The International Journal Of Engineering And Science (IJES)
|| Volume || 6 || Issue || 2 || Pages || PP 17-26 || 2017 ||
ISSN (e): 2319 – 1813 ISSN (p): 2319 – 1805

Equilibrium and Kinetics Adsorption of Cadmium and Lead Ions from Aqueous Solution Using Bamboo Based Activated Carbon

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ABSTRACT

Sourcing cheap adsorbents for the treatment of waste water is imperative for local environments. The adsorption of cadmium (Cd) and lead (Pb) from aqueous solution onto bamboo activated carbon prepared by chemical activation with $ZnCl_2$ *was investigated. The unwashed chemical activated bamboo carbon (UCABC) achieved up to 87.81% and 96.45% removal of Cd and Pb at pH-5 and 11, respectively. Removal equilibrium was attained within 1hr and 2.5hrs for Cd and Pb, respectively. The Cd and Pb adsorption increased with adsorbent dosage decrease while removal rate (%) increased with Cd and Pb concentration. Adsorption isotherm of Cd and Pb onto UCABC was determined and correlated with four isotherm models (Langmuir, Freundlich, Temkin and Hills). The equilibrium data fitted into Freundlich Cd* (R^2 = 0.9873, SSE = 0.045)*, Pb* (R^2 =0.9903, SSE = 0.051)*; Temkin Cd* (R^2 =0.9730, SSE = 0.052)*, Pb* (R^2 = 0.9079, SSE = 0.056)*; Hills Cd* (R^2 = 0.9961, SSE = 0.048)*, Pb* ($R^{2.}$= 0.9183, SSE = 0.053) *and Langmuir Cd* (R^2 = 0.9653, SSE = 0.302)*, Pb* (R^2 = 0.9899, SSE = 0.136) *isotherms. The Freundlich fitting showed isotherm adsorption capacity constants* K_f *= 7.843 and 5.098 (mg/g) for Cd and Pb, respectively. Furthermore, their adsorption kinetics correlated with the Pseudo-first order, Pseudo-second order and Intra-particle diffusion models and could be best described by the Pseudo-second order equation, suggesting chemisorptions as the limiting process. This study demonstrated that the UCABC can remove* Cd^{2+} *and* Pb^{+} *ions from aqueous solution to avert expensive commercial adsorbents.*

Keywords: *Adsorbents, Bamboo activated carbon, Adsorption, Isotherms, Kinetics.*

Date of Submission: 21 November 2016 Date of Accepted: 09 February 2017

Nomenclature

a	Gradient of linear plots
A_t	Temkin isotherm constant relating to equilibrium binding energy (L/g)
b_t	Temkin isotherm constant relating to heat of adsorption.
UCABC	Unwashed Chemical Activated Bamboo Carbon.
Cal q_e	Calculated adsorbate concentration at equilibrium (mg/g)
C_e	Equilibrium concentration (mg/l)
C_o	Initial concentration of adsorbate (mg/l).
C_t	Concentration of adsorbate at any time t (mg/l)
Exp q_e	Experimental adsorbate equilibrium conc. (mg/g)
h	Initial adsorption rate (mg/g/mins)
K	Langmuir constant relating to rate of adsorption
K_D	Hills constant
K_f	Freundlich isotherm adsorption capacity constant
k_{id}	Intra particle diffusion rate constant (min^{-1})
K_{p1}	First order rate constant (mg/mins)
K_{p2}	Second order rate constant (mg/mins)
m	Mass of adsorbent (g)
N	Number of data points.
n	Freundlich isotherm constant relating to adsorption intensity
nH	Hills coefficient describing cooperativity
q_e	Mass of solute adsorbed per unit mass of adsorbed (mg/g)
q_o	Maximum monolayer adsorption capacity (mg/g)
q_t	Amount adsorbed at time t (mg/g)
q_{SH}	Hills equilibrium constant relating to max uptake saturation (mg/l)
R	Fraction of the amount adsorbed
R^2	Coefficient of determination
R_L	Dimensionless separation factor
T	Absolute temperature (Kelvin) (K)
t	Contact time (min)
V	Experimental volume of wastewater (liters)

I. INTRODUCTION

Land and water bodies are polluted with all kinds of chemicals and toxic substances which are discharged from industrial and domestic effluents. The indiscriminate release of heavy metals via wastewater into the environment without proper treatment has resulted in a total pollution of the environment. This has caused many water bodies receiving loads of pollutants that exceed the maximum permissible limit designed to protect the environment thereby, causing ineffectiveness of purification systems which may lead to accumulation of toxic products in the receiving water bodies with potentially serious consequences on the ecosystem (Beg et al, 2001). The presence of these heavy metals in the environment has led to many environmental problems since most of them are toxic, carcinogenic and persistence in nature. For example, the lead poisoning in Zamfara State, Nigeria in 2010 which claimed hundreds of lives clearly attests to the detrimental effect of heavy metals in the environment [On line www.iccon.org.ng/index. last assessed Jan. 2016]. Also, 1950 Japanese Scientists reported that more than 45 people died as a result of consuming fishes caught in Minamata Bay, which were found to contain high levels of mercury (Watanabe and Satoh, 1996). Therefore, the treatment of polluted industrial wastewater remains a topic of global concern. At least 20 metals are classified as toxic, in which lead and cadmium are among and many of these are emitted into the environment in quantities that pose risk to human health (Dwari et al, 2004).

Adsorption has been extensively studied as an effective method for removing a wide range of hazardous materials such as heavy metals and dyes from aqueous solutions. The most widely used adsorbent for separation of pollutants is activated carbon. However, commercial activated carbon is very expensive thus, efforts has been geared toward the use of agricultural by products as raw material for manufacturing activated carbon. Bamboo, an abundant natural resource, can be used to produce activated carbon (Hameed et al, 2006; Keith et al, 2005; Evbuomwan et al, 2013; Mahanim et al, 2011; Nwabane and Mordi, 2009). The use of natural material as raw materials for manufacturing activated carbon is advantageous as these raw materials are renewable and potentially less expensive. The objective of this study is to use bamboo activated carbon to remove cadmium and lead from aqueous solution. The equilibrium and kinetic studies were conducted to understand the nature and mechanism of the adsorption process.

II. EXPERIMENTAL

2.1 Preparation of Bamboo Activated Carbon

The Bamboo sticks *(Bamboosoidae Grasses L)* used in this study is the dominant bamboo in Nigeria found in the rain forest belt (Forestry Department, Food and Agriculture Organization, 2005). Fully matured Bamboo sticks were cut into (2-4cm) sizes, washed, outdoor dried and then processed in laboratory. The bamboo samples were chemically activated using $ZnCl_2$ (80% purity) at impregnation ratio of 1:2, then carbonized in a muffle furnace at 500^oC for 3hrs and grinded into powder. The bamboo activated carbon was not washed (to remove the activating chemical) rather they were passed through a set of sieves (50, 150, 250 and 425µm) to obtain different particle sizes for experimental tests. This set of samples was referred to as Unwashed Chemical Activated Bamboo Carbon (UCABC).

2.2 Optimum Conditions for Adsorption of Cd and Pb onto UCABC.

Wastewater samples were simulated in the laboratory by mixing $CdCl_2.2\frac{1}{2}H_2O$ salt and $(Pb(NO_3)_2)$ salt in distilled water to obtain the desired initial concentrations. All the chemicals used were of analytical grade. Batch adsorption studies were performed to determine the optimum conditions for the removal of Cd and Pb from the simulated wastewater. Effects of carbon dosage were studied at pH 7 with different adsorbent doses (1, 2, 3, 4 and 5g) and initial adsorbate concentration (20mg/l) and agitating for 1h. Effects of initial adsorbate conc. were studied at various concentration of Cd and Pb (10, 20, 30, 40 and 50mg/l) but using the optimum adsorbent dosage and other experimental conditions remained the same. Effects of adsorbate pH were studied by adjusting the adsorbate pH (3, 5, 7, 9 and 11) using 0.1M NaOH or HCL and then using optimum dosage and concentration while other experimental conditions remained the same. The effects of agitation time were investigated for 0.5, 1.0, 1.5, 2.0, 2.5 and 3.0hrs using optimum dosage, concentration and pH. The effects of particle size were conducted at various particle sizes (50, 150, 250 and 425µm) using the optimum dosage, concentration, pH and time. At the end of adsorption period, the various samples were filtered through Whatman filter paper (#542) and the filtrates were analyzed for residual concentrations of Cd and Pb using Atomic Adsorption Spectrometer (AAS) *(model Spectr AA 55B, Agilent Technologies, USA)*. The adsorption efficiency (Equation 1) of the test carbons was used as criterion for determining optimum conditions.

$$\% \text{ Removal} = \frac{(C_o - C_t)}{C_o} \times 100\% \qquad (1)$$

2.3 Equilibrium Adsorption Studies

The equilibrium adsorption studies were conducted at 25°C using optimum condition for Cd and Pb at fixed initial adsorbate conc. and varying adsorbent doses, to investigate the sorption capacity of UCABC. For Cd, 50ml of simulated wastewater samples of 50mg/l (pH 5) were measured into 5 different plastic containers and specified adsorbent doses (0.2, 0.4, 0.6, 0.8 and 1.0g) of 50μm were added to each of the plastic containers. The mixtures were agitated on a mechanical shaker for 1hr. The procedures were replicated for Pb using pH 11, particle size (250 - 425μm) and agitation time of 2.5hrs. At the end of the adsorption period, the mixtures were filtered and analyzed for residual Cd and Pb by AAS. The equilibrium adsorption capacity (q_e) of the adsorbent was obtained using Equation (2)

$$q_e = \frac{(C_o - C_e)}{M} V \qquad (2)$$

2.4 Adsorption Kinetics

The adsorption kinetics of Cd and Pb was processed at various intervals using two initial concentrations (50mg/l and 100mg/l). For Cd, 0.2g of UCABC (50μm) were mixed with 50ml of Cd solution (pH 5) and then attached to a mechanical shaker. The samples were agitated and then taken at 5, 10, 20, 30, 40, 50, 60, 70, 80, 100 and 120mins intervals and filtered. For Pb, 0.2g of UCABC (250 - 425μm size) was mixed with 50ml of Pb solution (pH 11) and the attached to a mechanical shaker. The samples were agitated and taken at 10, 20, 40, 60, 80, 100, 120,140, 160 and 180mins intervals and filtered. The filtrates were analyzed for residual concentrations of Cd and Pb by AAS The adsorption capacity of the adsorbents at preset time t, q_t, was obtained from Equation (3).

$$q_t = \frac{(C_o - C_t)}{M} V \qquad (3)$$

III. RESULTS AND DISCUSSION

3.1 Optimum Condition for Adsorption

The effect of adsorbent doses on Cd and Pb adsorption onto UCABC revealed that adsorption decreased with adsorbent dosage (Figure 1), while the results in Figure 2 showed that higher initial concentration of the adsorbate gave higher removal rate (%) with an optimum removal efficiency of 82.62% and 92.82% for Cd and Pb, respectively.

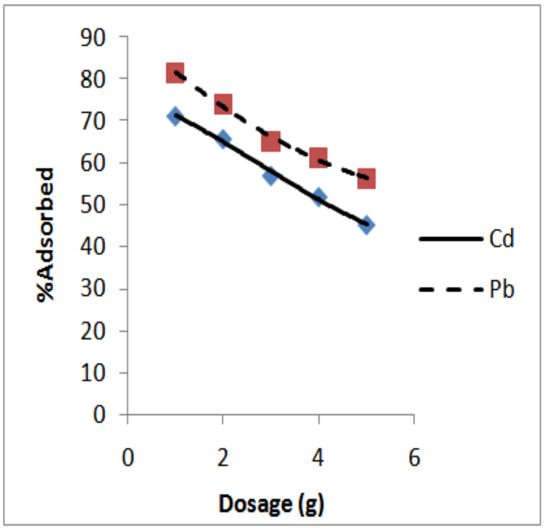


Figure 1: Effects of Adsorbent dosage UCABC on Adsorption of Cd and Pb

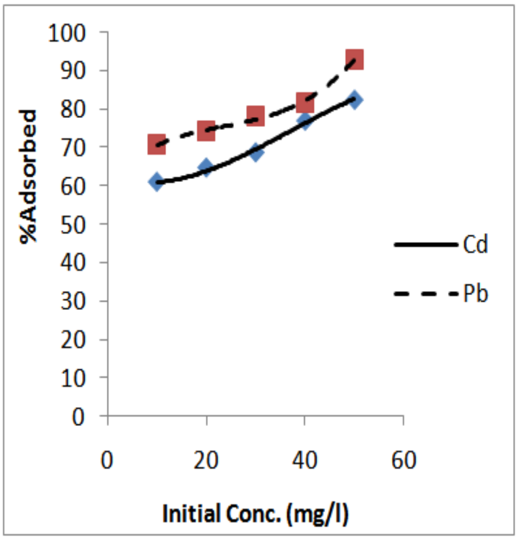


Figure 2: Effects of Initial concentration of Cd and Pb on Adsorption onto UCABC

The effect of pH on adsorption showed that removal efficiency (%) of Cd decreased while that of Pb increased with increase in pH-value. High removal efficiency of 87.81% at pH 5 was observed for Cd, while 96.45% was observed for Pb at pH 11 (Figure 3). Furthermore, the removal efficiency increased with agitation time and attained equilibrium in 1h for Cd and 2.5hrs for Pb (Figure 4).

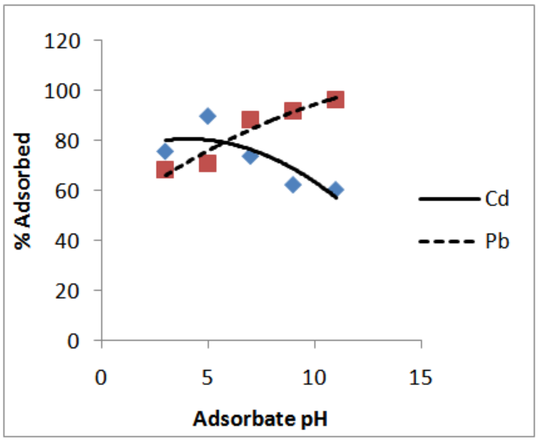


Figure 3: Effects of Adsorbate pH on Adsorption of Cd and Pb onto UCABC

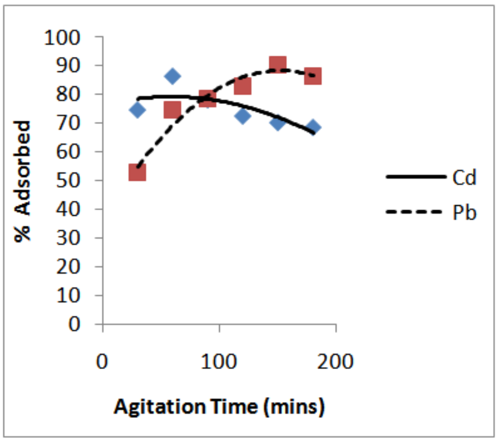


Figure 4: Effects of Agitation Time on Adsorption of Cd and Pb onto UCABC

3.2 Adsorption Isotherms

Adsorption isotherms were used to describe the interactions of solutes with adsorbents with a view to optimizing adsorbent dosage. The equilibrium data from Cd and Pb adsorption onto UCABC were modelled using Langmuir, Freundlich, Temkin and Hills isotherm models in order to obtain the best fit.

3.2.1 Langmuir Isotherm

Langmuir isotherm is based on following assumptions: (1) that the surface of the adsorbent is homogenous (all the adsorption sites are equivalent). (2) Adsorbed molecules do not interact. (3) All adsorption occurs through the same mechanism. (4) At the maximum adsorption, only a monolayer is formed. Mathematically, the Langmuir adsorption isotherm is expressed in Equation (4):

$$q_e = \frac{q_o K C_e}{1+K C_e} \qquad (4)$$

The linear form of Langmuir's isotherm model is given in Equation 5:

$$\frac{C_e}{q_e} = \frac{1}{q_o K} + \frac{C_e}{q_o} \qquad (5)$$

Linear plot of $\frac{C_e}{q_e}$ against C_e gives slope = $\frac{1}{q_o}$ and intercept = $\frac{1}{q_o k}$

The correlation of experimental data with Langmuir equation gave high correlation coefficient ($R^2 = 0.9653$ and 0.9899) for Cd and Pb respectively. The Langmuir adsorption capacity (q_o) was 1.912 and 2.023 (mg/g), the energy of adsorption (K) was -0.884 and -1.965 (mg^{-1}) for Cd and Pb respectively The Langmuir dimensionless equilibrium parameter R_L calculated from Equation 6.were given as -0.018 and -0.01 for Cd and Pb respectively.

$$R_L = \frac{1}{1+ KC_0} \qquad (6)$$

Observe that the value of R_L indicates the type of the isotherm to be either unfavorable ($R_L > 1$), linear ($R_L = 1$), favourable ($0 < R_L < 1$) or irreversible ($R_L = 0$).

3.2.2 Freundlich Isotherm

The Freundlich isotherm, which is based on the equilibrium relationship between heterogeneous surfaces, assumes interaction between the adsorbed molecules and multilayer formation on the surface of the adsorbent with an exponential distribution of the heat of adsorption. The Freundlich equation (Freundlich, 1906) is expressed in Equation (7):

$$q_e = K_f C_e^{\frac{1}{n}}, \qquad (7)$$

Linear form of Freundlich equation is given in Equation (8).

$$\log(q_e) = \log K_f + \frac{1}{n} \log C_e . \qquad (8)$$

Linear plot of **log q_e** against **log C_e** gives slope = 1/n and intercept = log K_f.

Correlation of experimental data with Freundlich model also gave high correlation coefficients ($R^2 = 0.9873$ and 0.9903) for both Cd and Pb adsorption as shown in Figs. 5 and 6. The Freundlich adsorption capacity (K_f) was as 7.843 and 5.098 (mg/g) for Cd and Pb respectively indicating good adsorption capacity for UCABC (Amuda and Ibrahim, 2006). The 1/n values obtained were -0.595 and -0.462 for Cd and Pb respectively. Note that the value for 1/*n* below one implies chemisorptions process while 1/*n* above one is indicative of cooperative adsorption (Haghseresht and Lu, 1998; Foo and Hameed, 2009; Fytianos et al, 2000).

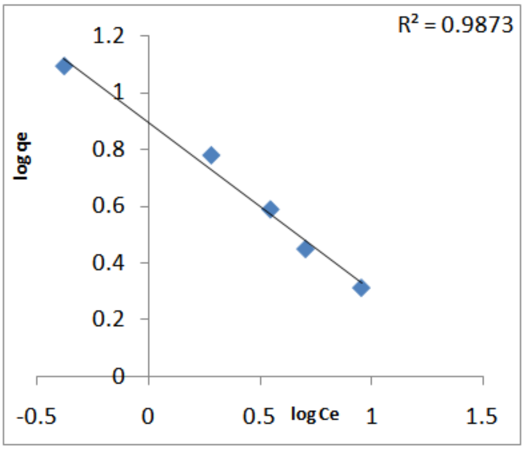


Figure 5: Freundlich Isotherm for the Adsorption of Cd onto UCABC.

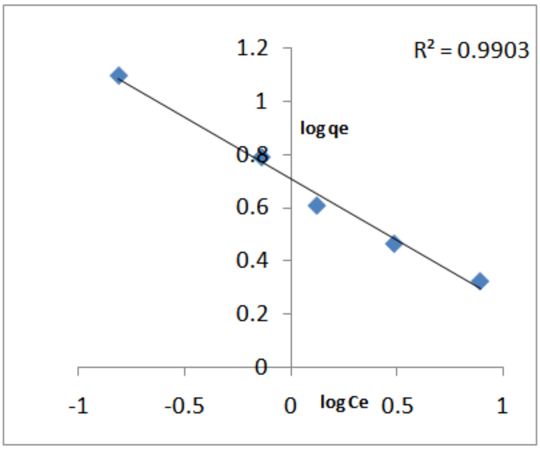


Figure 6: Freundlich Isotherm for the Adsorption of Pb onto UCABC.

3.2.3 Temkin Isotherm

The Temkin isotherm model assumes that the heat of adsorption (function of temperature) of all the molecules in the layer decreases linearly with coverage due to adsorbent-adsorbate interactions (Aharoni and Ungarish, 1977; Foo and Hameed, 2010). Also, the model assumes that the adsorption is characterized by a uniform distribution of the binding energies, up to some maximum binding energy. Temkin isotherm is represented in equation (9):

$$q_e = \frac{RT}{b_T} Log\ A_T\ C_e$$

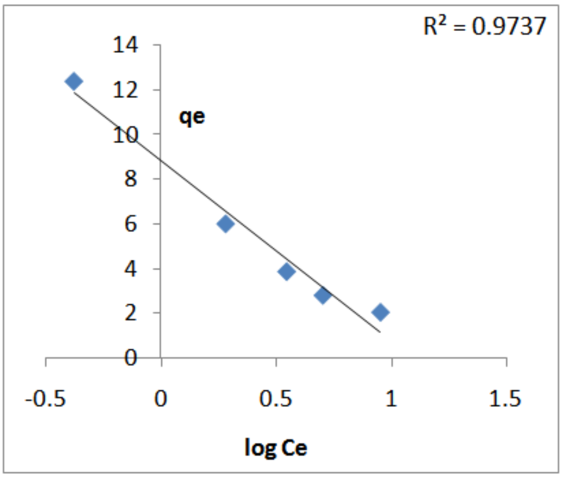
(9)

The linearized form of this model is given in Equation (10):

$$q_e = \frac{RT}{b_T} Log\ A_T + \frac{RT}{b_T} Log\ C_e$$

(10)

A plot of q_e versus log C_e enables the determination of the isotherm constants b_T and A_T from the slope and intercept respectively. Correlation of experimental data with Temkin model also gave high correlation coefficients ($R^2 = 0.973$ and 0.9079) for Cd and Pb, respectively as shown in Figures 7 and 8. The Temkin isotherm parameters (b_t = -306.74 and -403.70) and (A_t = 0.897 and 0.097) relates to the equilibrium binging energy and heat of adsorption for Cd and Pb, respectively.



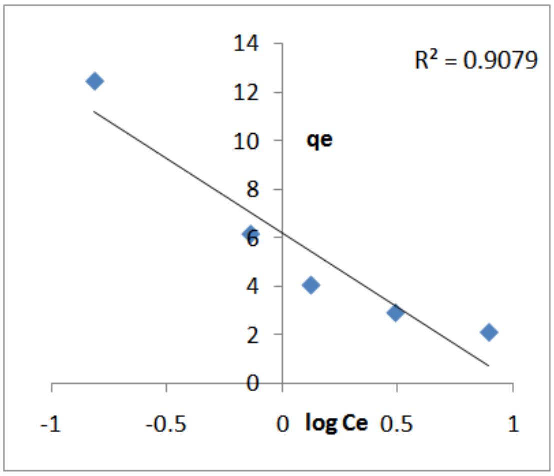


Figure 7: Temkin Isotherm for the Adsorption of Cd onto UCABC

Figure 8: Temkin Isotherm for the Adsorption of Pb onto UCABC

3.2.4 Hills Isotherm

Hills isotherm equation (Hill, 1910) was postulated to describe the binding of different species onto homogeneous substrates. The model assumes that adsorption is a cooperative phenomenon, with the ligand binding ability at one site on the macromolecule and this may influence different binding sites on the same macromolecule (Ringot et al, 2007; Foo and Hameed 2010). Hills isotherm model is represented in Equation (11):

$$q_e = \frac{q_{SH}\, C_e^{nH}}{K_D + C_e^{nH}} \quad (11)$$

The linearized form of the model is given in Equation (12):

$$Log\left(\frac{q_e}{q_{SH} - q_e}\right) = nH\ logC_e - \log K_D \quad (12)$$

A plot of log $\left(\frac{q_e}{q_{SH} - q_e}\right)$ versus log C_e enables the determination of the isotherm constants nH and K_D from the slope and intercept respectively. The correlation of experimental data with Hills model equations also gave high correlation coefficient ($R^2 = 0.9961$ and $R^2 = 0.9183$) for both Cd and Pb respectively as shown in Figures 7 and 8. The Hills isotherm parameters were given as (qsH = 18 and 14) (nH = -0.949 and 0.974) and (K_D = 0.936 and 0.9183) for Cd and Pb adsorption respectively.

3.3 Model Verification

To verify the authenticity of these isotherm models for the adsorption of Cd and Pb, interpolated and extrapolated C_e values from the equilibrium adsorption were used to calculate the Exp q_e and Cal q_e values for model verification. The calculated isotherm parameters were fitted into the isotherm model equations to get the calculated q_e values. The plots of Exp q_e and Cal q_e against dosage were presented in Figures 11 to 16.

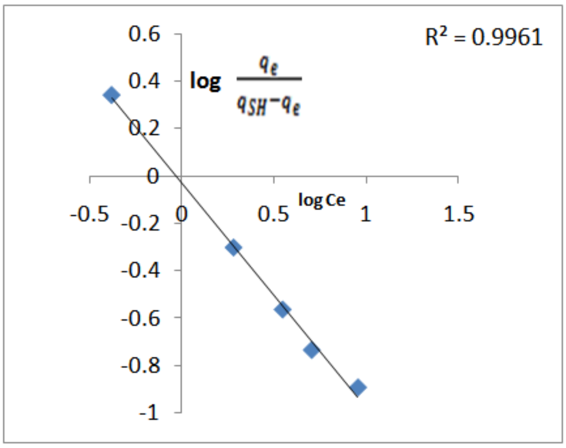


Figure 9: Hills Isotherm for Adsorption of Cd onto UCABC.

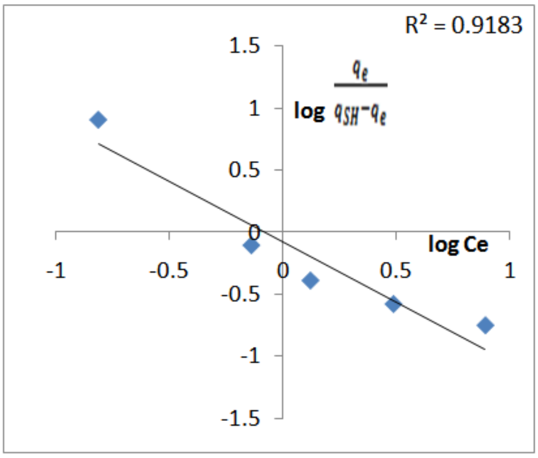


Figure 10: Hills Isotherm for Adsorption of Pb onto UCABC.

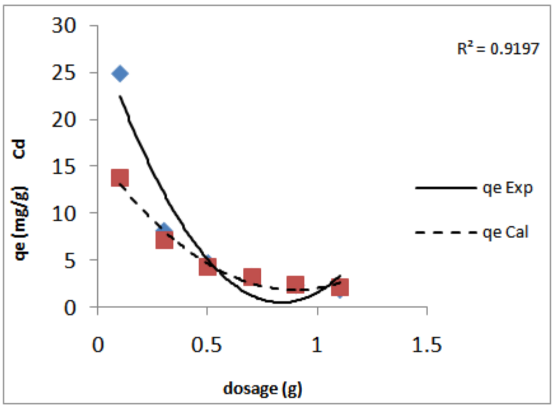


Figure 11: Freundlich Exp and Cal q_e for Adsorption of Cd onto UCABC.

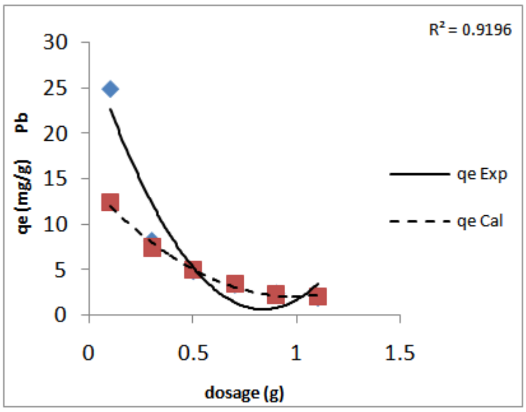


Figure 12: Freundlich Exp and Cal q_e for Adsorption of Pb onto UCABC.

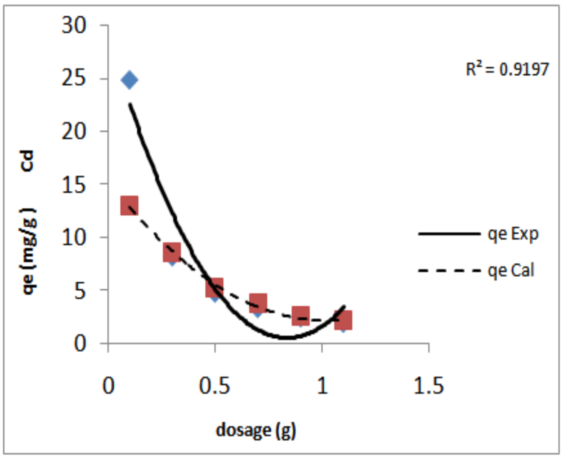


Figure 13: Hills Exp and Cal q_e for Adsorption of Cd onto UCABC.

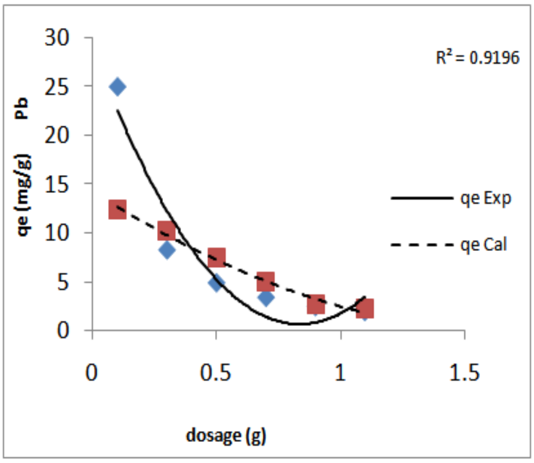


Figure 14: Hills Exp and Cal q_e for Adsorption of Pb onto UCABC.

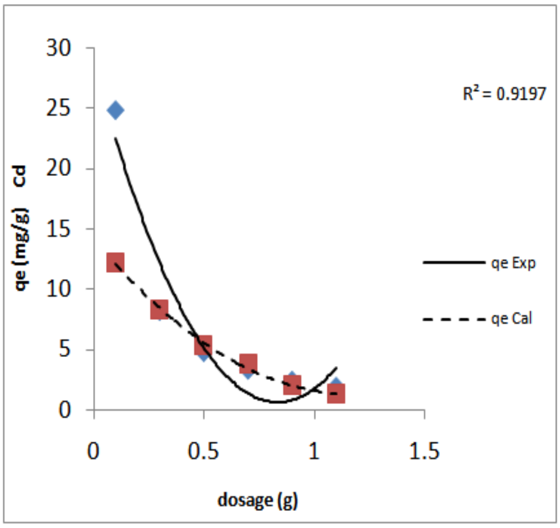


Figure 15: Temkin Exp and Cal q_e for Adsorption of Cd onto UCABC.

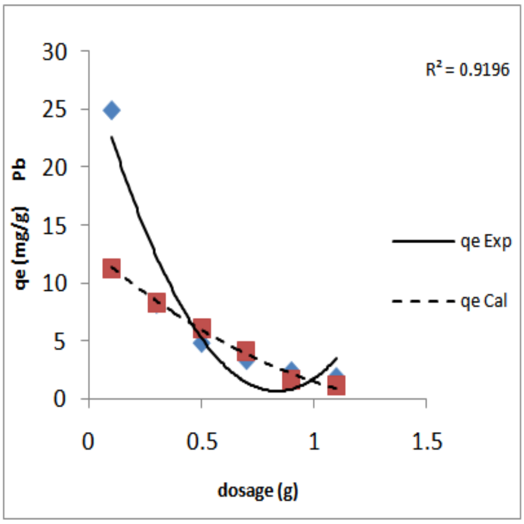


Figure 16: Temkin Exp and Cal q_e for Adsorption of Pb onto UCABC.

From the plots, it was observed that Exp q_e values correlated with the Cal q_e values for Freundlich, Temkin and Hills models but do not correspond with Langmuir models despite the high correlation coefficients. However, the applicability of the isotherm models for the adsorption of Cd and Pb was further verified.

3.4 Test for Isotherm Models

The applicability of these isotherm models was further verified through the sum of error squares (SSE, %) calculated from Equation 13: Note that the higher the value of R^2 and the lower the value of SSE, the better will be the goodness of fit.

$$\text{SSE (\%)} = \sqrt{\frac{\sum (q_{e,exp} - q_{e,cal})^2}{N}} \qquad (13)$$

The sum of error squares was calculated from the values of Exp q_e and Cal q_e values using the Excel software. Results of the test for validity of each isotherm model shown in Table 1 revealed that Freundlich isotherm model had the smallest SSE value (0.045%) and (0.054%) for Cd and Pb adsorption respectively. From these results, the adsorption of Cd and Pb onto UCABC fitted well into Freundlich, Hills and Temkin model but could be best described by Freundlich isotherm indicating chemisorptions adsorption with multilayer formation on heterogeneous surface of UCABC. Similar observations were made by Nwabane and Mordi, 2009; Ademiluyi et al, 2009).

Table 1: SSE (%) Values for the Adsorption of Cd and Pb onto UCABC

Equilibrium Models	SSE% Cd	SSE% Pb
Langmuir isotherm	0.302	0.136
Freundlich isotherm	0.045	0.051
Temkin isotherm	0.052	0.056
Hills isothrem	0.048	0.053

3.4 Adsorption Kinetics

The adsorption kinetics was investigated to understand the mechanism of adsorption process in terms of the order of rate constant. The rate of adsorption was analyzed using pseudo-first order, pseudo second order and intra particle diffusion model equations.

3.4.1 Pseudo First Order Model

The pseudo first order equation is given in Equation 14:

$$\frac{dq}{dt} = K_{p1}(q_e - q_t) \qquad (14)$$

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 (14) is given in Equation 15:

$$\text{Log}(q_e - q_t) = \text{Log}(q_e) - k_{p1}\,t \qquad (15)$$

The values of log (q_e – q_t) from experimental data were linearly correlated with **t** and the values of $\mathbf{k_{p1}}$, and $\mathbf{q_e}$ were determined from the slope and intercept of the plots respectively. The R^2 values from the plots gave poor correlation and the Exp and Cal qe values were significantly different as shown in Table 2. These suggest that the adsorption data fitted poorly to pseudo first order kinetics. Also, low k_{p1} values were observed for Cd and Pb removal indicating lower rate of adsorption. Generally, the higher the value of k_{p1}, the greater the adsorption while the lower the Exp qe value the better the adsorption (Igwe and Abia, 2007).

Table 2: Kinetic Parameters of Equilibrium Adsorption (q_e) for Cd and Pb onto UCABC

Metals	C_o	Pseudo First Order					Pseudo Second Order				Intra Particle Diffusion		
		Exp. q_e	Cal q_e	K_{p1}	R^2	SSE (%)	Cal q_e	K_{p2}	R^2	SSE (%)	K_{id}	A	R^2
Cd	50	11.5	0.45	0.001	0.003	0.17	10.79	-0.13	0.9981	0.007	93.35	-0.015	0.361
	100	22.0	0.37	0.003	0.014		21.23	-0.08	0.9981		85.27	0.004	0.036
Pb	50	12.4	0.12	0.004	0.235	0.19	11.78	0.042	0.9993	0.009	100.55	-0.008	0.169
	100	24.0	0.34	0.002	0.039		22.88	-0.08	0.9987		91.14	0.0067	0.057

3.4.2 Pseudo-Second Order Model

The pseudo-second-order equation expressed in Equation 16, predicts the behaviour of the adsorbent over the whole range of data and it is in agreement with chemisorption being the rate controlling step (Ho and McKay, 1999):

$$\frac{dq}{dt} = k_{p2}(q_e - q_t)^2 \qquad (16)$$

Integrating Equation 16 at the same boundary conditions t=0 to t=t and qt=0 to qt=qt, the integrated form is given in Equation (17):

$$\frac{1}{q_e - q_t} = \frac{1}{q_e + k_{p2}} \qquad (17)$$

Equation (17) is the integrated rate law for a pseudo second order reaction and rearranging in linear form is expressed in Equation 18:

$$\frac{t}{q_t} = \frac{1}{k_{p2}\, q_e^{\,2}} + \frac{1}{q_e} t \qquad (18)$$

The pseudo second order plots for the adsorption of Cd and Pb onto UCABC at two different concentrations were presented in Figures 17 and 18. The corresponding second order kinetic constants and the correlation coefficients were given in Table 2. A correlation was observed between the experimental q_e and the calculated q_e values with the R^2 values ranging from 0.9981 and 0.9993. Thus, the adsorption of Cd and Pb onto UCABC fitted well into pseudo second order kinetics. Furthermore, it was observed that the equilibrium adsorption capacity, q_e increased with increase in initial Cd and Pb concentrations. The same tend was observed by (Akpen et al, 2011).

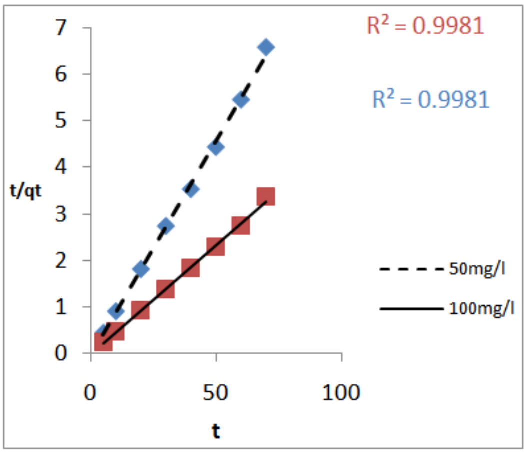


Figure 17: Pseudo-second-order kinetics for Cd adsorption onto UCABC.

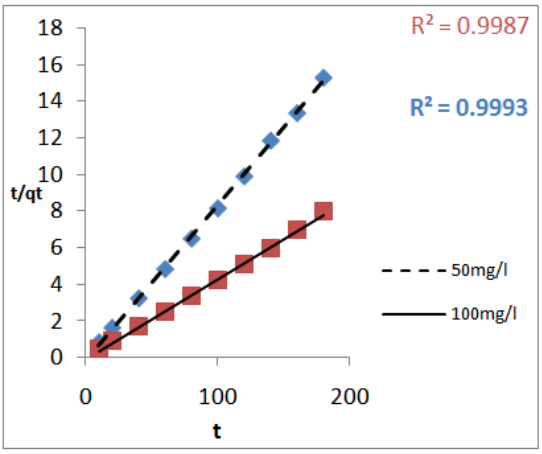


Figure 18: Pseudo second order kinetics for Pb adsorption onto UCABC

3.4.3 Intra-Particle Diffusion Model

Intra-particle diffusion model (Weber and Morris, 1963) is expressed in Equation (18):

$$R = K_{id}\,(t)^{a} \qquad (19)$$

The linearized form is expressed in Equation (20) as:

$$\text{Log } R = \text{Log } K_{id} + a \text{ Log } (t) \qquad (20)$$

The plot of **log R** vs. **log t** gives a linear plot from which the values of **'a'** and $\mathbf{K_{id}}$ would be determined from the slope and intercept respectively. If Intra Particle diffusion occurs, then a plot of log R against log t will give a linear plot which will pass through the origin if Intra Particle Diffusion was the only rate limiting parameter controlling the process.

However, the linear plots from this study did not pass through the origin. The deviation from the origin may be due to the variation of mass transfer in the initial and final stages of adsorption (Sivakumar and Palanisamy, 2009). This indicates that intra particle diffusion was not the sole rate controlling step involved in the adsorption of Cd and Pb onto UCABC. The Intra Particle diffusion rate, K_{id} and the coefficients of determination (R^2) were presented in Table 2. In general, high K_{id} values indicate a better adsorption mechanism, which is related to an improved bounding between the adsorbent particles and adsorbates (Demirbas et al, 2004).

3.4.4 Test of Kinetic Models

The applicability of these kinetic models was verified using SSE, % (Equation 13). The Exp q_e and Cal q_e values were used to calculate the SSE using the Excel® platform and the results were presented in Tables 2. Results of the test for validity of each Kinetic model showed that pseudo second order kinetic model had the smallest SSE value of 0.007% and 0.009% for Cd and Pb adsorption respectively. Note that the higher the value of R^2 and the lower the value of SSE, the better will be the goodness of fit. From these results, the adsorption of Cd and Pb onto UCABC was best described by the Pseudo Second Order Kinetic Model. Similar observations have been reported by (Hameed et al 206; Foo and Hameed, 2010; Wang et al, 2010).

IV. CONCLUSION

This study demonstrated the adsorptive capacity of Unwashed Chemical Activated Bamboo Carbon (UCABC) in the removal of Cd and Pb from wastewater. The UCABC achieved up to 87.81% and 96.45% removal efficiency for Cd and Pb, respectively. The amount of Cd and Pb adsorbed increased with adsorbent dosage decrease; while the removal rate (%) increased with increase in initial Cd and Pb concentration. The adsorption behaviour of Cd and Pb was described by Freundlich, Temkin and Hills Isotherms with a best fit in Freundlich equation indicating multilayer adsorption on heterogeneous surface. The kinetic data followed pseudo second order model suggesting that chemisorptions may be the rate limiting step in the adsorption process and it may involve the sharing or exchange of electrons between adsorbent (UCABC) and adsorbates (Cd and Pb).

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