
KINETIC, EQUILIBRIUM AND THERMODYNAMIC ASSESSMENT OF THE ADSORPTION OF CADMIUM USING WATER LILLY (*Nymphaea ampla*) ROOT BIOMASS

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ABSTRACT

The adsorption of cadmium (II) ions from aqueous solutions by *Nymphaea ampla* root biomass was investigated under batch mode. The effects of initial cadmium concentration, solution pH, sorbent dose, contact time and temperature on the adsorption were studied. A biosorbent dose of 50mg showed optimum adsorption capacity of 2.256mg/g (70%) for an initial metal concentration of 2mg/L at 15°C and pH 6.5. Optimum sorption equilibrium time was observed in 30minutes. Four isotherms; Langmuir, Freundlich, Temkin and Dubinin-Radushkevich (D-R) isotherm models were used to model the equilibrium sorption experimental data. Temkin isotherm yielded best fit to the experimental equilibrium adsorption data with correlation coefficient (R^2) of 0.980 followed by Langmuir isotherm (0.946), D-R isotherm (0.926) and Freundlich isotherm (0.537). The adsorption kinetics was determined by fitting pseudo-first order, pseudo-second order and intra-particle diffusion kinetic models to the experimental data with the pseudo-second order model providing the best description for cadmium (II) ion adsorption onto *Nymphaea ampla* root biomass. Thermodynamic parameters such as Gibbs free energy (ΔG^0), the enthalpy (ΔH^0), the entropy (ΔS^0) changes and the sticking probability (S^*) were evaluated and it was found that the adsorption process was spontaneous, feasible, and exothermic and follows physisorption mechanism. Therefore, the experiments showed that *Nymphaea ampla* root biomass can be effectively used as a low cost adsorbent for the removal of cadmium (II) ions from aqueous solutions.

Keywords: Adsorption, Cadmium (II) ion, *Nymphaea ampla*, equilibrium, Kinetics, thermodynamic.

INTRODUCTION

The toxicity and health hazards associated with heavy metals have been established beyond all reasonable doubts (Mahamadi, 2011). They can accumulate in living tissues causing various diseases and disorders (Asiagwu, 2012). Till recent years, the surge of industrial activities and processes such as mining, metal pigment, refining ores, fertilizer industries, battery manufacturing, paper industries and pesticides result in the release of heavy metals

into the environment (Witek-Krowiak *et al.*, 2011, Ahalya, 2003). The major toxic heavy metal ions hazardous to humans as well as other forms of life are Cr, Fe, Cu, Co, Ni, Cd, Hg, Pb, Zn etc. (Amal *et al.*, 2010). Cadmium, like other metals occurs naturally in nature and is found in association with zinc minerals. It is one of the most toxic metals because of the absence of a homeostatic control for it in the human body (Dawodu *et al.*, 2012). It has the potential to accumulate steadily in the human body when exposed through air, water or food sources and causes serious health problems to man, animals and aquatic life (Cheung *et al.*, 2000, Wu *et al.*, 2010, Morrow, 2010, Zahara *et al.*, 2008). Cadmium causes kidney and liver damages. Crustaceans are sensitive to the toxic effects of cadmium and most animal species have shown this metal to be teratogenic (Gupta *et al.*, 2008). The maximum contamination level (MCL) of cadmium in drinking water allowable by WHO and EPA is 0.005g/L (WHO, 2011). For this reason, proper treatment of industrial wastewater which releases cadmium into the ecosystem becomes very crucial. Considerable attention has been given to methods for metal removal such as electrochemical methods, reverse osmosis, chemical precipitation, ion exchange, biological processes, flotation and membrane processes (Park *et al.*, 2010). Unfortunately, these methods have their own inherent limitations such as less efficient, sensitive operating conditions, generation of secondary sludge and cost for their disposal (Rao *et al.*, 2010). In addition, these methods are also limited in the decontamination of aquatic systems with adsorbates in low concentration range (Vieira *et al.*, 2000; Volesky, 2007). Due to these limitations, considerable interests and studies have been on the use of sorbent materials of biological origin of recent particularly biosorbents. So far, the bioremediation process called biosorption has been found to be an economically feasible alternative for metal removal (Tien, 2002, Vijayaragheavan and Yun, 2008). In this study, the potential of *Nymphaea ampla* root biomass as a low cost adsorbent for the removal of cadmium (II) ions from aqueous solutions was investigated. The effect of various experimental parameters such as initial cadmium (II) concentration, pH, contact time, adsorbent dose and temperature were investigated. Adsorption isotherms, kinetics and thermodynamic parameters were also evaluated and reported.

MATERIALS AND METHOD

Preparation of Adsorbent

The *Nymphaea ampla* plants used in this study were harvested from a dam at Jarawa village in Jos North Local Government Area of Plateau State, Nigeria. The roots were carefully separated from the stems, thoroughly washed with deionized water and air-dried. The dried roots were then grinded, sifted through a sieve of 250 μ m mesh size and stored in air-tight containers for use.

Sorption Experiments

The reagents used in this study were of analytical grade. A stock solution (1000mg/L) of cadmium (II) was prepared by dissolving appropriate amount of Cd(NO₃)₂ in deionized water. From the stock solution, lower concentrations were prepared by accurate dilutions. The pH of each solution was adjusted to the required experimental value by the use of the pH meter to determine the pH after drop wise addition of 0.1M NaOH or 0.1M HNO₃ to the desired values. The sorption experiment was conducted using the batch method to determine the effects of the different parameters on the sorption process. The influence of initial cadmium ion concentration was performed in the range 0.5mg/L to 3.5mg/L, pH (4.5 to 7.0), time (5 to 120mins), adsorbent dose (10 to 120mg) and temperature (15 to 55°C). In each case, the parameter to be studied was varied while others were kept constant. At the end of the agitation time required in each case, the solution was filtered and the filtrate analyzed for residual cadmium (II) ion concentration using atomic adsorption spectrophotometer (AAS).

The data obtained in the batch mode studies was used to calculate the metal uptake capacity (q_e) and the biosorption efficiency (E) by using the following equations:

$$q_e = \frac{(C_i - C_e)V}{M} \quad (1)$$

$$E = \left[\frac{C_i - C_f}{C_i} \right] \times 100 \quad (2)$$

Where C_i = Initial cadmium concentration in mg/L, C_f = Final cadmium concentration in mg/L, V = Volume of the reaction mixture (L) and M = mass of the adsorbent in the reaction mixture (g).

RESULTS AND DISCUSSION

Effect of Initial Concentration on Adsorption

From Figure 1, it is evident that cadmium (II) ions removal increased with increase in initial concentration. This gradual increase in efficiency of the biomass could be due to availability of uncovered surface area of the adsorbent (Qadeer *et al.*, 2005). It could also be explained in terms of progressive increase in the electrostatic interaction between the metal ions and the adsorbent active sites. At low cadmium concentration, saturation of biomass by cadmium (II) ions could not be achieved, as the number of cadmium (II) ions was smaller than the number of binding sites present on the biomass. Consequently, increasing the concentration of cadmium in the solution is expected to result to increase in cadmium uptake until saturation of biomass is attained (Hanif *et al.*, 2007, Zubair *et al.*, 2008). Again, the number of collisions between metal ions and the biosorbent increases with increasing initial metal concentration so that biosorption process is enhanced. This is similar to the result reported by Hans *et al.*, 2005 for the adsorption of copper (II) and lead (II) on chaff.

Effect of pH

It is known that pH of a solution affects the surface charge of the biomass, the speciation of metal ions in aqueous solution and ionization of functional groups of the cell wall (Villar *et al.*, 2005, Biswajit *et al.*, 2012). As can be seen from Figure 2, the adsorption of cadmium (II) ions by *Nymphaea ampla* root biomass was strongly affected by pH. The optimum cadmium (II) ions adsorption was attained at pH 6.5 with 3.1185mg/g (93.56 %) cadmium (II) ions adsorbed. There is a sharp increase in metal uptake with increasing pH. The low adsorption observed at lower pH maybe due to higher concentration and mobility of H⁺ ions present in the solution which favoured the preferential adsorption of H⁺ ions rather than cadmium (II) ions; the adsorbent surface being surrounded by H⁺, thereby preventing the metal ions from approaching the binding sites on the adsorbent. The adsorbent surface becomes more positively charged such that the attraction between biomass and metal cations is reduced (Najua *et al.*, 2008). Furthermore, at pH above 6.5, insoluble cadmium hydroxide starts precipitating as Cd(OH)₂ and Cd(OH)₃⁻ from the solution leading to reduced biosorption (Yun-Shan and Ofomaja, 2006, Dawodu *et al.*, 2012).

Effect of Contact Time

The kinetic of metal adsorption governs the rate which determines the residence time (Krishan *et al.*, 2003). The result of the effect of time on the removal of cadmium (II) ions by *Nymphaea ampla* root biomass is presented in Figure 3. A rapid increase in adsorption with increase in time was observed within the first thirty minutes after which the rate of adsorption reduced up to 50 minutes. There was no significant change in the rate of adsorption up to 120 minutes which showed attainment of equilibrium. The fast uptake capacity obtained at the initial stage may be explained by an increased availability in the number of active binding sites on the adsorbent surface. The insignificant adsorption observed as time progresses is due to the fact that every adsorbent has a limited number of active sites which becomes occupied with time and further shaking resulted in desorption (Badmus *et al.* 2007).

Effect of Biosorbent Dose

From Figure 4, the percentage cadmium (II) ions adsorbed increased linearly with increase in adsorbent dose. Such a trend is mostly attributed to an increase in the sorptive surface area and the availability of more binding sites on the surface of the adsorbent (Saleem and Bhatti, 2011). Optimum cadmium uptake 1.6970mg/g (84.85%) was observed with 50mg dose. But the cadmium uptake decreased to 0.6829mg/g (81.95%) when the biosorbent dose increased to 120mg. This could be as a result of overlapping or partial aggregation and screening effect on the biomass surface, which occurred at high biomass dose, thus giving rise to decrease in the number of active sites and lower cadmium uptake per unit mass of biosorbent (Boota *et al.*, 2009; Bhatti *et al.*, 2009).

Effect of Temperature

Figure 5 indicates that the biosorbent capacity decreased with increase in temperature. This shows that the biosorption of cadmium (II) ions onto *Nymphaea ampla* root biomass was exothermic. This follows the adsorption theory that; adsorption decreases with increase in temperature as molecules earlier adsorbed on the surface tend to desorb from the surface at elevated temperatures (Spiff *et al.*, 2005) as the attractive forces between biomass surface and metals ions get weakened by the effect of high temperature (Spiff *et al.*, 2005; Bhatti *et al.*, 2009). Moreover, at higher temperatures, thickness of the boundary layer decreases due to increased tendency of the metal ion to escape from the biomass surface to the solution phase (Cruz *et al.*, 2004).

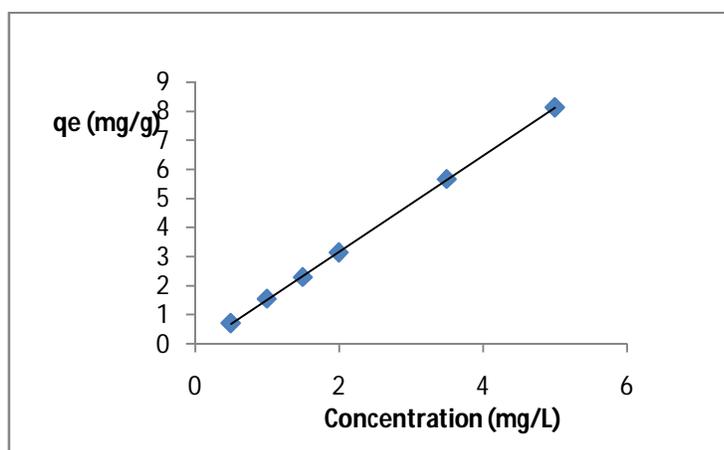


Figure1. Effect of initial concentration (adsorbent dose = 30mg, time = 45mins).

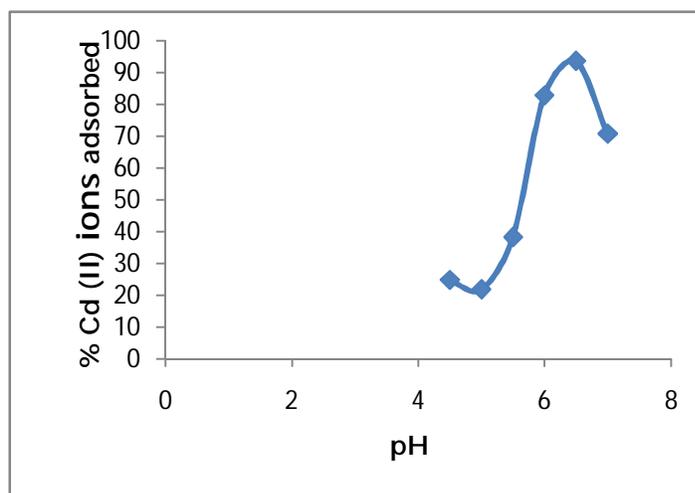


Figure 2. Effect of pH (adsorbent dose =30mg, initial concentration = 2.0mg/L).

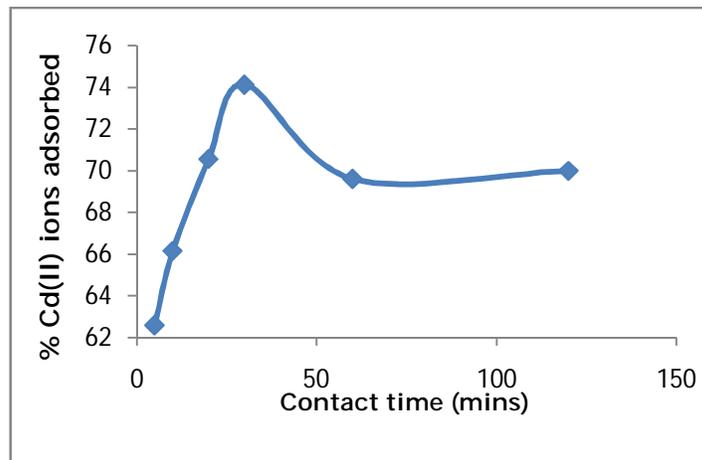


Figure 3. Effect of contact time (pH = 6.5, initial concentration = 2.0mg/L, adsorbent dose = 30mg).

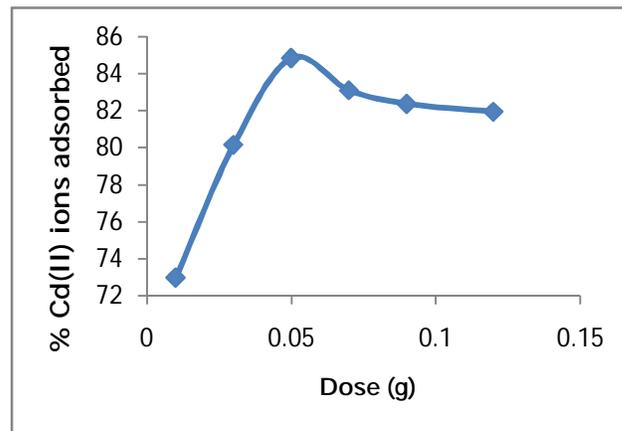


Figure 4. Effect of adsorbent dose (pH = 6.5, initial concentration = 2.0mg/L, time = 30min).

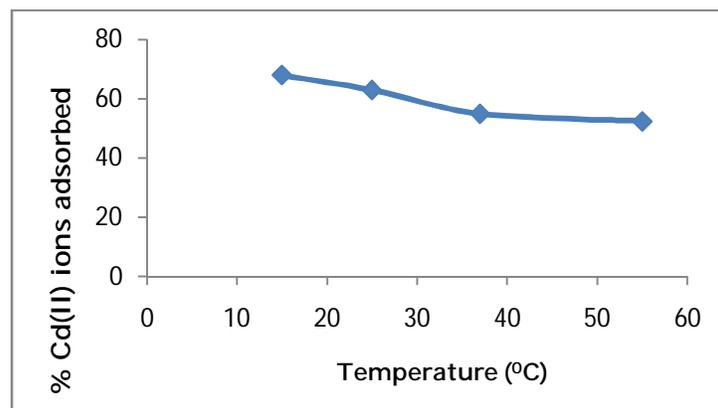


Figure 5. Effect of temperature (pH = 6.5, initial concentration = 2.0mg/L, time = 30min, adsorbent dose = 50mg).

ISOTHERM ANALYSIS

The adsorption potential of *Nymphaea ampla* root biomass was predicted using isotherm based equilibrium modeling. Experimental data on the effect of initial cadmium ion concentration on the adsorption capacity of *Nymphaea ampla* root biomass were fitted to four two-parameter isotherm models namely; Langmuir, Freundlich, Temkin and Dubinin-Radushkevich (D-R) isotherm models to evaluate the feasibility of adsorbate-adsorbent (metal ions to biomass) interaction. This adsorption data was analyzed with the help of the following forms of isotherms:

$$\text{Langmuir Isotherm: } q_e = \frac{q_{\max} K_L C_{\max}}{1 + K_L C_e} \quad (3)$$

$$\text{Linearised Langmuir Isotherm: } \frac{q_e}{C_e} = K_L q_{\max} - k_L q_e \quad (4)$$

Where q_{\max} is the maximum adsorption capacity (mg/g) and K_L is the Langmuir equilibrium constant (L/mg) related to energy of adsorption which quantitatively reflects the affinity between the adsorbent and adsorbate. The essential features of the Langmuir isotherm can be expressed in terms of a dimensionless constant; separation factor (R_L) defined by the relationship:

$$R_L = \frac{1}{1 + K_L C_i} \quad (5)$$

The value of R_L indicates the type of Langmuir isotherm to be irreversible ($R_L=0$), favourable ($0 < R_L < 1$), linear ($R_L = 1$) or unfavourable ($R_L > 1$). Apparently when $K_L > 0$, sorption is favourable (Langmuir, 1918). The Freundlich isotherm, applicable to non-ideal heterogeneous surfaces was chosen to estimate the adsorption intensity of the adsorbent and the linear form of the isotherm can be represented as:

$$\ln q_e = \ln K_F + 1/n \ln C_e \quad (6)$$

Where K_F and n are Freundlich constants which correlated to the maximum adsorption capacity and adsorption intensity respectively (Freundlich, 1906).

Temkin isotherm takes into account the interactions between adsorbents and metal ions to be adsorbed and is based on the assumption that the free energy of sorption is a function of the surface coverage (Yu and Ya Juan, 2008).

$$\text{Temkin isotherm: } q_e = RT/b_T \ln(AC_e) \quad (7)$$

$$\text{Linearised Temkin isotherm: } q_e = B \ln A + B \ln C_e \quad (8)$$

where $RT/b_T = B$; where T is the temperature (K) and R is the ideal gas constant ($8.314 \text{ J mol}^{-1} \text{ K}^{-1}$), and A and B are constants. The constant b_T is related to the heat of adsorption and A is the equilibrium binding constant (L/g) corresponding to the maximum binding energy.

The Dubinin-Radushkevich model was chosen to estimate the heterogeneity of the surface energies. The linear form of D-R isotherm equation is represented as:

$$\ln q_e = \ln q_m - \beta \varepsilon^2; \text{ where } \varepsilon = RT \ln(1 + 1/C_e) \quad (9)$$

Where q_e is the theoretical saturation capacity (mol/g), β is the mean free energy of adsorption per mole of the adsorbate (mol²/J²) and ε is the Polanyi potential, R (Jmol⁻¹K⁻¹) is the gas constant and T (°K) is the absolute temperature. The constant β gives an idea about the mean free energy E (J/mol) of adsorption per molecule of the adsorbate when it is transferred to the surface of the solid from infinity in the solution and can be calculated from the relationship:

$$E = \frac{1}{\sqrt{2\beta}} \quad (10)$$

If the magnitude of E is between 8 and 16KJ mol⁻¹, the sorption process is supposed to proceed via chemisorption, while for values of $E < 8$ KJ mol⁻¹, the sorption process is of physical nature (Kundu *et al.*, 2006). As shown in Table 1, the Temkin isotherm model ($R^2 = 0.9933$) yielded best fit to the experimental equilibrium adsorption data followed by the Langmuir ($R^2 = 0.9467$), D-R ($R^2 = 0.9217$) and Freundlich ($R^2 = 0.5003$) isotherm models respectively for cadmium adsorption according to the values of R^2 obtained. It can also be seen from the table that the Langmuir maximum adsorption capacity (q_{max}) is 1.4mg/g and the equilibrium constant K_L is 7.58L/mg. The separation factor, R_L values as shown in Table 2 were found to be less than one and greater than zero indicating favourable adsorption of cadmium (II) ions onto the biomass (Asiagwu, 2012). The Freundlich constant K_F indicates the sorption capacity of the sorbent and the value is 23.57mg/g. The value of "n" obtained was 1.2. The value of n between 1 and 10 represents a favourable adsorption and indicates physisorption (Egila *et al.*, 2011). Physisorption process usually have adsorption energies <40KJ/mol and above this value, sorption is of chemisorption mechanism (Horsfall *et al.*, 2004). If the mean biosorption is between 8KJ/mol and 16KJ/mol, the biosorption process follows chemical ion exchange mechanism (Lodeiro *et al.*, 2006). The value of the apparent energy of adsorption (2.5KJ/mol) obtained indicated physisorption between *Nymphaea ampla* root biomass and cadmium ions.

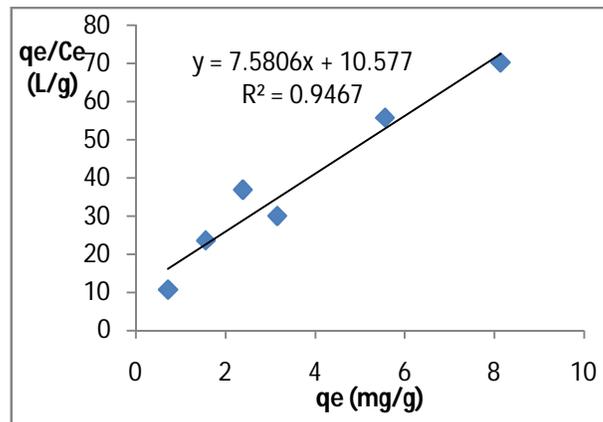


Figure 6. Langmuir isotherm model for cadmium adsorption

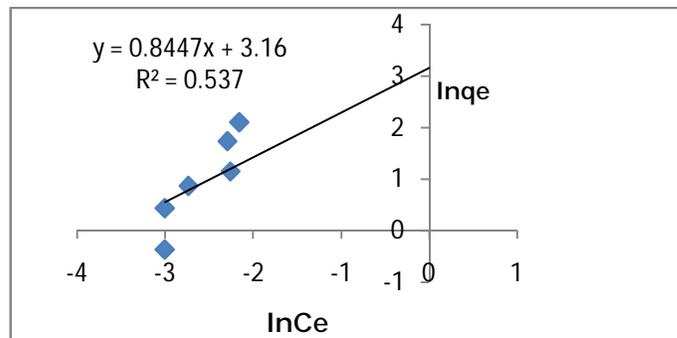


Figure 7. Freundlich isotherm model for cadmium adsorption

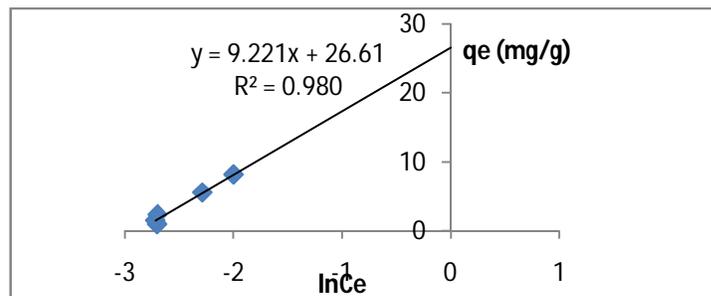


Figure 8. Temkin isotherm model for cadmium (II) adsorption

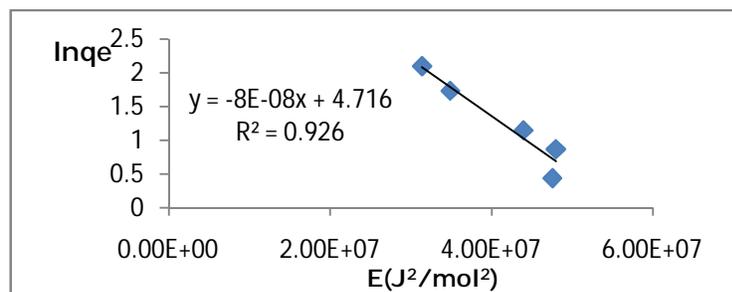


Figure 9. Dubinin-Radushkevich (D-R) isotherm model for cadmium (II) adsorption

Table1. Summary of Adsorption Isotherm Constants for Cd (II) ions Sorption onto *Nymphaea ampla* Root Biomass

Langmuir Isotherm	Freundlich Isotherm	Temkin Isotherm	D-R Isotherm
$q_{max} = 1.4\text{mg/g}$	$K_F = 23.57\text{mg/g}$	$A_T = 0.055\text{L/mg}$	$q_m = 110\text{ mg/g}$
$K_L = 7.58\text{L/mg}$	$1/n = 0.845$	$B = 0.083\text{mg/g}$	$\beta = 8 \times 10^{-11}\text{KJ/mol}$
$R^2 = 0.946$	$n = 1.18$	$b_T = 0.30\text{KJ/mol}$	$E = 2.50\text{KJ/mol}$
	$R^2 = 0.537$	$R^2 = 0.980$	$R^2 = 0.926$

Table2. Dimensionless Langmuir Separation Factor

Concentration(mg/L)	0.5	1.0	1.5	2.0	3.5	5.0
R_L	0.2088	0.1168	0.0808	0.0619	0.0363	0.0250

Adsorption Kinetic Modeling

Kinetic data were fitted using Lagergren pseudo-first order model (Lagergren, 1891), a pseudo-second order model (Saleem and Bhatti, 2011) and an intraparticle diffusion (Weber and Morris, 1963) models to investigate the mechanism of biosorption and potential rate controlling steps such as mass transport and chemical reaction processes. The first-order Lagergren equation is given as:

$$\log(q_e - q_t) = \log q_e - \frac{k_1 t}{2.303} \quad (11)$$

The pseudo-second order equation is,

$$\frac{t}{q_t} = \frac{1}{k_2 q_e^2} + \frac{t}{q_e} \quad (12)$$

Where q_e is the mass of metal adsorbed at equilibrium (mg/g), q_t the mass of metal adsorbed at time t (min), k_1 is the pseudo- first order rate constant of adsorption (min^{-1}) and k_2 the pseudo-second order rate constant of adsorption (mg/g.min).

The intraparticle diffusion equation can be written as follows,

$$q_t = k_d t^{1/2} + I \quad (13)$$

Where I is the intercept which describe the boundary layer thickness and k_d ($\text{mg/g.min}^{1/2}$) is the rate constant of intraparticle diffusion. The values of the model constants are shown in Table 3. It is clear from the table that the pseudo-second order model showed excellent linearity with correlation coefficient ($R^2 > 0.998$) in comparison to the other kinetic model. High value of rate constant K_2 suggests lower competition for the surface active sites by the metal ions and consequently high sorption rate. Figure 12 presents intraparticle plot for cadmium (II) ion sorption onto biomass. Intra-particle diffusion is the rate-limiting step if the

plot of q_t versus $t^{1/2}$ is linear and passes through the origin. It is clear from Figure 12 that the linear plot did not pass through the origin. The deviation could be due to the difference in the rate of mass transfer in the initial and final stages of sorption. This indicates the existence of some boundary layer effect and further showed that intra-particle diffusion was not the only rate-limiting step (Biswajit *et al.*, 2012). Similar results were obtained by Verma *et al.*, 2010 who worked on adsorption of cadmium (II) ions onto *Psidium guajava* leaves.

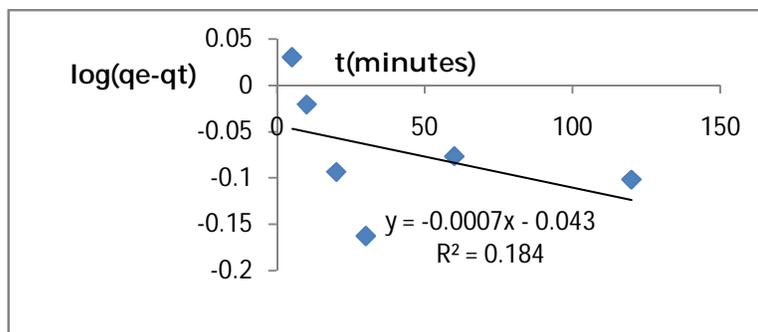


Figure10. First order kinetics for cadmium (II) adsorption

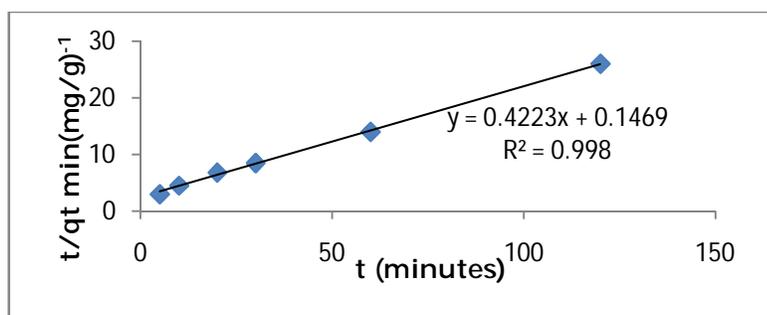


Figure11. Second order kinetics for cadmium (II) adsorption

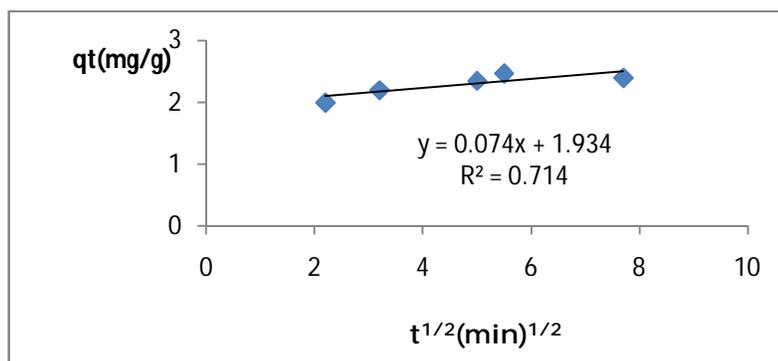


Figure12. Intra-particle diffusion model for cadmium (II) adsorption

Table 3. Comparison between Kinetic Models for Cd(II) ions Sorption unto *Nymphaea ampla* Root Biomass

Pseudo- first order	Pseudo-second order	Intra-particle diffusion
$q_{e,exp} = 2.4708\text{mg/g}$	$K_2 = 1.214\text{g/mg}^{-1}\text{min}^{-1}$	$K_d = 0.074\text{mg/g}\cdot\text{min}^{-1/2}$
$q_{e,cal} = 0.9041\text{mg/g}$	$q_{e,cal} = 2.3695\text{mg/g}$	$I = 1.934$
$K_1 = 1.6 \times 10^{-3}\text{mg/g}$ $R^2 = 0.1831$	$R^2 = 0.9980$	$R^2 = 0.714$

Thermodynamic Treatment of Sorption Process

In order to study the feasibility of the adsorption process, Gibb's free energy (ΔG^0), enthalpy (ΔH^0) and entropy (ΔS^0) changes were estimated from the following equations:

$$K_c = \frac{C_{Ae}}{C_e} \quad (14)$$

$$\Delta G = -RT \ln k_c \quad (15)$$

$$\log K_c = \frac{\Delta S^0}{2.303R} - \frac{\Delta H}{2.303RT} \quad (16)$$

Where C_e is the equilibrium concentration in solution in mg/L and C_{Ae} is the equilibrium concentration on the sorbent in mg/L and K_c is the thermodynamic equilibrium constant. T is the absolute temperature in Kelvin and R is the universal gas constant ($8.314\text{JK}^{-1}\text{mol}^{-1}$). The potential sticking probability (S^*) was also calculated and used to deduce the activation energy (E_a) for the sorption process and to ascertain whether the sorption process was of physisorption or chemisorption mechanism. They were calculated using the Arrhenius type equation related to surface coverage (Θ) as follows:

$$\theta = \left(1 - \frac{C_e}{C_i}\right) \text{ and } S^* = (1 - \theta) \exp - \frac{E_a}{RT} \quad (17)$$

The sticking probability, S^* , is a function of the adsorbate/adsorbent system under consideration but must satisfy the condition $0 < S^* < 1$ and is dependent on the temperature of the system. The values of E_a and S^* can be calculated from slope and intercept of the plot of $\ln(1-\Theta)$ versus $1/T$ respectively. $S^* > 1$ indicates no sorption, $S^* = 1$ indicates mixture of physisorption and chemisorption, $S^* = 0$ indicates that chemisorption is the predominant mechanism and $0 < S^* < 1$ indicates that physisorption is the predominant mechanism. The thermodynamic treatment of the sorption data indicates that ΔG^0 values were negative at all temperatures investigated. The negative values of ΔG^0 (Table 4) indicate the spontaneous nature of the sorption process. The negative value of ΔS^0 , (Table 5) showed decrease in randomness at the solid-liquid interface. The value of E_a was found to be -2.0KJ and indicates the exothermic nature of the adsorption process which is in accordance with the

negative value of ΔH^0 . S^* value as shown in Table 5 indicates that the probability of cadmium (II) ions to stick on the surface of the biomass is very high as $S^* < 1$, this value also confirms that physisorption is the predominant sorption mechanism (Spiff *et al.*, 2005).

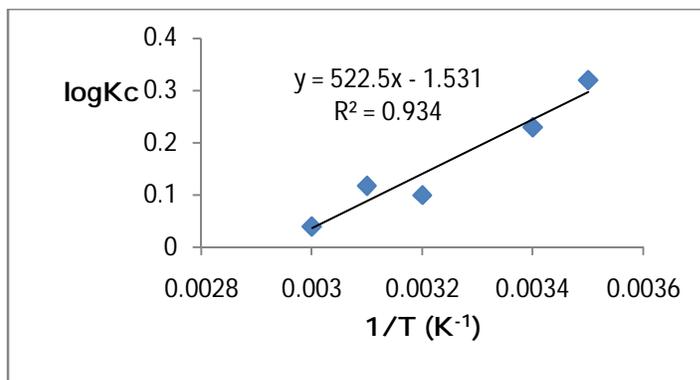


Figure13. Plot of $\log K_c$ against $1/T$ for cadmium (II) adsorption

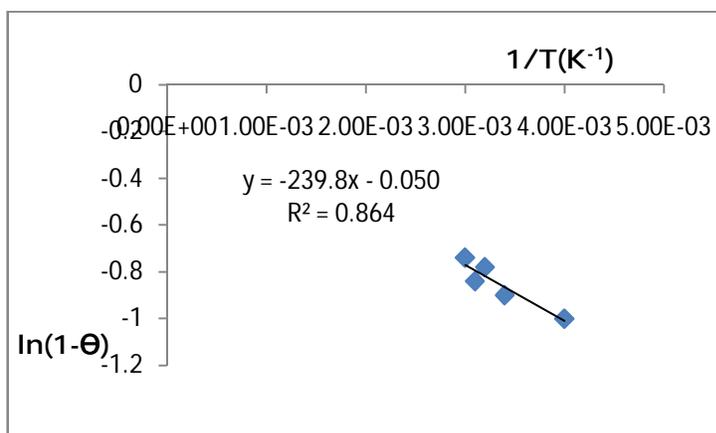


Figure14. Relationship between temperature and sticking probability for Cd(II)adsorption.

Table 4. Values for Gibb's Free Energy at Various Temperatures

T (°K)	288	298	310	318	328
ΔG^0 (KJ/mol)	-1.7681	-1.1311	-0.4392	-0.7155	-0.2703

Table 5. Thermodynamic Parameters for Adsorption of Cd (II) ions onto *Nymphaea ampla* Biomass

ΔS^0 (KJ/mol)	ΔH^0 (KJ/mol)	E_a (KJ/mol)	S^*
-0.0293	-10.000	-2.000	0.9500

CONCLUSION

The results indicated that the adsorption of cadmium (II) ions from aqueous solutions using *Nymphaea ampla* root biomass is dependent on initial cadmium concentration, solution pH, adsorbent dosage, contact time and temperature. A biosorbent dosage of 50mg showed optimum adsorption capacity of 1.69mg/g (84.85%) for an initial concentration of 2mg/L at pH 6.5. The optimum sorption equilibrium time was observed in 30 minutes and the optimum temperature was 15°C. The study on equilibrium sorption revealed that Temkin isotherm model gave the best fit to the experimental data. The separation factor (R_L) obtained showed favourable adsorption. In the study of kinetics of sorption, the pseudo-second order kinetic model provided better correlation of the sorption data. Intra-particle diffusion proved not to be the sole rate controlling factor. The calculated thermodynamic parameters obtained showed the sorption process to be exothermic and spontaneous in nature. Furthermore, calculated sticking probability indicated excellent sticking of the metal ions onto the biomass. On the whole, the results clearly established that *Nymphaea ampla* root biomass maybe used as an alternative, environmental friendly, inexpensive and effective adsorbent for the removal of cadmium (II) ions from aqueous solutions.

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