
Adsorption Efficiency of Pulverized *Jatropha curcas* Shell in the Removal of Cadmium(II) and Lead(II) Ions from Aqueous Solution

S.A. Adeyemi, A.O. Aliyu and A.G.O. Logunleko

Department of Chemistry,

Sikiru Adetona College of Education, Science and Technology,

Omu-Ajose, Ogun State, Nigeria.

Corresponding Author: shamsuad2@gmail.com

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ABSTRACT

This study focused on the efficiency of *Jatropha curcas* shell (Physic nut shell) in the removal of hazardous Cd^{2+} and Pb^{2+} ions from an aqueous solution in a batch mode process using atomic absorption spectrophotometer (AAS) in determining the metals. The effect of pH, biomass dosage, contact time, and effect of concentration at 30 ± 2 °C was investigated; Maximum 98.8% and 96.6% sorption were attained within 30 minutes (60 minutes was selected as contact time) at the optimum equilibrium of pH 6 for cadmium and lead respectively. Adsorption efficiencies of 93.6% and 98.5% were recorded at the lowest initial concentrations for cadmium and lead, respectively, while maximum sorption capacities of 98.2% and 98.8% were obtained at the optimum adsorbent dosage. Sorption of Cd^{2+} and Pb^{2+} adsorption was better explained by the pseudo-second-order model. Kinetic analysis revealed that the pseudo-second-order model best described the adsorption process, indicating chemisorption as the dominant mechanism. Equilibrium data fitted the Langmuir isotherm better ($R^2 = 0.9865$ for Cd^{2+} and $R^2 = 0.9982$ for Pb^{2+}) than the Freundlich model, suggesting monolayer adsorption on a homogeneous surface. Based on this result, Physic nut shell (PNS) has proved to be a promising, and effective, means of extirpating toxic cadmium and lead from aqueous solution.

Keywords: Adsorption, Efficiency, Isotherm, *Jatropha curcas*, Kinetics

INTRODUCTION

Most industrial effluents discharged into the environment contain heavy metals that make their way into the aquatic medium, which has direct and indirect adverse effects on humans and other organisms. These environmental challenges are giving environmental chemists restless minds, due to the associated health risk posed by these non-biodegradable hazardous elements.

Anthropogenic activities in urban areas and cities generate more chemical emissions to the environment from industries and other related actions, which mostly cause environmental problems [1].

Although metal finds many useful applications in our daily life, increased industrialization and various domestic activities have contributed largely to the introduction of heavy metals into the aquatic medium, as well as into the terrestrial environment [2]. The persistence of the heavy metals in the ecosystem and their incremental accumulation in the food chain poses a negative impact on human health [3, 4].

Cadmium adversely affects the liver and kidneys of human and animals; meanwhile, epidemiological data indicate that chronic exposure of it have carcinogenic effects on human beings such as breast cancer, kidney cancer, lung cancer, pancreas cancer and prostate cancer to mention few [5]. According to United States Environmental Protection Agency group Cd in B1 carcinogen class and consider 0.005 mg/l cadmium in drinking water as permissible limit [6].

High concentration of lead will cause severe damage to the nervous system and affect the function of brain cells [7]. It is necessary to sequester these deadly substances from heavy metal-bearing effluent before being discharged into the environment [8].

Conventional techniques for removing dissolved heavy metals such as ion-exchange, precipitation, electro-dialysis, and reverse osmosis methods, are costly and generate a huge amount of metal-bearing sludge. Based on that, a promising and low-cost effective sorption method has been introduced using biomass to extirpate heavy metals from its aqueous solution and industrial metal-bearing effluents [9].

This research was conducted to examine and evaluate efficiency *Jatropha curcas* shell in the removal of hazardous Cd^{2+} and Pb^{2+} ions from an aqueous solution, as well as investigating the effect of biomass concentration, pH, contact time, and effect of concentration at 30 ± 2 °C while the removal is taking place. Using PNS to remove heavy metals will drastically reduce the environmental health threat caused by these hazardous metals.

MATERIALS AND METHODS

Materials

Jatropha curcas shells, Analytical grade $\text{CdCl}_2 \cdot 5/2\text{H}_2\text{O}$ and $\text{Pb}(\text{NO}_3)_2$ salts, Digital pH meter, Rotary shaker, and Atomic absorption spectrophotometer.

Sorbent Collection

Dried *Jatropha curcas* shells were collected from the Alowolodu farm settlement, Oke-Odan, Ogun State, Nigeria; washed with distilled water to remove sand, then dried in oven-dried at 55 °C for 2 hours and grounded into a powdery form to a maximum particle size of 2 mm.

Preparation of Cd²⁺ and Pb²⁺ Solution

A stock solution (1000 mg/L) of cadmium and lead was prepared by dissolving the required amount of analytical grade 2.03 g of CdCl₂·5/2H₂O and 1.60 g of Pb(NO₃)₂ respectively, in deionized and double-distilled water, and then working solution of Cd(II) and Pb(II) concentrations were obtained by dilution with distilled water.

Batch Experiments

The batch experiments were conducted in 100 mL Erlenmeyer flasks containing 25 mL of solution. A weighted amount of 0.4 g pulverized physic nut shell was added to cadmium and lead solutions. The mixtures were shaken on a rotary shaker at 130 rpm for 1 h at 30±2 °C. The effect of pH (4.0-9.0), initial metal concentration (100-500 mg/L), sorbent dosage (0.4-2.4 g/L), and contact time (30-180 min) was investigated to find the optimum conditions for the cadmium and lead metals biosorption and the filtrates measured using a Flame Atomic Absorption Spectrophotometer (PerkinElmer Analyst 200) at 283.3 nm for lead and 228.8 nm (calibration 0-5 mg/L) for cadmium. The amount of Cd²⁺ and Pb²⁺ adsorbed (q_e) in mg g⁻¹ and the removal efficiency of physic nut shell were calculated by equations 1 and 2 respectively [10].

$$q_e = \left(\frac{C_o - C_e}{m} \right) V \quad (1)$$

$$\% \text{ removal efficiency} = \left(\frac{C_o - C_t}{C_o} \right) \times 100 \quad (2)$$

Where: q_e is the amount of metal uptake (mg/g), V(L) is the volume of metal ion solutions, C_o and C_e are the initial, final metal ion concentration (mg/L) and C_t (mg/L) is liquid-phase concentration at time t.

Adsorption Isotherm models and kinetics models

Langmuir and Freundlich isotherm were used to analyzed results obtained [11].

$$\frac{1}{q_e} = \frac{1}{[(KLq_m)C_e]} + \frac{1}{q_m} \quad (3)$$

K_L is the Langmuir constant (L/mg) that shows the energy of adsorption and q_m is the maximum monolayer adsorption capacity (mg/g). K_L and q_m can be obtained from the intercept and incline of the linear plot of C_e/q_e against C_e , respectively.

$$R_L = \frac{1}{[1 + K_L C_0]} \quad (4)$$

R_L is the dimensionless parameter that describe the nature of adsorption process either unfavourable ($R_L > 1$), linear ($R_L = 1$), favourable ($0 < R_L < 1$), or reversible ($R_L = 0$) [12].

$$\text{Log } q_e = \text{Log } K_f + \left(\frac{1}{n}\right) \text{Log } C_e \quad (5)$$

Where K_f is the sorption capacity constant and n is the intensity constant, q_e is the amount of metal ions adsorbed (mg/g) at equilibrium; C_e is final metal ion concentration (mg/L); $1/n$, n , K_f and R^2 were calculated from the plot of $\text{Log } q_e$ versus $\text{Log } C_e$. The slope is the value of $1/n$ and intercept is equal to $\text{Log } K_f$.

The controlling mechanism of the sorption process was examined through two kinetics models whose expressions are shown in equations (6) and (7) respectively. K_1 and K_2 are pseudo-first-order and pseudo-second-order rate constant. The second-order rate constant is used to calculate the initial sorption rate (h) as given in equation (8).

$$\text{Log } (q_e - q_t) = \log(q_e) - \frac{k_1 t}{2.303} \quad (6)$$

$$\frac{t}{q_t} = \frac{1}{K_2 q_e^2} + \frac{t}{q_e} \quad (7)$$

$$h = K_2 q_e^2 \quad (8)$$

RESULTS AND DISCUSSION

Effects of pH, Biomass Concentration, Metal ion Concentration and Contact Time

As shown in Fig. 1, it was observed that the sorption percent increase from acidic medium pH 4 to pH 6 (optimal sorption attained), and a decrease in significant sorption changes occur when the solutions turned to neutral and to the basic medium of pH 8 and pH 9 respectively. Therefore, the optimum sorption was 98.8% and 96.6% observed in the cadmium and lead ion solutions respectively. As presented in Fig. 2, an increase in biomass concentration aids the increasing amount of cadmium(II) and lead(II) ions extirpated from the solution. This could be attributed to the availability of more sorbent surface area and sites for the ions [13]. At an initial

concentration of 100 mg/l high percentage of 93.6% and 98.5% adsorption is observed for cadmium and lead metal ion solutions, but as the concentration increases beyond 100 mg/l to 500 mg/l, decreases in metal sorption occurs.

Invariably, efficiency decreases observed could be due to an increase in metal ions that compete for the available fixed binding site. This observation agrees with the findings of AJayKumar *et al.* [14]. The contact time of 60 min was selected as the optimal contact time for further experiments because pulverized physic nut shell had been saturated within 30 minutes before the expiration 180 min of the investigation for cadmium and lead ion respectively.

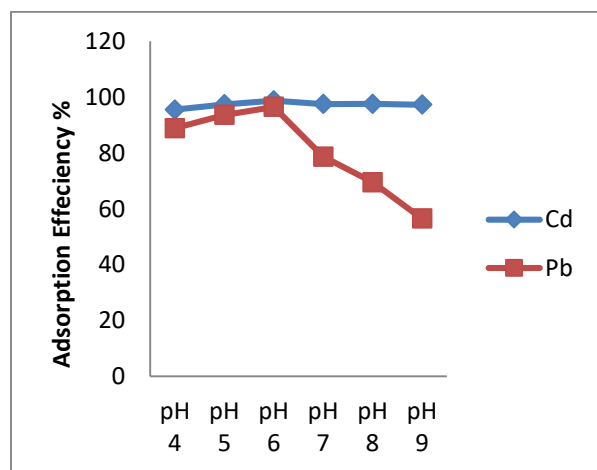


Fig. 1: Effect of pH on Cd^{2+} and Pb^{2+} sorption by PNS.

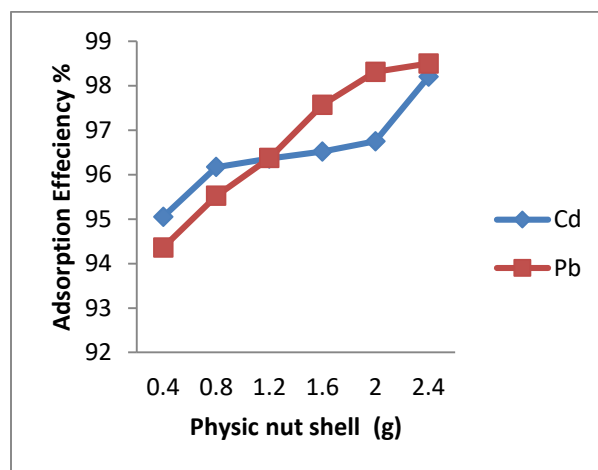


Fig. 2: Effect of dosage on Cd^{2+} and Pb^{2+} adsorption onto PNS.

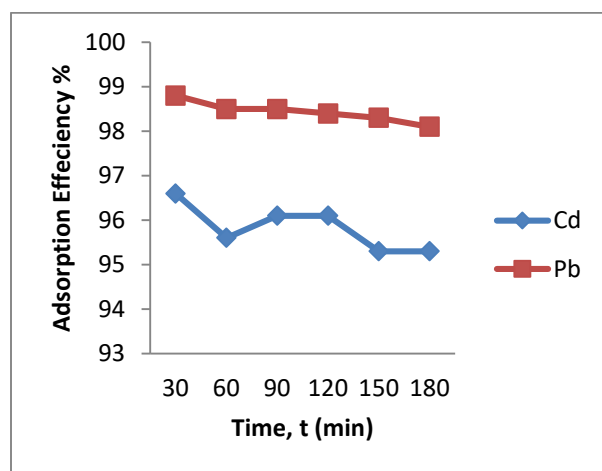


Fig. 3: Effect of contact time on Cd^{2+} and Pb^{2+} sorption by PNS.

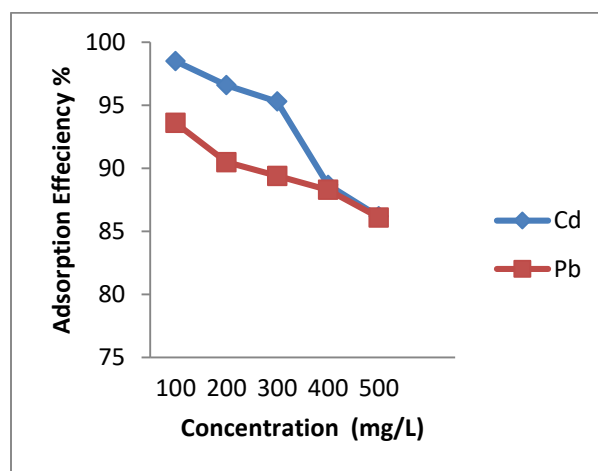


Fig. 4: Effect of initial concentration on Cd^{2+} and Pb^{2+} sorption by PNS.

Table 1: Langmuir and Freundlich isotherms parameters for the adsorption of metals by pulverized physic nut shell

Metal	Langmuir isotherm parameters				Freundlich isotherm parameters			
	Q _{max}	R _L	K _L	R ²	1/n	n	K _F	R ²
Cd	10.0	0.244	0.0310	0.9865	0.2	5.0	3.67	0.9771
Pb	74.1	0.033	0.2353	0.9982	0.02	4.9	2.48	0.9927

Table 2: Pseudo-first and second order parameters for the adsorption of metal ion by pulverized physic nut shell

Metal	Pseudo-first order parameters				Pseudo-second order parameters				
	q _e (cal)mg/g	K ₁ (1/min)	R ²	q _e (exp)mg/g	q _e (cal)mg/g	h(mg/g.min)	K ₂ (g/mg.min)	R ²	q _e (exp)mg/g
Cd	3.6308	0.0106	0.3201	2.1329	2.0846	8.90	2.049	0.9996	2.1329
Pb	2.4820	0.0357	0.5883	2.4683	2.4697	14.03	2.301	0.9998	2.4683

As shown in Table 1, Langmuir and Freundlich isotherms equilibrium models were fitted, but in comparison, the Langmuir isotherm is the best fit to the experimental equilibrium adsorption data than the Freundlich isotherm, which means that metals ions are taken up independently on a single type of binding site without interrupt sorption of the next ion [15].

Table 2 reveals the high correlation coefficient and other parameter of the pseudo-second-order kinetic and the straight line in the plotted graphs passes through the experimental points and the calculated q_e matched the experimental q_e closely, indicating that chemisorption is likely the rate-controlling mechanism, compared to pseudo-first-order kinetic, which indicates the better finest of second-order kinetic in the described adsorption process. Similar findings have been reported in related work by Nada *et al.* [16].

CONCLUSION

The Langmuir isotherm model fits well for the sorption of Cd²⁺ and Pb²⁺ which proved the feasibility and efficiency of low-cost ‘agro-waste’ pulverized physic nut shell in their removal from aqueous solution. This finding indicates that the aim of the study has been successfully achieved. The valorization will drastically reduce the environmental health threat caused by these hazardous metals, save lives and increase economy.

Limitations and Future Research Recommendations

This study was conducted under controlled laboratory batch conditions using synthetic single-metal solutions, which may not fully represent real wastewater systems containing mixed contaminants. The limited temperature range, lack of extensive surface characterization, and absence of long-term regeneration and reuse tests also restrict the generalization of the findings. Future studies should therefore focus on applying *Jatropha curcas* shell to real industrial effluents and continuous-flow column systems to evaluate large-scale performance. Additional

research is needed to investigate thermodynamic behavior over wider temperature ranges, optimize sorbent regeneration, and enhance adsorption capacity through chemical or physical modification. Comprehensive characterization, life-cycle cost analysis, and environmental impact assessments are also recommended to establish the practical feasibility and sustainability of Physic nut shell as an efficient biosorbent for the removal of toxic heavy metals from aqueous environments.

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