Adsorption of Cadmium(II) Ions from Aqueous Solution onto Kaolinite and Metakaolinite

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Abstract

The removal of cadmium(II) ions from aqueous solution by adsorption on kaolinite (KAO.1) and metakaolinite (MKB) was investigated depending on the initial concentration, adsorbents dosage, initial pH of solution, and contact time. The influences of those factors have been experimentally verified by a batch method at (27±3 °C). These results have showed that the amount of cadmium(II) ions adsorbed increases with increased contact time and that equilibrium adsorption is reached in 10 minutes, the optimum value of pH was 8.0 and the effect of absorbent dose for the uptake of cadmium(II) ions by kaolinite and metakaolinite was found to decrease by increasing the absorbent dose. The experimental results obtained are described by Langmuir, Freundlich and Dubinin-Kaganer-Radushkevich (D-K-R) isotherm models. The Langmuir and D-K-R adsorption isotherms described the adsorption data very well. The maximum adsorption capacity; Q_{max}, determined from the Langmuir adsorption isotherm studies was found to be 7.407 and 9.174 mg/g for KAO.1 and MKB respectively. Pseudo-first order, pseudo-second order, Elovich and the intraparticular diffusion kinetic models were used to describe the kinetic data obtained. The experimental data fitted well to the pseudo-second order kinetic model, which indicates that
chemical adsorption is the rate-limiting step. The results indicate that kaolinite and metakaolinite adsorb cadmium(II) ions efficiently and could be employed as a low-cost alternative in waste water treatment for the elimination of cadmium(II) ions.

Keywords: adsorption, kaolinite, metakaolinite, cadmium, kinetic model, isotherm model

1. INTRODUCTION

Most of the metals are known to be toxic and half of these including cadmium, chromium, copper, lead, mercury, nickel, selenium, silver and zinc. These metals are released into the environment in quantities that pose a risk to human health (Rao et al., 2010).

Health metal contamination exist in aqueous waste streams from diverse industries such as metal plating manufacturing, batteries, as well as agricultural sources where fertilizers and fungidal sprays are intensively used (Shih et al., 2010). Cu, Zn, Hg and Cd are harmful waste introduced by industries that pose a risk of contamination groundwater and other water resources (Achour and Youcef, 2003). Heavy metals are not biodegradable and tend to accumulate in living organisms, causing various diseases and disorders (Teker and Imamoglu, 2005). As far as cadmium is concerned, it causes serious renal damage anemia and hypertention (Mahvi et al., 2007).

The reduction of the pollutant to an acceptable level is necessary when toxic metals are present in solution (Cheng et al., 2012). Decontamination of surface and underground water supplies is a major concern and conventional methods such as: Chemical precipitation, Membrane Filtration (Reverse Osmosis and Electro dialysis), Electrolytic processes, Biosorption and Adsorption can be used for decontamination of effluents (Igwé et al., 2008; Zohre et al., 2010). These techniques which have been mentioned above, with the exception of adsorption are expensive and also have disadvantages such as incomplete metal removal, high reagent, energy requirements and generation of toxic sludge or other waste products that require proper disposal (Ketcha et al., 2009). Due to the problems mentioned above this research has been interested in using Adsorption since it is cheaper, making use of low cost and local Adsorbents, which are adapted in efficiently removing heavy metal ions found in low concentrations in solution.

In the present investigation local kaolinite clay obtained from Kribi in the South Region of Cameroon, and the metakaolinite obtained from heating it at 700 °C have been used as adsorbents for the removal of cadmium(II) ion. The effect of such factors as contact time, initial pH and initial concentration was investigated. The kinetics of cadmium(II) ion adsorption on both adsorbents was analyzed by various kinetic models. Experimental equilibrium data were fitted to the Langmuir, Freundlich and Dubinin-Kaganer-Radushkevich.
2. MATERIALS AND METHODS

2.1 Adsorbent

The kaolinite clay was collected from Kribi in the South Region of Cameroon. Particles of ore that passed through an 80 μm sieve were extensively washed with tap water to remove dirt and other particulate matter, followed by washing in distilled water. The resulting slurry was allowed to sediment and particles of size less than or equal to 2 μm were obtained. After complete drying in the sun, one part of the kaolinite was used to prepare metakaolinite. This was done by heating the part in a furnace at the rate of 5 °C/min to a temperature of 700 °C. Heating was maintained at this temperature for 6 hours before being allowed to cool in the furnace to 40 °C. The dried adsorbent was ground in a laboratory mortar and sieved in standard test sieves for use during adsorption experiments. The adsorbents were heated in an oven at 110 °C for 24 hours and allowed to cool in a desiccator containing CaCl₂ (drying agent) for 1 hour before being used in the adsorption process.

2.2 Adsorbent Characterization

Difrap+d8 model bruker and Philips equipment were used to obtain the X-ray diffraction (XRD) pattern of kaolinite and metakaolinite samples respectively, to identify the crystalline compounds. Infrared spectra of the both samples were measured from 400 to 4000 cm⁻¹ using a brukeralpha–p spectrometer with ethanol as solvent. The BET specific area and total pore volume of kaolinite and metakaolinite were determined by standard multipoint techniques of nitrogen adsorption, using TriStar 3000 V6.05A equipment. The chemical analysis of kaolinite and metakaolinite is obtained by Harrison method and X florescence. The Specific area of the kaolinite and metakaolinite is obtained by volumetric equipment as described by Haul and Dumbgen.

2.3 Preparation of cadmium(II) Ion Solution

All reagents used in this study were of analytical grade. A stock solution of copper (II) ion of concentration 1000 ppm (1000 mg/L) was prepared by dissolving 1.8158g of CdSO₄ in a 1000ml volumetric flask. This was swirled until all the salt dissolved, transferred into a 1-L volumetric flask and completed with distilled water up to the mark. This solution was stirred on a magnetic stirrer for one hour to obtain homogeneity. All experimental solutions were prepared by diluting the stock solution to the required concentration.

2.4 Batch adsorption measurement

Batch adsorption was carried out at room temperature. The effect of contact time, mass of adsorbent, pH of solution and the initial concentration of cadmium (II)
ions were studied by using kinetic and equilibrium models. In each experiment, 20 mL of cadmium(II) ion solution of known concentration was mixed with a known mass of adsorbent. The pH of the mixture was adjusted either with 0.1 N HCl or 0.1 N NaOH as required before agitating for the required length of time. The concentration of cadmium(II) ion after adsorption was determined by using a direct complexometric titration method.

2.5 Adsorption Equilibrium Studies

For each run the adsorbent is mixed with 20 mL solution of nickel ion at different initial concentrations (50–150 mg/L). The suspensions were stirred for 15 minutes by using a magnetic stirrer. The amount of Cd²⁺ ion adsorbed at equilibrium, Qe (mg/g) was calculated using equation:

\[
Q_e = \left( \frac{C_0 - C_e}{m} \right) x V
\]

(1)

Where, C₀ and Cₑ are Cd²⁺ ion concentrations initially and at equilibrium respectively, V the volume of the solution (L) and m the adsorbent mass. The equilibrium data were then fitted by using the Langmuir, the Freundlich and Dubinin-Kaganer-Radushkevich adsorption isotherm models.

**Langmuir Adsorption Isotherm Studies**

The Langmuir adsorption equation is one of the most common isotherm equations for modeling equilibrium data in solid-liquid systems. This equation is valid for monolayer adsorption onto a surface with a finite number of identical sites which are homogeneously distributed over the adsorbent surface. The general form of the Langmuir equation is (Ketcha Mbadcam et al., 2011):

\[
Q_e = \frac{Q_m K_L C_e}{1+K_L C_e}
\]

(2)

Where \( C_e \) is the equilibrium concentration of cadmium(II) ions (mg/L), \( Q_e \) is the amount of cadmium(II) ions adsorbed per unit mass of the adsorbent, \( K_L \) is the Langmuir adsorption constant (L/mg) and \( Q_m \) is the maximum amount of per unit mass of adsorbent to form a complete monolayer on the surface (mg/L). The linear form of this equation is as follows:

\[
\frac{1}{Q_e} = \frac{1}{Q_m K_L C_e} + \frac{1}{Q_m}
\]

(3)
Adsorption of Cadmium(II) ions

The essential characteristics of a Langmuir isotherm can be expressed in terms of a dimensionless constant separation factor or equilibrium parameter, $R_L$, which is defined as:

$$R_L = \frac{1}{1 + KCo}$$  \hspace{1cm} (4)

The $R_L$ value indicates the shape of the isotherm to be either unfavorable ($R_L > 1$), linear ($R_L = 1$), favorable ($0 < R_L < 1$), or irreversible ($R_L = 0$) as shown in Table 3 in this work.

Freundlich Adsorption Isotherm Studies

Freundlich equation is an empirical equation based on the adsorption on a heterogeneous surface (Augustine et al., 2007):

$$Q_e = K_f C_e^{1/n}$$  \hspace{1cm} (5)

Where, $C_e$ is the equilibrium concentration of Cd$^{2+}$ ion (mg/L), $Q_e$ is the amount of Cd$^{2+}$ ion bound to per gram of the adsorbent at equilibrium (mg/g), $K_f$ and $n$ are the Freundlich constants related to sorption capacity and sorption intensity of the sorbent respectively. The linear form of the Freundlich isotherm equation is:

$$\ln Q_e = \ln K_f + \frac{1}{n} \ln C_e$$  \hspace{1cm} (6)

Dubinin-Kaganer-Radushkevich (D-K-R) Isotherm Studies

Langmuir and Freundlich isotherms are insufficient to explain the physical and chemical characteristics of adsorption. D-K-R isotherm is commonly used to describe the sorption isotherms of single solute systems. The D-K-R isotherm, apart from being analogue of Langmuir isotherm, is more general than Langmuir isotherm as it rejects the homogeneous surface or constant adsorption potential. The D-K-R isotherm is expressed as (Ketcha Mbadcam et al., 2012):

$$Q_e = Q_{\text{max}} \exp \left[ \frac{R^2 T \ln \left( \frac{1}{C_e} \right)}{-2E_a^2} \right]^{\frac{1}{2}}$$  \hspace{1cm} (7)

Where, $E_a$: is the main energy of adsorption and gives information about the physical and chemical features of adsorption. The linear form of the D-K-R isotherm equation is:
\ln Q_e = \ln Q_{\text{max}} - \beta \varepsilon^2 \quad (8)

Where, \( \varepsilon = RT \ln \left( 1 + \frac{1}{C_d} \right) \) is called the Polanyi Potential.

### 2.6 Kinetic Adsorption Experiments

Kinetic adsorption experiments were conducted using a series of 20 mL solutions containing fixed amount of adsorbent and cadmium(II) ions (50 ppm). The solutions were vigorously agitated with a magnetic stirrer for increasing time intervals. At the end of each run, the solution is filtered and the Cd\textsuperscript{2+} ion concentration in the filtrate is determined. Kinetics models have been used to fit experimental data.

#### The Pseudo-First Order Model

The pseudo-first order equation of Lagergren is generally expressed as follows (Ketcha Mbadcam et al, 2012):

\[
\frac{dQ}{dt} = k_1 (Q_e - Q_t)
\]

Where, \( Q_e \) and \( Q_t \) are the sorption capacity at equilibrium and at time \( t \) respectively (mg·g\textsuperscript{-1}) and \( K_1 \) is the rate constant of pseudo-first order sorption (L·min\textsuperscript{-1}). After integration and applying boundary conditions, \( t = 0 \) to \( t = t \) and \( Q_t=0 \) to \( Q_t=Q_t \) the integrated form of equation is:

\[
\ln (Q_e - Q_t) = \ln(Q_e) - K_1 t \quad \text{or} \quad \ln(C_t) = -K_1 t + \ln(C_o) \quad \text{after reduction}
\]

Where,

\( K_1 \) is the rate constant of pseudo first order adsorption (mg\textsuperscript{-1} min\textsuperscript{-1}).

#### The Pseudo-Second Order Model

If the rate of the sorption is a second order mechanism, the pseudo-second order chemisorption kinetic rate equation is expressed as (Augustine et al., 2007):

\[
\frac{dQ}{dt} = k_2 (Q_e - Q_t)^2
\]

(11)
Adsorption of Cadmium(II) ions

Where \( k_2 \) is the rate constant of pseudo-second order sorption (g.mg\(^{-1}\).min\(^{-1}\)). The integrated and rearranged form of equation is:

\[
\frac{t}{Q_t} = \frac{1}{k_2Q_c^2} + \frac{t}{Q_c}
\]  

(12)

**The Elovich Equation**

The Elovich equation is general expressed as follows (Zora and Snezana, 2006):

\[
\frac{dQ}{dt} = \alpha \exp(-\beta Q_t)
\]  

(13)

Where \( \alpha \) is the initial sorption rate (mg\(^{-1}\).g.min\(^{-1}\)) and \( \beta \) is the desorption constant (g.mg\(^{-1}\)) during any one experiment. The integrated and simplified equation is:

\[
Q_t = \frac{1}{\beta} \ln(\alpha \beta) + \frac{1}{\beta} \ln t
\]  

(14)

**The Intraparticle Diffusion Model**

The linear form of this equation is expressed as follows (Zora and Snezana, 2006):

\[
\ln P = \ln k_{id} + a \ln t
\]  

(15)

Where, \( P \) is the percent removal of cadmium ions at time \( t \), \( K_{id} \) is the intraparticulate diffusion rate constant and \( a \) is a gradient whose value depends on the adsorption mechanism.

3. RESULTS AND DISCUSSIONS

3.1 Characterization of Adsorbents

The XRD (Fig.1.) shows that the major constituents of the KAO.1 are Anatase, illite, Quartz, Kaolinite, and Lepidocrocite. In the case of MKB there is complete disappearance of the more intense pics of kaolinite (2\(\Theta\) = 9° and 2\(\Theta\)=67°), the amorphous phase on MKB confirmed the presence of metakaolinite. The chemical analysis (Table 1) shows that the major elements are SiO\(_2\) and Al\(_2\)O\(_3\). BET measurements on the kaolinite and metakaolinite showed their surface area to be 20.1819 and 33.8331 m\(^2\)/g respectively. The pore volume of 0.0814 and 0.0935 cm\(^3\)/g for KAO.1 and MKB respectively. This means that when heating kaolinite, there is increasing in surface area and the pore volume.
A FTIR spectroscopy analysis also carried out on the kaolinite and metakaolinite powders gave the functional groups shown in Figures 2. A very strong and broad band at 3688-3618 cm\(^{-1}\) corresponds to OH stretching mode in the KAO.1 sample (Silva et al., 2007). The 1698-1521 cm\(^{-1}\) sharp band can be ascribed to the bending mode of H\(_2\)O molecules in the KAO.1 and MKB samples (Tchakouté et al., 2012). The characteristic sharp bands at 908 cm\(^{-1}\) can be assigned to the Al–O–H bending vibration of kaolinite. The bands at 1114, 1025 and 1000 cm\(^{-1}\) on KAO.1 sample correspond respectively to bending vibrations of Si-O, Si-O-Si et Si-O-Al, in the MKB sample the last band appear at 1037 cm\(^{-1}\) (Churchman et al., 2005).

The transformation of kaolinite to metakaolinite is proved by the disparition of the band at 3688-3618 cm\(^{-1}\) on MKB sample wich corresponds to the dehydroxylation of kaolinite and the presence of the band at 1698-1521 cm\(^{-1}\) of the molecules H\(_2\)O on the MKB sample is due to the hygroscopic property of metakaolinite after heating it at 700 °C (Tchakouté et al., 2012).

Fig.1. XRD Patterns of KAO.1 and MKB

A=Anatase; I=illite ; Q=Quartz; K = Kaolinite; L=Lepidocrocite
Adsorption of Cadmium(II) ions

Fig. 2. FTIR Spectra of KAO.1 and MKB Samples

<table>
<thead>
<tr>
<th>OXIDES (%)</th>
<th>KAO.1</th>
<th>MKB</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>49.52</td>
<td>46.99</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>32.04</td>
<td>34.66</td>
</tr>
<tr>
<td>Na₂O</td>
<td>0.05</td>
<td>10.55</td>
</tr>
<tr>
<td>TiO</td>
<td>0.99</td>
<td>0.94</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>0.75</td>
<td>0.79</td>
</tr>
<tr>
<td>K₂O</td>
<td>0.69</td>
<td>0.68</td>
</tr>
<tr>
<td>MgO</td>
<td>0.13</td>
<td>0.16</td>
</tr>
<tr>
<td>CaO</td>
<td>0.04</td>
<td>0.06</td>
</tr>
<tr>
<td>l.i</td>
<td>15.73</td>
<td>5.05</td>
</tr>
<tr>
<td>Total</td>
<td>99.94</td>
<td>99.91</td>
</tr>
</tbody>
</table>

3.2 Effect of Contact Time

In order to determine the effect of the contact time, 0.5 g of the adsorbent was stirred with a 20 mL solution of cadmium (II) ions of initial concentration 50 mg/L for a time interval between 5 to 40 minutes for KAO.1 and MKB with pH=8. The experimental results obtained for the adsorption of cadmium ions
during varying contact times are shown in (Fig.3). It is clear from the graph that amount of uptake $Q_t$ (mg gm$^{-1}$) increased with increased contact time and after certain period of time; it reached to a constant value beyond which no further adsorption took place. The results showed that, the adsorption was fast at initial stage of contact period and after that near the equilibrium it became slower. With the lapse of time, the surface adsorption sites were exhausted. The remaining vacant sites were difficult to be occupied by the cation due to repulsive forces between adsorbate present in solid and bulk phases (Soug et al., 2009). Adsorptions reach equilibrium within 10 min for KAO.1 and MKB as represented by Fig.3.

![Figure 3: Effect of Agitation Time on the Adsorption of Cadmium(II) Ions on KAO.1 and MKB.](image)

### 3.3 Effect of the Amount of Adsorbents

To study the effect of adsorbent dosage on the adsorption of cadmium(II) ions, a series of adsorption experiments were carried out with different adsorption dosages varying from 0.1 to 1.1 g at initial concentration of 50 ppm. The effect of absorbent dose for the uptake of cadmium(II) ions by kaolinite and metakaolinite was found to decrease by increasing the adsorbent dose. This may be allocated to the fact that as the amount in grams of adsorbent is increased the total surface area available for the adsorption of cadmium(II) ions reduces as a result of overlapping or aggregation of adsorption sites (Ndi Nsami and Ketcha Mbadcam, 2013). Furthermore, maximum quantity adsorbed, $Qe = 6.875$ and $7.638$ mg/g for KAO.1 and MKB respectively, was reached by 0.1 g of each of the absorbents (see Figure 4).
3.4 Effect of Initial pH on Cadmium(II) Ion Adsorption

pH is an important parameter influencing heavy metal adsorption from aqueous solutions. It affects both the surface charge of adsorbent and the degree of ionization of the heavy metal in solution (Rao et al., 2010). (Fig.5) represents the effect of initial pH of the solution on the adsorption of cadmium(II) onto KAO.1 and MKB using 50 mg/L initial cadmium (II) concentration and 0.5 g of adsorbent, in the present study the pH was varied between 3 and 10.
The lower adsorption at pH less than 6 this may be attributed to the competition between the hydrogen and cadmium ions on the sorption sites (Malferrari et al., 2007). At pH values higher than 8.0 insoluble cadmium hydroxide starts, precipitating from the solutions making true sorption studies impossible (Yang et al., 2001; Yu et al., 2007). According to the Fig.5 we saw that the optimum adsorption pH was between 7 and 8 for KAO.1 and MKB, the working pH value for cadmium removal onto KAO.1 and MKB was chosen as 8.0 and the other adsorption experiments were performed at this pH value.

3.5 Kinetic Modeling of Cadmium(II) Ions Adsorption

The kinetics of the adsorption of cadmium(II) ions has been studied to analyze the adsorption rates of cadmium(II) ions onto Kaolinite and Metakaolinite. Four simple kinetic models were tested. The straight-line plots are presented on Figures 6 to 9, while the parameters for these models are given in Table 2. It can be noted that with Kaolinite and Metakaolinite, the elimination of the cadmium(II) ions adequately follows the kinetic model of the pseudo second order, giving a very good coefficient of correlation, $R^2=0.999$, this implies that cadmium (II) ions adsorption on both adsorbent may occur through a chemical process involving the valence forces of the shared or exchanged electrons (Ecboon et al., 2010). This means that the chemisorption reaction or an activated process becomes more predominant in the rate-controlling step for the cadmium system.

![Figure 6: Linearized Pseudo-First Order Plots for Co=50 mg/L, V=20 mL, pH=8.0, m=0.5 g Adsorbent](image-url)
Adsorption of Cadmium(II) ions

Figure.7: Linearized Pseudo-Second Order Plots for Co=50 mg/L, V=20 mL, pH=8.0, m=0.5 g Adsorbent

Figure.8: Linearized Elovich plots for Co=50 mg/L, V=20 mL, pH=8.0, m=0.5 g Adsorbent

Figure.9: Linearized Intraparticle Diffusion Plots for Co=50 mg/L, V=20 mL, pH=8.0, m=0.5 g Adsorbent.
Table 2: Kinetic Models Parameters of Adsorption

<table>
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<tr>
<th>Models</th>
<th>Parameters</th>
<th>Adsorbents</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>KAO.1</td>
</tr>
<tr>
<td>Pseudo-first order</td>
<td>$R^2$</td>
<td>0.241</td>
</tr>
<tr>
<td></td>
<td>$K_1$ (min$^{-1}$)</td>
<td>0.007</td>
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<tr>
<td>Pseudo-second Order</td>
<td>$R^2$</td>
<td>0.999</td>
</tr>
<tr>
<td></td>
<td>$h$ (mg/g min)</td>
<td>3.663</td>
</tr>
<tr>
<td></td>
<td>$K_2$ (g/mg. min)</td>
<td>1.663</td>
</tr>
<tr>
<td>Elovich</td>
<td>$R^2$</td>
<td>0.142</td>
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<tr>
<td></td>
<td>$\beta$ (g/mg)</td>
<td>20.833</td>
</tr>
<tr>
<td>Intra-particle</td>
<td>$a$ (mg/g min) $\times 10^9$</td>
<td>7.163</td>
</tr>
<tr>
<td>Diffusion</td>
<td>$K_{id}$ (min$^{-1}$)</td>
<td>64.715</td>
</tr>
<tr>
<td></td>
<td>$a$ (mg/g)</td>
<td>0.036</td>
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</table>

3.6 Adsorption Isotherms Studies

Data obtained from these studies have been tested with the Langmuir, Freundlich and Dubinin-Kaganer-Raduskevich linearized equations. These results are summarized in table 3. The studies were conducted with 0.5 g of each adsorbent. The results are shown in Figure 10. The isotherm for the adsorption of cadmium(II) ions on kaolinite and metakaolinite is of type II. It represents the formation of a monolayer followed by multi-layer. This type of isotherm is a characteristic of adsorption on adsorbents that are nonporous solids.

The adsorption parameters in Table 3 show that the data both fitted Langmuir and D-K-R isotherms but fitted better in D-K-R isotherm equation by comparing the $R^2$ values. This implies that a monolayer sorption proceeds over a surface containing a finite number of adsorption sites and uniform strategies of adsorption with no transmigration of adsorbate in the plane of surface. The separation factor $R_L$ (Table 4) value indicates that cadmium(II) ion adsorption on both adsorbent is favourable for the higher initial cadmium(II) ion concentrations than for the lower ones (Zaid and Mohammed, 2009). The positive value of sorption energy ($E_a = 158.114$ and $129.100$ kJ/mol) indicate that the adsorption of cadmium(II) ions by KAO.1 and MKB respectively is endothermic and the values are more than 8 KJ/mol the limited value for physical adsorption, this also indicates the strong interaction between the both adsorbents and the cadmium (II) ions (El-Saïd et al., 2010).

The $Q_{max}$ values obtained for the present system in comparison with those reported earlier for sorption of cadmium(II) ions onto various adsorbents (Table 5) revealed that KAO.1 and MKB were effective adsorbent in removing cadmium(II) ions.
Adsorption of Cadmium(II) ions

Figure 10: Adsorption Isotherms of Cadmium(II) Ions on KAO.1 and MKB for Co=50 mg/L, V=20 mL, pH=8.0, m=0.5 g Adsorbent

Figure 11: Linear Plot of Langmuir Model, for Co=50 mg/L, V=20 mL, pH=8.0, m=0.5 g Adsorbent

Figure 12: Linear Plot of the model of Freundlich for Co=50 mg/L, V=20 mL, pH=8.0, m=0.5 g Adsorbent
Figure 13: Linear Transform of the Model of D-K-R for $C_0=50$ mg/L, $V=20$ mL, $pH=8.0$, $m=0.5$ g Adsorbent

Table 3: Isotherm Models Parameters of Adsorption

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<td></td>
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<td>KAO.1</td>
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<tr>
<td>Langmuir</td>
<td>$R^2$</td>
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<td>0.911</td>
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<tr>
<td>Isotherm</td>
<td>$Q_{max}$ (mg/g)</td>
<td>7.407</td>
<td>9.174</td>
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<td></td>
<td>$K(\times10^{-3}L/mg)$</td>
<td>8.706</td>
<td>9.790</td>
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<tr>
<td>Freundlich</td>
<td>$R^2$</td>
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<td>1.169</td>
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<td>$K_F (L/g)$</td>
<td>0.048</td>
<td>0.061</td>
</tr>
<tr>
<td>D-K-R Isotherm</td>
<td>$R^2$</td>
<td>0.910</td>
<td>0.969</td>
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<td></td>
<td>$Q_{max}$ (mg/g)</td>
<td>1.061</td>
<td>1.142</td>
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<tr>
<td></td>
<td>$E_a$ (KJ/mol)</td>
<td>158.114</td>
<td>129.100</td>
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Table 4: Langmuir Isotherm with Separation Factor ($R_L$)

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<tr>
<td>KAO.1</td>
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<td>0.605</td>
<td>0.535</td>
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<tr>
<td>MKB</td>
<td>0.671</td>
<td>0.577</td>
<td>0.505</td>
<td>0.450</td>
<td>0.405</td>
</tr>
</tbody>
</table>
Table 5: Comparison of Adsorption Capacity of Cadmium(II) Ions with others Adsorbents

<table>
<thead>
<tr>
<th>Adsorbents</th>
<th>$Q_m$ (mg/g)</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Montmorillonite</td>
<td>0.150</td>
<td>Ecboon et al., 2010</td>
</tr>
<tr>
<td>Rice Husk Ash</td>
<td>3.84</td>
<td>El-Said et al., 2010</td>
</tr>
<tr>
<td>Activated carbon</td>
<td>63.28</td>
<td>Achour and Youcef, 2004</td>
</tr>
<tr>
<td>KAO.1</td>
<td>7.407</td>
<td>Present study</td>
</tr>
<tr>
<td>MKB</td>
<td>9.174</td>
<td>Present study</td>
</tr>
</tbody>
</table>

4. CONCLUSION

In this study, Kaolinite (KAO.1) and Metakaolinite (MKB) have been used as adsorbents for the elimination of cadmium(II) ions from aqueous solutions. Adsorption was influenced by various parameters such as contact time, absorbent dosage, initial pH and initial cadmium(II) ions concentration. The adsorbent dosage had an effect on the adsorption process of cadmium(II) ions. The maximum uptake of cadmium(II) ions occurred at an initial pH of 8.0. Adsorption was increase with increasing initial cadmium(II) concentration 50-150 mg/L. The maximum cadmium(II) ion uptake capacity was 7.407 and 9.174 mg/g for KAO.1 and MKB, respectively. The kinetics of cadmium(II) ion adsorption nicely followed pseudo second-order for both adsorbents. Langmuir and D-K-R isotherms could be used to describe adsorption cadmium(II) by both adsorbents. Kinetic and isotherm studies revealed that KAO.1 and MKB can be effectively employed for the adsorption of cadmium(II) ions.

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