o \) is the maximum adsorption capacity that can be taken up per mass of adsorbant \( g \), \( K_L \) is the Langumir constant related to the sorption energy between the adsorbate and adsorbent.

To determine if the adsorption process was favourable or unfavourable, the dimensionless equilibrium constant [separation factor] RL was calculated from the following equation.

\[ RL = \frac{1}{1 + Q_o C_0} \]  

Freundlich method was adopted for analysing adsorption equilibrium of metal onto each activated carbon material. For this, the Freundlich model can be expressed below.

\[ \log q_e = \log K_F + \frac{1}{n} \log C_e \]  

where \( q_e \) is the amount of copper adsorbed at equilibrium \( mg/g \), \( C_e \) is the equilibrium concentration of the adsorbate \( mg/L \), \( K_F \) and \( n \) are the Freundlich constants.

The Tempkin isotherm assumes that the heat of adsorption of all the molecules in the layer increases linearly with coverage [Allen et al 2004]. This is due to the interactions that exist between the metal and activated carbon molecules in this cases. This linear form of this isotherm can be given by,

\[ q_e = \frac{RT}{bT} \ln aT + \frac{RT}{bT} \ln C_e \]  

\( q_e \) is the amount adsorbed at equilibrium in gram
\( a \) is the equilibrium binding constant corresponding to the maximum binding energy [L/g], \( R \) is the gas constant [8.314] J/mol k and \( T \) is the absolute temperate, \( RT/bT \) is the Tempkin constant related to heat of adsorption \( [J/mol] \). The slopes and intercept obtained from the graphical plot \( q_e \) against \( \ln C_e \) were used to calculate the Tempkin constants.

The linear form of the Dubinin- Radushkevich isotherm [Pamahesh et al., 2006] can be given as;

\[ \ln q_e = \ln q_D - \frac{B}{\bar{E}^2} \]  

where \( \bar{E} \) is known as Polanyi potential.

\[ \bar{E} = RT \ln \left[ 1 + \frac{1}{C_e} \right] \]  

R=> is the universal gas constant [KJ/molk]
\( T \) => absolute temperature[k]
\( q_D \) =amount of metal adsorbed [g] at equilibrium per unit weight of adsorbent.
\( B \) = is a constant related to the mean free energy of adsorption[mol²/J]
\( \bar{E} \) = is the Polanyi potential which is related to the equilibrium concentration \( [C_e] \) measured in \( [J/mol] \). The relation between mean energy for sorption and \( B \) is given as

\[ E = 1/\sqrt{2B} \]  

The \( E \) value gives relation of physical and chemical nature of adsorption.

In 1938 Brunauer, Emmett and Teller proposed a theory called B.E.T theory. This theory suggests that the physical adsorption resulting in the formation of multilayer is the true picture of
adsorption. The adsorption form a single layer at low concentration followed by the attachment of further layers with increase in concentration. It assumes that,

[i] The soil surface possesses uniform, localized sites.
[ii] Adsorption at one side does not affect the adsorption at neighbouring sites.
[iii] The adsorption occurs successively on second, third and nth layers with the surface area available that surface area available.
[iv] The surface area available for the nth layer is equal to the coverage of the [n-1]th layer.
[v] The energy of adsorption in the first layer [ie] monolayer. [E_1] is a constant.

Based on the above assumptions, Brunauer, Emmett and Teller derived the following equation.

\[
\frac{C_T}{x} = \frac{1}{x} k + \frac{k-1}{x} \frac{C_T}{C_T_0}
\]

Where,

- \( C_T \) = concentration of solute [adsorbate] at initial time.
- \( C_T_0 \) = concentration of solute [adsorbate] at equilibrium time.
- \( K \) = constant \([min^{-1}]\) related to the energy [enthalpy] of adsorption.
- \( x/m \) = amount of solute adsorbed by activated carbon.
- \( x \) = amount adsorbed by activated carbon at equilibrium.

The Redlich-peterson isotherm combines the features of Langmuir and Freundlich isotherms. It can be represented as [Repo et al. 2011 a]

\[
q_e = \left( \frac{x}{m} \right) = q_o b C_T \left[ 1 + \alpha R \beta C_T \right]
\]

The numerator is from the Langmuir isotherm and has the benefit of approaching the Henry region at infinite dilution. [Davoudinejad and Gharbania 2013]. This isotherm model is an empirical isotherm incorporating three parameters. It combines elements from both Langmuir and Freundlich equations, therefore the mechanism of adsorption is a mix and does not follow ideal monolayer adsorption [Brouers and Musawi 2015].

This model is defined by the following expression:

\[
q_e = A \frac{C_T}{1 + B C_T^\beta}
\]

where \( A \) is Redlich-peterson isotherm constant, \( B \) is constant, \( \beta \) is exponent that lies between 0 and 1, \( C_T \) is equilibrium liquid-phase concentration of the AC adsorbent and \( q_e \) is equilibrium adsorbate loading on the AC adsorbent.

At high liquid-phase concentrations of the adsorbate, [Ayawei et al 2015] reduces to the Freundlich equation:

\[
q_e = \frac{A}{B} C_T^{\alpha}\beta
\]

where \( A/B = K_F \) and \( \alpha = 1/n \) of the Freundlich isotherm model.

Harkin-Jura isotherm model assumes the possibility of multilayer adsorption on the surface of adsorbents having heterogeneous pore distribution [Foo and Hameed; 2010]. This model is expressed as follows:

\[
\frac{1}{q_e^2} = B/A - 1/A \log C_T
\]

where \( B \) and \( A \) are Harkin-Jura that can be obtained from plotting \( 1/q_e^2 \) versus \( \log C_T \). Foo and Hameed reported that the Harkin-Jura isotherm model showed a better fit to the adsorption data than Freundlich and Tempkin isotherm.

3. Adsorption Kinetics Studies:

Adsorption kinetics are one of the important characteristics is the defining the efficiency of an adsorption process and to understand the behaviour of the adsorbent. The Kinetics of Cr[VI] adsorption onto the activated carbon were analyzed using pseudo first-order and pseudo second-order kinetic models. The correlation coefficient, \( R^2 \), were used to find the fitting between the experimental data and the predicted data. High value of \( R^2 \) indicates that the
model successfully describes the kinetics of metal ions absorption. These models can be explain as:

Lagergren proposed a method for adsorption analysis namely pseudo first-order kinetic equation. The linear form of this equation is [Santhy and Selvapathy 2006]

\[
\ln(q_e - q) = \ln q_e - k_1 t \quad \text{or} \quad \log(q_e - q) = \log q_e - k_1/2.303 t
\]

where \( q_e \) and \( q \) are the amounts of adsorbate adsorbed at equilibrium and at time \( t \), respectively and \( k_1 \) is the rate constant of pseudo first order adsorption.

The sorption kinetics can also be described by pseudo second-order model. The linear form of pseudo second-order equation is expressed as [Bulut and Ozacar 2008]

\[
t/q = 1/k_2 q_e^2 + 1/q_e t
\]

where, \( k_2 \) is the equilibrium rate constant of pseudo second-order adsorption. Equation[4.14] does not have the problem of assigning an effective \( q_e \). If the pseudo second-order kinetic equation is applicable, the plot of \( t/q \) against \( t \) should give a linear relationship, from with \( q_e \) and \( k_2 \) can be determined from the slope and intercept of the plot.

### 4. Experimental works

#### Materials and Methods:

4.1 Water

The whole experimental study was carried out using distilled water (DDWater). Tap water was distilled with stiller distillatory plant and stored in amber-colour glass bottles. Conductivity of the distilled water was less than 1 µmho/cm

4.2 Preparation of adsorbate

A stock standard chromium solution was prepared by dissolving an approximate quantity of chromium in 1 L volumetric flask and making to the mark with deionized water. The working solutions were prepared by diluting the stock solution with deionized water to give the required concentration of the working solutions. Five difference concentrations of the adsorbate were prepared as 0.1, 0.2, 0.3, 0.4 and 0.5 Molality

4.3 Preparation of activate carbon

The zingiber officinale skin were collected nearby our areas from cottage industry, hotel waste and kitchen waste. The zingiber officinale skin were then cleaned with distilled water to remove some surface impurities and dried in sunlight for 7 days pyrolysis treatment (activation step) was performed as follows. The dried material soaked in a solution of (1:4) KOH solution for 1h then the material were separated ,and dried in sunlight for 7 days and carbonized in muffle furnace at 600°C for 1 ¹/₂ hours. The carbonized material was powderized, sieved 0.25 mm size and stored in a tight lid container for further adsorption studies.

4.4 Equilibrium Studies:

The whole study was performed based on batch adsorption experiment. A representative procedure is described below. 1.0 gram of the activated carbon (Zingiber officinale skin) was taken in 250 ml reagent bottles provided with inner and outer lids, 50 mL of potassium dichromate solution in DD water if various concentration (0.1M, 0.2M, 0.3M, 0.4M, 0.5M) was poured into the bottle. The mixture was shaken for 6h (equilibration time was determined in a separate experiment and is described below( at room temperature 6h was found to be sufficient for complete adsorption. The supernatant from each adsorption solution was transferred to a whatman No-1 filter paper.

4.5 Kinetic studies:

The Kinetic studies were carried out by withdrawing and analyzing the samples at the time interval of every 5 minutes for the first 30 minutes and later at every 10 minutes until the consecutive residual metal concentrations become closer. The Kinetic data for the adsorption of chromium[VI] onto zingiber officinale skin activated carbon with the five initial metal
concentrations [0.1, 0.2, 0.3, 0.4 and 0.5 m] were tested with the well-known Kinetic models namely pseudo first-order model and pseudo second-order model.

5. Results and Discussion

Chromium is an essential element the diet of some animals and human beings. However, at higher concentrations all compounds of chromium are toxic. Prolonged use of chromium may cause epigastric pain, nausea, vomiting and severe diarrhoea. Thus, it take immediate action to remove chromium ion from aqueous solution before discharging into water or onto land. The present work is an investigation of removal of Cr[VI] from aqueous solution based on adsorption of Cr onto activated carbon. Adsorption onto activated carbon (AC) is considered as a user-friendly, effective purification and separation method for the removal of chromium(VI) from aqueous solution with the advantages of specific affinity, low cost and simple design. Zingiber officinale skin is a waste thrown from kitchen, hotels etc and also it is easily available in large quantity. Considering all these aspects the present study utilizes activated Zingiber officinale skin and investigates its chromium adsorption efficiency and behavior.

Effect of adsorbent dosage

![Effect of Adsorbent Dosage](image)

Adsorbent dosage is an important parameter because it determines the capacity of the adsorbent for a given chromium concentration and also determines the sorbent-sorbate equilibrium of the system (Killic et al 2011).

The effect of the adsorbent dosage on the adsorption of chromium was carried out with in the adsorbent dosage of 0.1-0.9 g of sample. The adsorbent dosage increases, the adsorption also increases. This is due to the fact that, an increase in adsorbent dosage increases the number of active sites available for adsorption. At lower adsorbent dosage (0.1 g) the amount of chromium...
removed is 0.02089, but when adsorbent dosage increases (0.9g) the amount of chromium removed is 0.1534g. At a higher dosage, there is limited availability of adsorbing species for the relatively larger number of surface sites or surface area on the adsorbent. It is reasonable to say that at higher adsorbent dosage, there would be a greater availability of exchangeable sites or surface area (Tumin et al.2008 ; Babel and Kurniawan 2004).

Effect of pH

![Fig 3](image)

The influence of pH on adsorption of chromium is investigated under the pH form 1 to 11. The pH of solution medium is essential and appropriate for the adsorption of chromium using AC. The pH of solution may change the surface charge of the adsorbent, the degree of ionization of the adsorbate molecule and extent of dissociation of functional groups on the active sites of the adsorbent. The percentage of metal removal at different pH is shown in figure-3 for the initial metal concentration of 0.1m. From this study, it is observed that, pH increases, the adsorption also increases, This is due to low competition of positively charged ions when At lower pH, the competition of hydrogen and metal ion is more, hence adsorption of Cr(VI) is minimum. By increasing the pH, the competition between hydrogen and metal ion is minimum. So adsorption of Cr(VI) is maximum (Sheeba Thavamani and Rajkumar August 2013)

Effect of initial chromium concentration

![Fig 4](image)

The initial concentration provides a good driving force to overcome all mass transfer resistance of chromium ions between the aqueous solution and solid phase. Initial chromium concentration on the adsorption process was investigated by varying initial metal ion concentration from 0.1 m
to 0.5m and results are presented in fig 4. The results indicate that the actual amount of chromium ions adsorbed (g) decreased with increase in the initial chromium concentration. This is because at lower concentration there are sufficient active sites that the adsorbate can easily occupy. However, the concentration is increases, the active adsorption sites are not sufficiently available for the adsorbate to occupy. Hence, Cr(VI) ions not completely adsorbed in solution due to the saturation of binding sites. In addition, the electrostatic repulsion between negative charges of adsorbate ions results in the decrease in the chromium removed from the aqueous solutions.

5.1 Adsorption isotherms Results:

Adsorption isotherms are mathematical models used to describe the distribution of the adsorbate species among the adsorbent and the liquid solution. This is usually based on assumptions related to the homogeneity / heterogeneity of adsorbents, possible interaction between the species and the type of coverage (Abdelkreem 2013). The results of adsorption isotherms are usually expressed as a plot of the concentrations of chemical substance adsorbed (mg/g) versus the concentration remaining in solution (mg/L).

In the present study seven isotherm models have been tested to analyse the equilibrium data of the synthetic activated carbon as absorbent Langmuir (Vunain et al 2013), Freundlich (Lalhmunsiama et al 2016), Dubinin Radushkvich models (Adekola et al 2016) Tempkin (Allen et al 2006), BET (Brunauer, Emmett and Teller 1938), Redlich-peterson model (Repo et al 2011 a), Harkin-Jura Isotherm (Foo and Hameed 2010) were employed to describe the sorption equilibrium data.

The linear form of Langmuir isotherm is described by equation.

\[
\frac{C_e}{q_e} = \frac{1}{Q_0K_L} + \frac{1}{Q_0}C_e
\]

And a plot of \(\frac{C_e}{q_e}\) against \(C_e\) is shown in the figure 5.

The maximum adsorption capacity (\(Q_0\)) and adsorption intensity (\(K_L\)) were calculated from the slope and intercept, respectively, of the straight line.

Where \(q_e\) is the monolayer adsorption capacity of adsorbent (mg/g),

\(C_e\) is the equilibrium concentration (g/L), \(Q_0\) is the maximum adsorption capacity that can be taken up per mass of adsorbent (g), \(K_L\) is the Langmuir constant related to the sorption energy between the adsorbate and adsorbent.

\(R_L\) value was calculated from equation

\[
R_L = \frac{1}{1 + K_LC_0}
\]

\(C_0\) is the highest initial metal concentration in solution (g/L).

\(R_L\) value is 0.9866 indicates, the adsorption of chromium on to AC derived from (Zingiber officinale skin) is favourable. Generally, the separation factor between and 0 and 1 gives rise to efficient adsorption performance.
The freundlich model can be expressed as below

\[ \log q_e = \log k_f + \frac{1}{n} \log C_e \]

Where \( q_e \) is the amount of chromium adsorbed at equilibrium (mg/g), \( C_e \) is the equilibrium concentration of the adsorbate (g/l), \( k_f \) and \( n \) are the freundlich constants and Freundlich exponent which represent adsorption capacity and adsorption intensity.

In this study, the values of \( k_f \) and \( n \) were obtained from the intercept and slope of a plot of \( \log q_e \) against \( \log C_e \).

In this study, the value of \( n=5.5617 \) increased value of \( n \) shows better adsorption; \( k_f=0.0859 \)

\( \frac{1}{n} = 0.1798 \) indicates stronger sorption strength. The adsorption of chromium onto AC derived from (Zingiber officinale skin) is stronger sorption strength generally \( \frac{1}{n} \) above 1 indicates stronger sorption strength (Angin et al. 2013, Mahapatra et al. 2012, Angin 2014). Here the value of \( n \) was between 1 and 10 which again proved that the processes are favourable at all the temperature (S. Nethaji et al. Nov 2012).

The Dubinin-Radushkevich (D-R) isotherm model can be expressed as below:
\[ \ln q_e = \ln q_s - BE^2 \]

Where \( q_s \) represents the amount of chromium adsorbed (g) at equilibrium per unit weight of adsorbent.

\( B \) is a constant related to the mean free energy of adsorption (\( \text{mmol}^2/\text{J}^2 \)) and \( \epsilon \) is the polani potential which is related to the equilibrium concentration \( (C_e) \) measured in (J/mol).

\[ \epsilon = \frac{1}{RT} \left( 1 + \frac{1}{C_e} \right) \]

Where \( R \) is the universal gas constant (KJ/mol) and \( T \) is the absolute temperature (K).

The constant \( B \) gives the mean free energy, \( E \)

\[ E = \frac{1}{\sqrt{2B}} \]

The isotherm constants \( q_s \) and \( B \) are calculated from the intercept and slope of a plot of \( \ln q_e \) versus \( \epsilon^2 \)

\( q_s = 0.0531 \text{ mg/g} \)

\( B = 6 \times 10^{-9} \text{ mmol}^2/\text{J}^2 \); \( E = 2.1812 \text{ KJ/mol} \)

E value smaller indicates, The absorption process is physical adsorption (ozecan, et al 2005).

The tempkin isotherm model

\[ q_e = B \ln c_e + Br \ln \Lambda \]
B is a constant related to the heat of adsorption and it is defined by the expression $B = RT/b$, where $b$ is the Tempkin constant (J/mol), $T$ is the absolute temperature (K), $R$ is the gas constant (8.314 J/mol K) and $A$ is the Tempkin isotherm constant (L/g).

In this study, the value of $B = -0.012$ J/mol, has negative value indicate, the adsorption is endothermic Tempkin constant ($a$) = 0.0458 J/mol, is a measure of heat of adsorption, puring adsorption, energy is adsorbed. So adsorption is endothermic. It involves low heat of adsorption (4-45 KJ/mol) indicate the adsorption is physisorption.

![Graph](image1)

**(Fig 9)**

![Graph](image2)

**(Fig 10)**

![Graph](image3)

**(Fig 11)**

<table>
<thead>
<tr>
<th>Table-1</th>
<th>Isotherm parameters</th>
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<table>
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<tr>
<th>Isotherm</th>
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<th>Cr(VI)</th>
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<td>D-R</td>
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<td>$B$</td>
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<td>TEMPKIN</td>
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<td>Harkin-Jura</td>
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Harkin-Jura isotherm model assumes the possibility of multilayer adsorption on the surface of adsorbent having a heterogeneous pore distribution. Comparing the $R^2$ values of the Langmuir, Freundlich, D-R and Tempkin isotherm, the Langmuir isotherm has a better fitting than the Freundlich, D-R and Tempkin (Table 1). This was indicative of the formation of monolayer coverage of the Cr(VI) adsorbate at the outer surface of the AC, and implies that the adsorption of Cr(VI) ions due to specific interactions of the metal ions with groups on the surface of the synthesized AC and no further adsorption occurs once a Cr(VI) molecule occupies a site.

5.2 Adsorption kinetics Results:

In order to define the adsorption kinetics of metal ions that kinetic parameters for the adsorption process were studied for the contact times ranging between 1 to 150 min and first order and second order kinetics were experimental data as shown in figures.

From first order kinetics equation the plot of $\log(q_e - q_t)$ vs. $t$ gives a straight line for first order adsorption kinetics and the rate constant $k_1$ is computed from the plot.

Where $q_e$ and $q_t$ are the adsorption capacity at equilibrium and at time $t$ respectively and $k_1$ is the rate constant of the pseudo first order adsorption process.
The granular activated carbon was found to have a good adsorption capacity for Cr[VI] from aqueous solution. This adsorbent could be effectively for the removal of these metal ions.

The experimental data showed good fit to the Langmuir isotherm and Redlich-peterson isotherm models. The correlation Coefficient $R^2$ is greater than 0.977.

The experimental data was applied to kinetic models, pseudo first order and pseudo second order models a comparison between the two models showed pseudo first order model described the adsorption process very well and gave best fit with the experimental data with $R^2$ values of 0.99.

6. Conclusion:

The granular activated carbon was found to have a good adsorption capacity for Cr[VI] from aqueous solution. This adsorbent could be effectively for the removal of these metal ions.

The experimental data showed good fit to the Langmuir isotherm and Redlich-peterson isotherm models. The correlation Coefficient $R^2$ is greater than 0.977.

The experimental data was applied to kinetic models, pseudo first order and pseudo second order models a comparison between the two models showed pseudo first order model described the adsorption process very well and gave best fit with the experimental data with $R^2$ values of 0.99.

REFERENCES


Table 2: Kinetics parameters for the adsorption Pb[II] and Cu[II] onto Allium Sativum Skin activated carbon.

<table>
<thead>
<tr>
<th>$q_e$</th>
<th>$K$</th>
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Pseudo first order kinetics for Cr[VI] adsorption on zingiber officinale AC at time 10, 20, 30, 45 and 60 minutes.

Pseudo Second Order Kinetics for Cr[VI] adsorption on zingiber officinale AC at time 10, 20, 30, 45, 60 minutes.

