

Removal of Heavy Metals from Aqueous Solution using Bamboo Based Activated Carbon

Udeh, N. U¹ and Agunwamba, J. C²

¹Department of Environmental Engineering, University of Port Harcourt, Rivers, Nigeria.

²Department of Civil and Environmental Engineering, University of Nigeria Nsukka, Enugu, Nigeria.

ABSTRACT:- This study investigated the removal of cadmium and lead from aqueous solution using bamboo activated carbon. Bamboo activated carbon was prepared by physicochemical activation using ZnCl₂ at different impregnation ratios (1:2; 1:3; and 1:4) ZnCl₂/Bamboo. Batch adsorption studies were conducted to evaluate the optimum conditions for adsorption of cadmium and lead. Their adsorption isotherms were also determined by correlating with Langmuir, Freundlich, Temkin and Hills isotherms models using regression analyses. The kinetic studies were correlated with pseudo first order and pseudo second order equations. The results showed that the amount of cadmium and lead adsorbed increased as the adsorbent dosage decrease while the percentage removal rate increased with increase in cadmium and lead concentrations. High removal efficiency of 83.44% and 96.09% was achieved at pH 9 and pH 11 within 1.5hrs and 1hr using 50µm particle size for cadmium and lead, respectively. The equilibrium data fitted into Freundlich, Temkin and Hills isotherm but fitted precisely into Freundlich isotherm with K_f values of 7.01 and 2.128mg/g for cadmium and lead, respectively. The rate of adsorption could be described by Pseudo second order equation, indicating a chemisorptions process onto heterogeneous surfaces forming multilayer on the surface of activated carbon.

Keywords: Adsorbent, Adsorption, Bamboo activated carbon, Isotherm, Kinetic studies.

I. INTRODUCTION

The release of heavy metals via water pollution has caused enamours threat to the environment and public health due to their toxicity, accumulation in the food chain and persistence in nature [1]. Lead and cadmium are one of the major toxic pollutants, which entered the water streams through various industrial operations such as battery manufacturing, metal planting and finishing, paint manufacturing, petroleum refining, glass manufacturing and many others. Environmental and occupational exposure of these heavy metals can cause severe toxic damage to neuronal system, kidneys, reproductive system, liver and brain [2], [3]. Since lead and cadmium do not degrade in the environment, their safe and effective disposal is important. Various treatment options used to remove heavy metals from aqueous solution include chemical precipitation, electrochemical reduction, ion exchange, reverse osmosis, membrane separation and adsorption. Compared with other treatment method, adsorption appears to be an attractive process due to its simplicity, effectiveness and economical in the removal of heavy metals from aqueous solution [4]. Commercial activated carbon is the most widely used adsorbent for removal of pollutants from aqueous medium; however its use is restricted due to high cost. Thus, efforts have been geared toward the use of low cost adsorbents for adsorption processes. Natural renewable materials, like bamboo, can be converted into low cost adsorbents [5], [6], [7], [8], [9]. The focus of this research is to evaluate the adsorption potential of bamboo-based activated carbon for the removal of lead and cadmium. The use of bamboo sticks as raw materials for manufacturing activated carbon is advantageous as these raw materials are renewable and potentially less expensive. The equilibrium and kinetic studies were investigated to understand the mechanism and nature of the adsorption process.

II. MATERIALS AND METHODS

2.1 Preparation of Bamboo Activated Carbon

The Bamboo sticks (*Bamboosoidae Grasses L*) is the dominant bamboo in Nigeria found in the rain forest belt. Fully matured Bamboo sticks were cut into (2- 4cm) sizes, washed, air dried and then carbonized in a muffle furnace at 500°C for 3 hrs. The carbonized bamboo samples were grinded into powder and impregnated

with Zinc Chloride ($ZnCl_2$) (activating agent) at weight ratio of 1:3 ($ZnCl_2$ /Bamboo). The resultant mixture was heated to a paste and then washed with distilled water to a pH 6 and then dried in an oven between temperature ranges of $100^\circ C$ to $110^\circ C$ for 6 hrs. The sample was named Physically Activated Bamboo Carbon. The PABC was characterized in terms of surface area, porosity, carbon yield and bulk density. The surface area was determined using Sear's method as reported by [10]. Carbon yield was measured using the method reported by [11]. The dried weight of PABC was determined before and after carbonization and the carbon yield, Y_{ch} calculated from Equation 1:

$$Y_{ch} = \frac{W_o}{W_{ch}} \times 100\%$$

(1) Where: W_o = mass of bamboo carbon retrieved from the furnace. W_{ch} = mass of air-dried bamboo samples before carbonization.

The Porosity was calculated from equation (2):

$$n = 1 - \frac{\rho}{\rho_w G_s (1+w)}$$

Where: n = Porosity, ρ = Bulk density of AC particles, ρ_w = Density of water, G_s = Specific gravity of AC particles and w = Moisture content.

The Bulk density was measured using the method reported by [12] while the moisture content was calculated from equation (3):

$$w = \frac{W_o - W_d}{W_o} \times 100\%$$

Where: W_o = original weight (g), W_d = weight after drying (g), w = moisture content (%)

The Specific gravity G_s was calculated from equation (4):

$$G_s = \frac{M_2 - M_1}{(M_2 + M_4) - (M_1 + M_3)}$$

Where M_1 = mass of the empty pycnometer, M_2 = mass of oven dried AC inside the pycnometer, M_3 = mass of oven dried AC inside the pycnometer filled with water, M_4 = mass of pycnometer filled with water.

2.2. Batch Adsorption Studies

The adsorption of Cadmium (Cd) and Lead (Pb) ions from aqueous solution was investigated by batch method. Wastewater samples were simulated in the laboratory by mixing $CdCl_2 \cdot 2\frac{1}{2}H_2O$ salt and $(Pb(NO_3)_2)$ salt in distilled water to obtain the desired initial concentrations. All the chemicals used were of analytical grade. The optimum conditions for the adsorption of Cd and Pb was investigated. The effect of adsorbent dose was investigated using 50ml of simulated wastewater samples of pH 7 and 20mg/l initial adsorbate concentration with different adsorbent doses (1, 2, 3, 4 and 5g). The mixtures were attached to a mechanical shaker and then agitated for 1 hr and then filtered through Whatman filter paper (#542) and the filtrates were then separately analyzed for residual concentrations of Cd and Pb using Atomic Adsorption Spectrometer (AAS). The optimum adsorbent dosage for the adsorption of Cd and Pb was noted and adopted for the next experiment. The effect of initial concentrations of Cd and Pb was conducted by adjusting the initial concentration of the adsorbates (10, 20, 30, 40 and 50mg/l) via dilution of the simulated wastewater samples while the optimum condition of adsorbent dosages were adopted. The experimental procedure remained the same and the optimum initial concentrations of Cd and Pb were noted. The effect of agitation time on the adsorption of Cd and Pb was conducted by varying the agitation time (0.5, 1.0, 1.5, 2.0, 2.5 and 3.0hr) but adopting the optimum adsorbent doses and optimum initial concentration of adsorbates. The residual concentration of Cd and Pb was analyzed and their optimum agitation time for adsorption was noted. The effect of adsorbate pH was studied by adjusting the pH to 3, 5, 7, 9 and 11 by adding 0.1M (NaOH) or HCl solutions as the case may be. The optimum adsorbent dosage, initial concentration and agitation time for Cd and Pb were adopted while other test conditions and experimental procedure remained same. Their optimum adsorbate pH was noted. The effect of different particle size was investigated on four particle sizes ($425\mu m$, $250\mu m$, $150\mu m$ and $50\mu m$) using the optimum values of agitation time, adsorbent dose, initial concentration of adsorbates and pH, while other test procedure remained the same. The adsorption efficiency of the test carbons was used as criterion for determining optimum conditions. The adsorption efficiency was thus calculated from equation (5):

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

(5)

Where: C_o = initial conc. of adsorbate and C_t = final concentration of the adsorbate after time (t)

2.3 Batch Equilibrium Studies

Equilibrium studies were performed at room temperature (25°C). The equilibrium adsorption studies were conducted using optimum condition for Cd and Pb to investigate the sorption capacity of PABC. For Cd adsorption, 50ml of simulated wastewater samples of 50mg/l initial Cd conc. and pH-9 were measured into 5 different plastic containers and different adsorbent doses of 0.2, 0.4, 0.6, 0.8 and 1.0g (50 µm size) were added to each of the plastic containers. The mixtures were agitated on a mechanical shaker for 1.5hrs. In the case of Pb, adsorbate pH of 11 and agitation time of 1hr was used. At the end of the adsorption period, the mixtures were filtered and then separately analyzed for residual conc. of Cd and Pb using AAS. The equilibrium adsorption capacity (q_e) of the adsorbent was obtained using the mass equilibrium equation given in equation (6):

$$q_e = \frac{(C_o - C_e)V}{M} \quad (6)$$

Where: C_o is the initial concentrations of the adsorbate (mg/l); C_e is the equilibrium concentration of adsorbate (mg/l); V is the experimental volume of wastewater (L), M is mass of adsorbent (g).

2.3.1 Adsorption isotherms

Adsorption isotherms are used to describe the relationship between the amount adsorbed and its concentration in the equilibrium solution at constant temperature. The adsorption of Cd and Pb was modelled using Langmuir, Freundlich, Temkin and Hills isotherms. Linear form of Langmuir equation is given in equation (7):

$$\frac{C_e}{q_e} = \frac{1}{q_o K} + \frac{C_e}{q_o} \quad (7)$$

Where: C_e is equilibrium concentration of the adsorbate (mg/l), q_e is mass of solute adsorbed per unit mass of adsorbent, q_o is a constant related to the adsorption capacity (mg/g) and K is experimental constant.

Linear form of Freundlich equation is given in equation (8):

$$\log(q_e) = \log k + \frac{1}{n} \log C_e \quad (8)$$

Where: C_e is equilibrium concentration of the adsorbate, q_e is mass of solute adsorbed per unit mass of adsorbent, k and n are Freundlich constants representing the adsorption capacity of adsorbents and the intensity of the adsorption, respectively.

Linear form of Temkin equation is given in equation (9):

$$q_e = \frac{RT}{b_T} \log A_T + \frac{RT}{b_T} \log C_e \quad (9)$$

Where: b_T and A_T are the Temkin constants, A_T is the equilibrium binding constant corresponding to the maximum binding energy, b_T is related to the heat of adsorption (J/mol), R is the universal gas constant (8.314 J/mol K) and T is the absolute temperature in kelvin (K).

Linear Form of Hills equation is given in equation (10):

$$\text{Log} \left(\frac{q_e}{q_{SH} - q_e} \right) = nH \log C_e - \log K_D \quad (10)$$

Where q_{SH} , nH and K_D are Hill isotherm constants.

Note that nH is Hills coefficient describing cooperativity. If $nH > 1$ = positive cooperative binding (the binding of one molecule onto the adsorbent, increases the affinity for other molecules to bind) while $nH < 1$ = negative cooperative binding (the binding of one molecule onto the adsorbent decreases the affinity for other molecules to bind). However, $nH = 1$ non cooperative binding (the affinity of the adsorbate to bind onto the adsorbent is not dependent on whether or not other molecules are already bound).

2.4. Batch Kinetics Study

The adsorption kinetics was processed at varying time intervals using two initial concentrations (50 and 100mg/l) of Cd and Pb. For Cd adsorption, 0.2g of bamboo activated carbon were mixed with 50ml of Cd solution (pH 9) and (50µ size) and then attached to a mechanical shaker. The samples were agitated and then taken at intervals of (5, 10, 20, 30, 40, 50, 60, 70, 80, 100 and 120 mins) and filtered. The concentrations of Cd at these time intervals were analyzed with AAS. The same procedures were replicated for Pb using pH 11. The samples were taken at intervals of (10, 20, 40, 60, 80, 100, 120, 140, 160 and 180 mins) and then filtered. The adsorption capacity of the adsorbents at preset time (t), q_t , was calculated from equation (11):

$$q_t = \frac{(C_o - C_t)V}{M} \quad (11)$$

Where: C_o is the initial concentrations of the adsorbates (mg/l); C_t is the concentration of the adsorbate at any time t (mg/l); V is the volume of the solution used (L) and M is the mass of adsorbent used.

2.4.1 Kinetics of Adsorption

In order to investigate the mechanism of adsorption, the Pseudo first order and Pseudo second order equations developed by [13] were used to investigate rate of Cd and Pb removal.

The Pseudo first order equation in Logarithmic form is given in equation (12):

$$\log(q_e - q_t) = \log(q_e) - \frac{k_{p1}}{2.303}t \quad (12)$$

Where: q_e is the adsorption capacity at equilibrium (mg/g), q_t is the adsorption capacity at time t (mg/g), k_{p1} is the rate constant of first order adsorption (mg/min).

Linear form of Pseudo Second order equation is given in equation (13):

$$\frac{t}{q_t} = \frac{1}{k_{p2}q_e^2} + \frac{1}{q_e}t \quad (13)$$

Where: k_{p2} is the rate constant of pseudo second order adsorption (mg/min).

III. RESULTS AND DISCUSSION

3.1 Characterization of Bamboo Carbon

The results on the characterization of PABC are presented on Table 1. Similar observations were reported by [9] & [7].

Table 1: Characterisation of Bamboo Activated Carbon (PABC)

Parameters	Value
Surface area (m ² /g)	359
Bulk density (g/cm ³)	0.56
Specific gravity	1.28
Moisture content (%)	2.95
Porosity	0.89
Ash content (%)	6.70
Carbon yield (%)	27.69
pH	6.6

3.2 Optimum Conditions for Adsorption of Cadmium and Lead

The results of the batch adsorption for the removal of cadmium and lead from simulated wastewater onto bamboo activated carbon are shown in Fig. 1 to 5.

3.2.1 Effects of Adsorbent dose

The effects of different adsorbent doses on adsorption of cadmium and lead on PABC revealed that as the adsorbent dosage increased, the amount adsorbed per unit mass of the adsorbent decreased as shown in Figure 1. This decrease in unit adsorption may be due to adsorption sites remaining unsaturated during adsorption [14]. Thus, more active sites are utilized at lower adsorbent dose, producing higher adsorption efficiency, while only part of active sites were occupied by Cd and Pb ions at higher adsorbent dose, leading to lower adsorption efficiency [15]. Therefore, removal efficiency of 68.32% and 71.64% for Cd and Pb respectively were achieved. Thus, the optimum dosage of 1g was used for further studies.

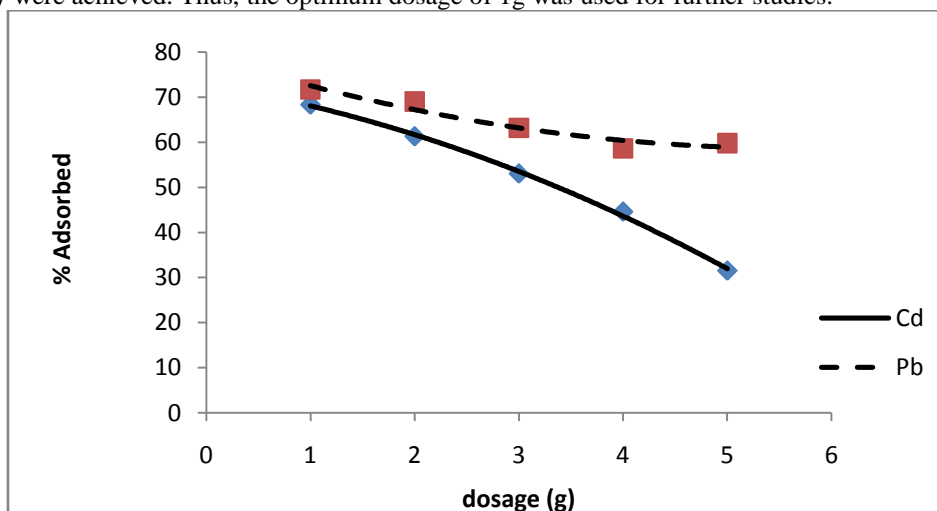


Figure 1: Cadmium and Lead removal as a function of Adsorbent Dose

3.2.2 Effect of Initial Adsorbate Concentration

The effect of different initial concentration of Cd and Pb on adsorption onto PABC showed that the percentage removal rate increased with increase in ion concentration as shown in Fig. 2. This may be that more metal ions are available in the solution for the adsorption at higher concentration [16]. Thus, Cd and Pb removal was highly dependent on concentration and this might also be due to high driving force for mass transfer at higher concentrations [9]. Optimum removal efficiency of 74.63% and 88.34% at 50mg/l were observed for Cd and Pb respectively.

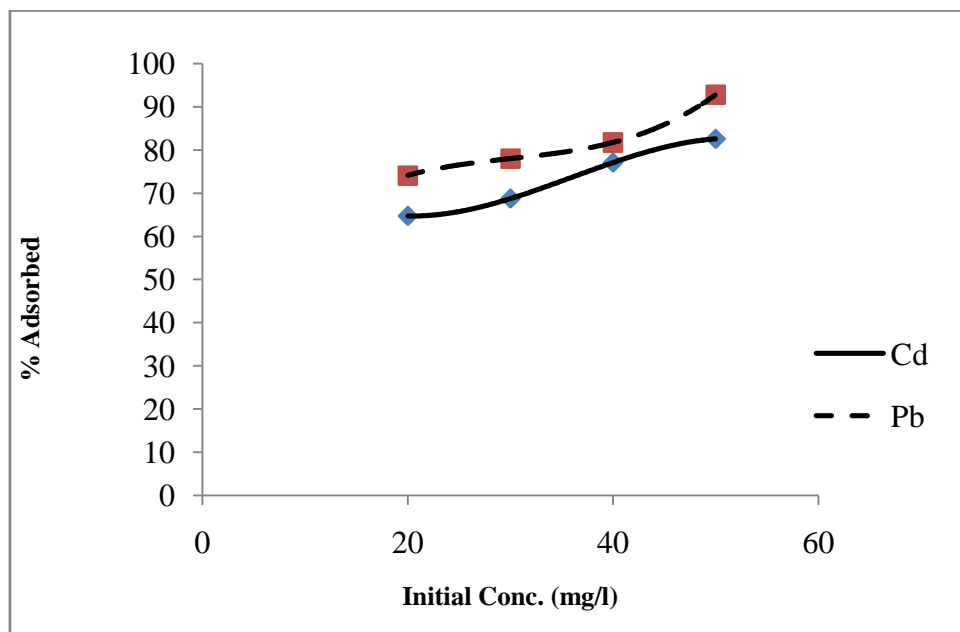


Figure 2: Cadmium and Lead removal as a function of Initial Conc.

3.2.3 Effect of Agitation Time

The effects of agitation time on the adsorption of Cd and Pb onto PABC revealed an increase in adsorption of the metal ion with increase in agitation time and this may be due to increase in kinetic energy of the metal ions and decrease in boundary layer resistance due to mass transfer in the bulk solution. Similar observation was made by [17]. The removal efficiency increased with time and attained at 90 mins (72%) for Cd and 60 mins (87.84%) for Pb as shown in Fig. 3.

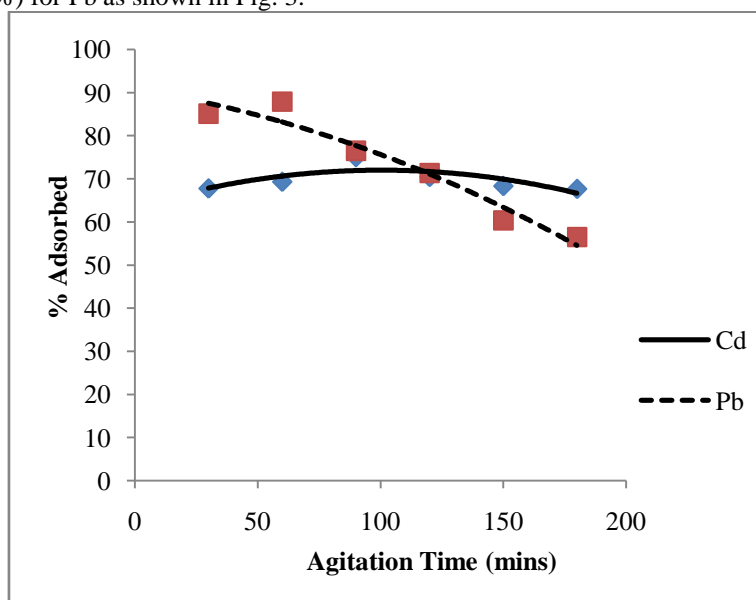


Figure 3: Cadmium and Lead removal as a function of Agitation time

3.2.4 Effects of pH

The adsorbate pH affects the solubility of the metal ions. The effects of pH on Cd and Pb removal onto PABC tend towards alkaline as shown in Fig. 4. At lower pH value, the H⁺ ions compete with the metal cation for adsorption sites [18],[19] while at extreme acidic condition, the metal cations are completely released [20]. High removal efficiency of 78.57% at pH-9 was observed for Cd removal while 94.49% at pH-11 was observed for Pb. Thus, alkaline medium tend to support adsorption of Cd and Pb with PABC more than acidic medium.

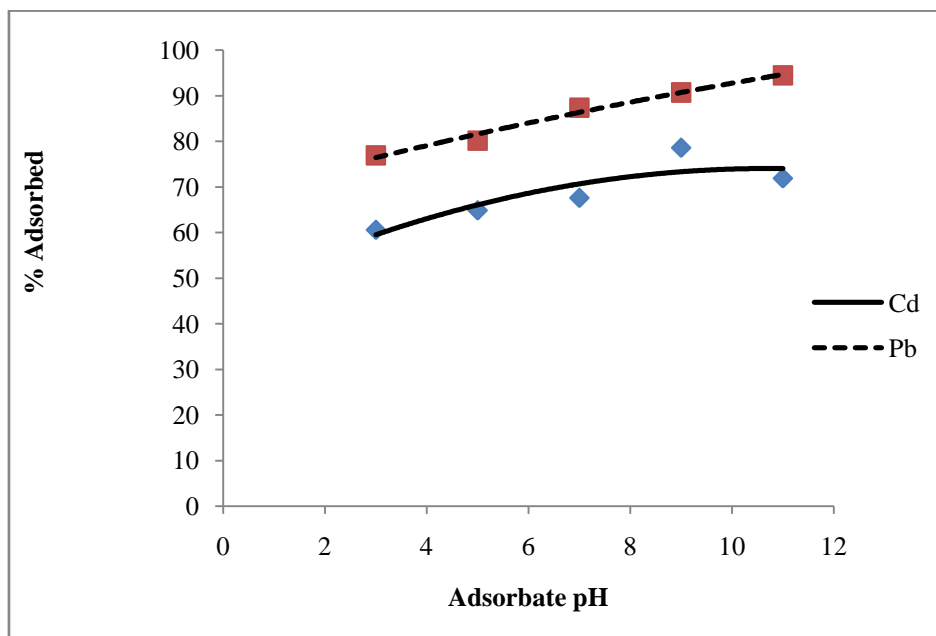


Figure 4: Cadmium and Lead removal as a function of Adsorbate pH

3.2.5 Effects of Particle Size

The removal rate of Cd and Pb increased with smaller particle size as shown in Fig. 5. This may be that smaller particle produces shorter time to equilibrium. High removal efficiency of 83.44% and 96.09% was achieved with 50 μm particle size for Cd and Pb removal respectively.

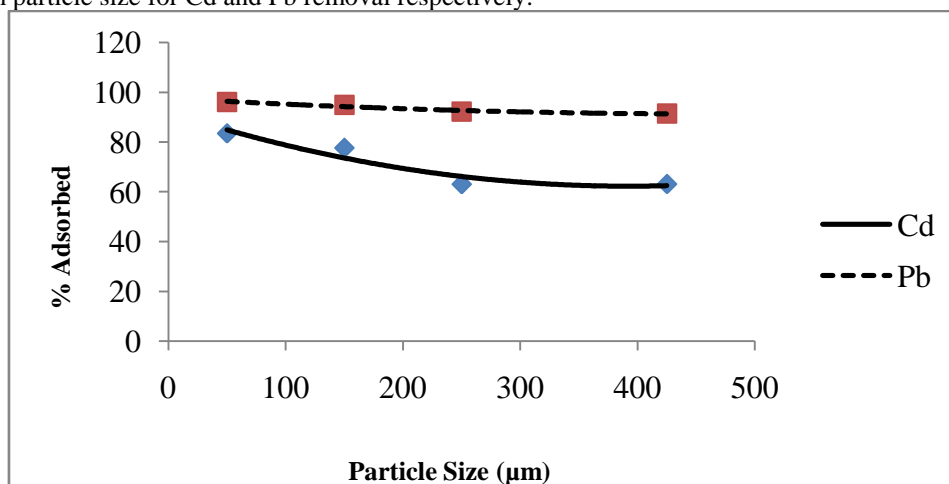


Figure 5: Cadmium and Lead removal as a function of Particle size

3.3 Equilibrium Adsorption

Results from the equilibrium adsorption of Cd and Pb onto PABC were modelled using Langmuir, Freundlich, Temkin and Hills isotherm models in order to obtain the best fitting isotherm. The linear correlation of equilibrium data with Langmuir, Freundlich, Temkin and Hills equations gave high correlation coefficient (R^2)

for both Cd and Pb Adsorption. The linear models and the corresponding isotherm parameters for all the isotherm models tested are presented in Table 2.

Table 2: Equilibrium Model Parameters for the Adsorption of Cd and Pb onto PABC.

Cadmium (Cd)			Lead (Pb)		
Linearized Models	Parameters	Value	Linearized Models	Parameters	Value
Langmuir Isotherm Y = 0.5205x - 0.4585	q _o (mg/g)	1.921	Langmuir isotherm Y = 0.434x - 0.0518	q _o (mg/g)	2.304
	K (L/mg)	-1.135		K (L/mg)	-8.382
	R ²	0.9799		R ²	0.9474
	R _L	0.017		R _L	-0.002
	SSE,%	0.131		SSE,%	0.058
Freundlich Isotherm Y = -0.5667x + 0.8457	K _f (mg/g)	7.01	Freundlich Isotherm Y = -0.7036x + 0.3279	K _f (mg/g)	2.128
	1/n	-0.567		1/n	-0.704
	R ²	0.9845		R ²	0.9907
	SSE,%	0.039		SSE,%	0.031
	A _T (L/mg)	0.077		A _T (L/mg)	0.873
Temkin Isotherm Y = 7.1953x + 7.9997	b _T (J/mol)	-344.33	Temkin Isotherm Y = -10.211x + 0.6034	b _T (J/mol)	-242.64
	R ²	0.8653		R ²	0.9791
	SSE,%	0.052		SSE,%	0.046
	q _{SH}	16		q _{SH}	13
	nH	-0.958		nH	-2.021
Hills Isotherm Y = -0.9583x + 0.0043	K _D	0.990	Hills Isotherm Y = -2.0213x - 1.0295	K _D	0.093
	R ²	0.9149		R ²	0.9483
	SSE,%	0.050		SSE,%	0.092

3.3.1 Model Verification

The isotherm models were verified with another set of experimental data. The calculated isotherm parameters were fitted into the isotherm model equations to get the calculated q_e values. For Cd removal, the Experimental q_e (Exp q_e) and Calculated q_e (Cal q_e) correlated with Freundlich, Temkin and Hills models but did not correlate with Langmuir models. In the case of Pb removal, the Exp. q_e and Cal. q_e correlated with Freundlich, Temkin and Langmuir but did not correlate with Hills models. These are shown in Figs. 6 to 11.

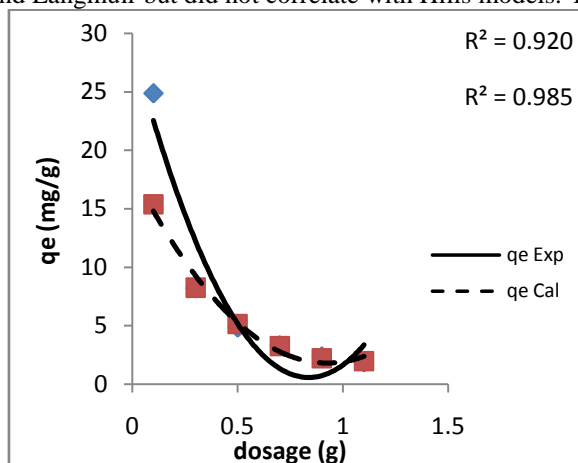


Figure 6: Freundlich Exp and Cal q_e for Adsorption of Cd

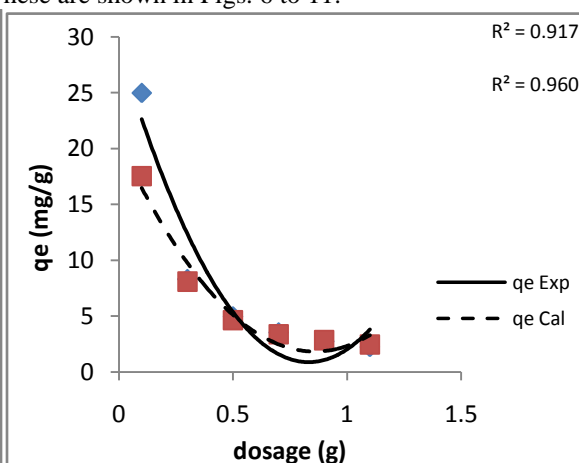


Figure 7: Freundlich Exp and Cal q_e for Adsorption of Pb

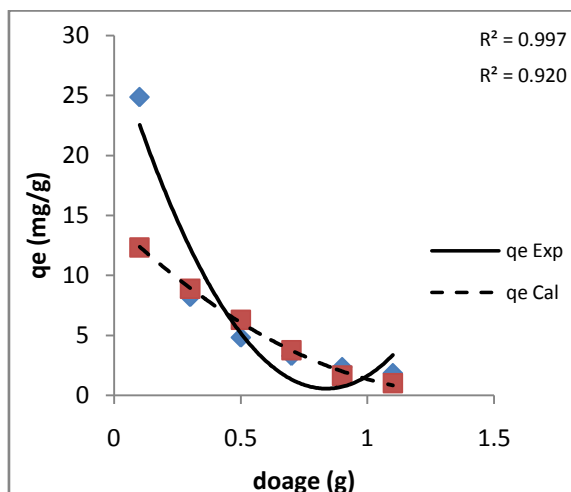


Figure 8: Temkin Exp and Cal qe for Adsorption of Cd

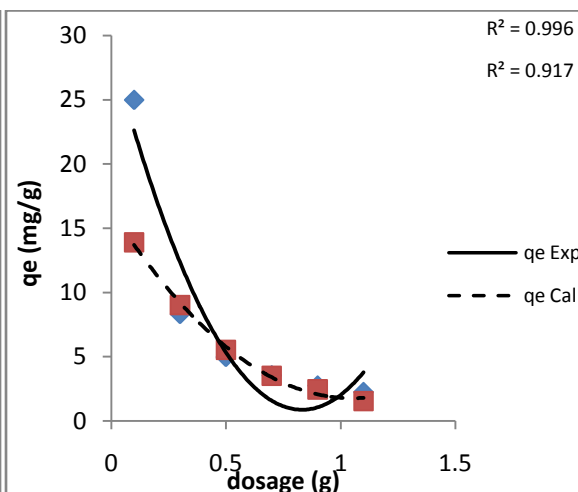


Figure 9: Temkin Exp and Cal qe for Adsorption of Pb

Pb

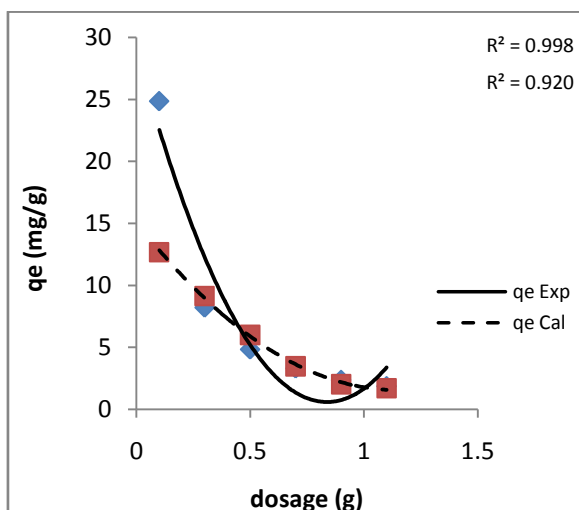


Figure 10: Hills Exp and Cal qe for Adsorption of Cd

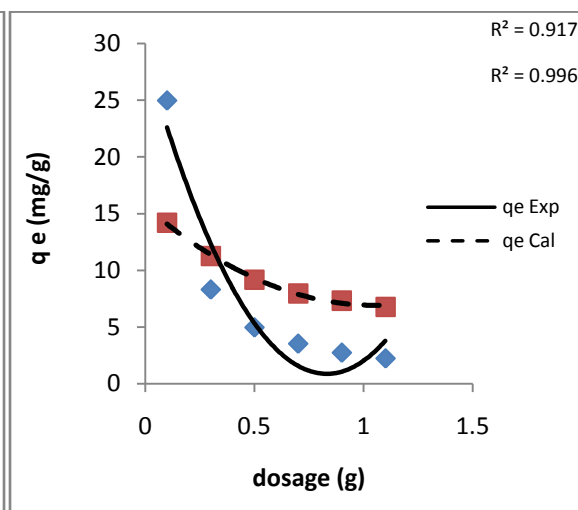


Figure 11: Langmuir Exp and Cal qe for Adsorption of Pb

3.3.2 Test for Isotherm Models

The applicability of these isotherm models was further verified using the sum of error squares (SSE, %) calculated from equation (14) using Excel software:

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

(14) Where: *N* is the number of data points.

Results of the SSE,% for each isotherm model presented in Table 2, showed that Freundlich isotherm model had the smallest SSE,% value for both Cd (0.039%) and Pb (0.031%) adsorption. 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 onto PABC fitted into Freundlich, Hills and Temkin model but could be best described by Freundlich isotherm while the adsorption of Pb onto PABC fitted into Freundlich, Temkin and Langmuir but could be best described by Freundlich. This indicates a chemisorption process onto heterogeneous surfaces forming multilayer on the surface of PABC. Similar observations were made by [9] & [21]. The Freundlich isotherm for the adsorption of Cd and Pb are shown in Figs. 12 and 13.

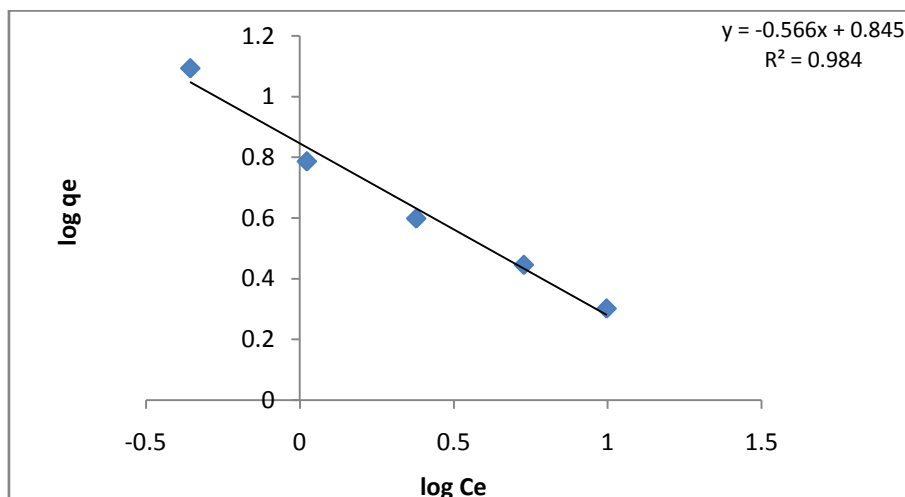


Figure 12: Freundlich Isotherm for the Adsorption of Cd onto PABC.

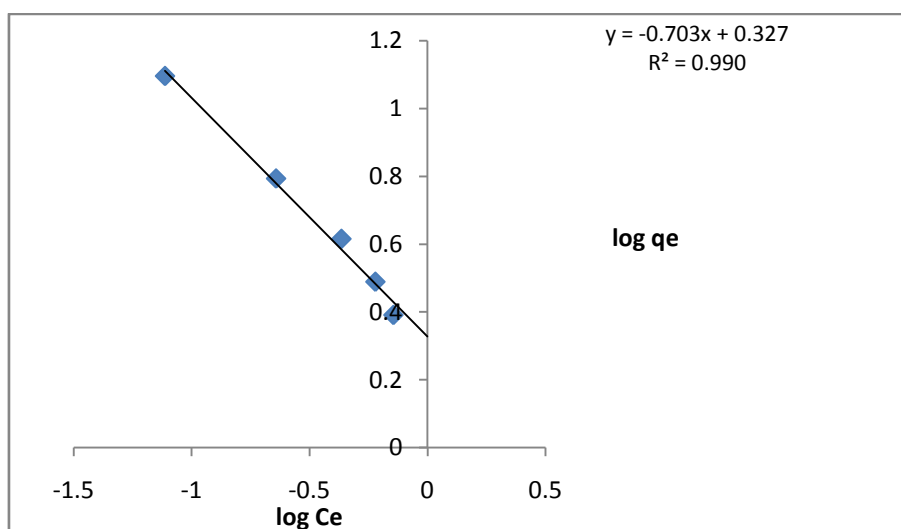


Figure 13: Freundlich Isotherm for the Adsorption of Pb onto PABC.

3.4 Adsorption Kinetics

The rate of adsorption of Cd and Pb onto PABC was modelled using Pseudo-first order and Pseudo second order equations. The integrated form of Pseudo first order equation is given in equation (15).

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

The linearized form of the integrated Pseudo second order equation is given in equation (16)

$$\frac{t}{q_t} = \frac{1}{k_{p2} q_e^2} + \frac{1}{q_e} t \quad (16)$$

Where: q_e is the adsorption capacity at equilibrium (mg/g), q_t is the adsorption capacity at time t (mg/g), k_{p1} is the rate constant of first order adsorption (mg/min) and k_{p2} is the rate constant for second order adsorption (mg/min).

The experimental data were linearly correlated with Pseudo First order and Pseudo second order models. Correlation with Pseudo First Order equation gave very low correlation coefficient (R^2) ranging between 0.0453 and 0.4135 for the two adsorbate concentrations tested. Also, the Exp q_e and the Cal q_e values did not correlate thus, adsorption of Cd and Pb onto PABC do not follow First Order kinetics. However, the Pseudo Second Order equation gave high correlation coefficient (R^2) ranging between 0.9992 and 1.000 for both Cd and Pb adsorption. A correlation was observed between the Exp q_e and the Cal q_e values as shown in Figs. 14 and 15.

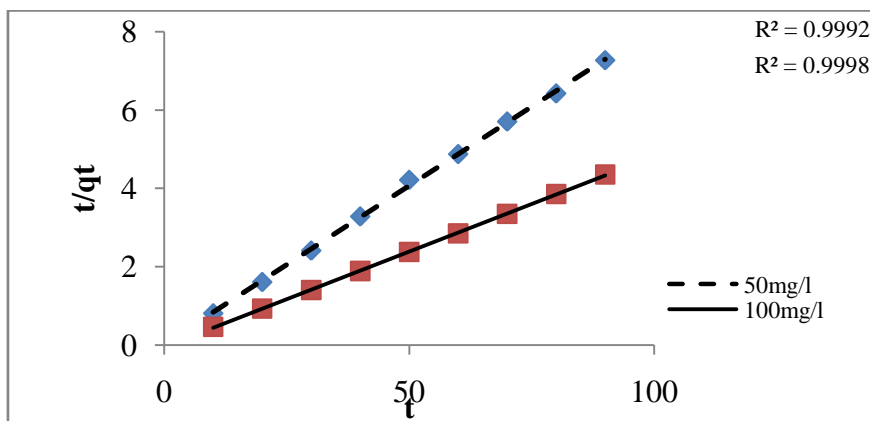


Figure 14: Pseudo-second-Order Plots for Adsorption of Cd onto PABC.

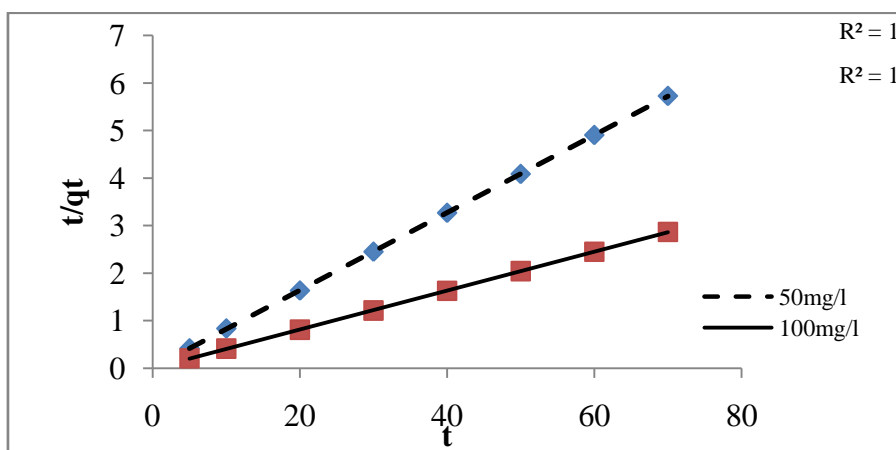


Figure 15: Pseudo-Second-Order Plots for Adsorption of Pb onto PABC

3.4.1 Test for Kinetic Model

The test for kinetic models was calculated from equation (14) using Excel software. From the results as presented in Table 3, Pseudo second order kinetic model had the least error (0.006 and 0.002) for both Cd and Pb removal respectively. Thus, the adsorption of Cd and Pb fitted well into Pseudo Second Order Kinetics. This suggests that Chemisorption may be the limiting step in the adsorption process. Similar observation was reported by [22]. The linear models and the corresponding kinetic constants for all the kinetic models tested are presented in Table 3.

Table 3: Kinetic Parameters and Exp. and Cal q_e for Cd and Pb Adsorption onto PABC

Metals	C_o	Pseudo First Order					Pseudo Second Order				
		Exp q_e	Cal q_e	K_{p1}	R^2	SSE (%)	Exp q_e	Cal q_e	K_{p2}	R^2	SSE (%)
Cd	50			0.008	0.160				0.21	0.999	
	100	12.45	0.06	0.011	1		12.45	12.38	-	2	
Pb	50	21.49	6	-	0.413	0.175	21.49	20.58	0.053	0.999	0.006
			0.09	-	5					8	
	100	12.24	8	0.018			12.24	12.25	0.600		
		24.69		-	0.135	0.192	24.69	24.45	1.673	1.000	0.002
			0.10	0.004	9				1.000		
			4		0.045						
			0.39		3						
			3								

IV. CONCLUSION

This study showed the adsorptive capacity of Physicochemical Activation Bamboo Carbon (PABC) for the removal Cd and Pb ions from wastewater. The batch adsorption studies revealed a high removal efficiency of 83.44% at pH-9 within 90mins for 50mg/l initial Cd conc. In the case of lead, high removal efficiency of 96.09% at pH-11 was achieved within 60mins. The adsorption behaviour of Cd and Pb was described by Freundlich, Temkin and Hills Isotherms but the equilibrium data fitted best into the Freundlich equation indicating multilayer adsorption on heterogeneous surface. The kinetic data follows Pseudo second order kinetic model suggesting that chemisorptions may be the rate limiting step in the adsorption process. This study showed that the PABC can remove Cd^{2+} and Pb^{2+} ions from aqueous solution to avert expensive commercial adsorbents. Models from these results can be used in treatment of wastewater containing cadmium or lead.

REFERENCES

- [1] Bahadir T, Bakan G, Altas L, Buyukgungor H, The Investigation of Lead Removal by Biosorption: An Application at Storage Battery Industry Wastewaters'. *Enzyme Microb. Technol.* 2007; 41 (), 98–102.
- [2] Wang S, Gong W, Liu X, Yao Y, Gao B, Yue Q, (2007) Removal of Lead (II) from Aqueous Solution by Adsorption onto Manganese Oxide-Coated Carbon Nanotubes. *Sep. Purif. Technol.* 2007; 58 (), 17–23.
- [3] Gupta VK, Agarwal S, Saleh TA, Synthesis and Characterization of Alumina-Coated Carbon Nanotubes and their Application for Lead Removal. *J. Hazard. Mater.* 2011; 185 (), 17–23.
- [4] Goel J, Kadirvelu K, Rajagopal C, Garg VK, Removal of Lead(II) by Adsorption using Treated Granular Activated Carbon: Batch and Column studies. *J. Hazard. Mater.*, 2005; 125 (), 211–220.
- [5] Hameed BH, Din ATM, Ahmad AL, Adsorption of Methylene Blue onto Bamboo-Based Activated Carbon: Kinetics and Equilibrium Studies. *J. Hazard. Mater.* 2006; 141 (3), 819 – 825.
- [6] Keith KH, Choy.JP, Gordon M, Production of Activated Carbon from Bamboo Scaffolding Waste – Process Design, Evaluation and Sensitivity analysis, *Chem. Engr. J.* 2005; 109 (1-3), 147 -165.
- [7] Evbuomwan BO, Abutu AS, Ezeh CP, The Effects of Carbonization Temperature on Some Physicochemical Properties of Bamboo Based Activated Carbon By Potassium Hydroxide (KOH) Activation. *J. Physical Sci.*, 2013; 3 (5), 187-191.
- [8] Mahanim SMA, Asma IW, Rafidah J, Puad E, Shaharuddin H, Production of Activated Carbon from Industrial Bamboo Wastes. *J. Tropical Forest Sci.*, 2011; 23 (4), 417-424.
- [9] Nwabanne JT, Mordi MI, Equilibrium Uptake and Sorption Dynamics for the Removal of Basic Dye using Bamboo. *Afri. J. Biotechnol.*, 2009; 8 (8), 1555-1559.
- [10] Al-Qodah, Z.; Shawabkah, R, Production and Characterization of Granular Activated Carbons from Activated Sludge. *Braz. J. Chem. Eng.* 2009; 26 (), 127-136.
- [11] Fapetu OP, Production of Charcoal from Tropical Biomass for Industrial and Metallurgical Processes. *NJEM*, 2000; 1 (2), 34-37.
- [12] Ahmedna M, Johns MM, Clarke SJ, Marshal WE, Rao RM, Potential of Agricultural By-Product Based Activated Carbons for Use in Raw Sugar Decolourization. *J. Science of Food and Agriculture.* 1997; 75 (1), 117-124.
- [13] Ho YS, McKay G, Pseudo-Second Order Model for Sorption Processes. *Process Biochem.* 1999; 34 (5), 451-465.
- [14] Bulut Y, Aydin H, A Kinetics and Thermodynamics Study of Methylene Blue Adsorption on Wheat Shells. *Desalination*, 2005; 194 (1-3), 259- 267.
- [15] Li Y, Du Q, Wang X, Zhang P, Wang D, Wang Z, Xia Y, Removal of Lead from Aqueous Solution by Activated Carbon prepared from Enteromorpha Prolifera by Zinc Chloride Activation. *J. Hazard, Mater.* 2010; 183 (), 583-589.
- [16] Okure IS, Okafor PC, Ibok UJ, Adsorption of Cu^{2+} , As^{3+} and Cd^{2+} ions from Aqueous Solution by Eggshell. *Glob. J. Pure Appl. Sci.* 2010; 16 (), 407.
- [17] Okuo JM, Ozioko AC, Adsorption of Lead and Mercury Ion on Chemically Treated Periwinkle Shell. *J. Chem. Soc Nig.* 2001; 26 (), 60.

- [18] Gundogdu A, Ozdes D, Duran C, Bulut VN, Soylak M, Senturk HB, Bio Sorption of Pb II Ions from Aqueous Solution by Pine Bark. *Chem. Eng. J.*, 2009; 153 (), 62-69.
- [19] Ahmad R, Kumar R, Haseeb S, Adsorption of Cu²⁺ from Aqueous Solution onto Iron Oxide Coated Eggshell Powder: Evaluation of Equilibrium Isotherm, Kinetics and Regeneration Capacity. *Arab J. Chem.* 2010; 5 (), 353-359.doi:10.1016/j.arabjc .2010.09.003.
- [20] Israel A, Ogali R, Akaranta O, Obot IB, Removal of Cu II from Aqueous Solution using Coconut Coir Dust, *Scholars Res. Library Der Pharamchemical* 2010; 2 (), 60-75.
- [21] Ademiluyi FT, Amadi SA, Amakama, Nimisingha J, Adsorption and Treatment of Organic Contaminants using Activated Carbon from Waste Nigeria Bamboo. *J. of Appl. Sci. Environ. Manage.* **2009; 13 (3), 39-47.**
- [22] Wang FY, Wang HW, Ma JW, Adsorption of Cadmium (II) ions from Aqueous Solution by a New Low-Cost Adsorbent-Bamboo Charcoal. *J. Hazard. Mater.* **2010; 177 (1-3), 300-306.**