Evaluation of the Removal Efficiency of Lead Ion from Aqueous Solution Using Unmodified and Modified Mahogany Sawdust

Ngozi Jane MADUELOSI*, Okpara Sergeant BULL, and Nornubari Solomon INORDEE

Department of Chemistry, Rivers State University, Nkpolu- Oriworukwo, Port Harcourt, Nigeria. P.M. B. 5080.

***Corresponding Author**

DOI: https://doi.org/10.51584/IJRIAS.2026.11010059

Received: 24 December 2025; Accepted: 30 December 2025; Published: 05 February 2026

ABSTRACT

This study was carried out to evaluate the efficiency of unmodified and modified acid and alkaline mahogany sawdust as adsorbents for the removal of lead (Pb) from aqueous solutions. The modification was done using HCl and NaOH solutions. The batch adsorption method was used to evaluate the performance of each adsorbent under varying conditions, including initial Pb^{2+} concentration, adsorbent dosage, contact time, and pH. The results showed that the maximum adsorption capacity for the control, acid, and alkaline modified adsorbents were 24.272 mg/g, 21.322 mg/ a n d 14.662 mg/g respectively. Removal efficiency of 98.44% was achieved with the acid-modified sawdust at an initial Pb concentration of 100 mg/L and pH 4 while the maximum removal efficiency by the alkaline and unmodified absorbents were 97.22% and 94.35% respectively. The data analyzed for adsorption kinetics and equilibrium isotherm fitted well with the pseudo-second order kinetic model and the Freundlich isotherm model. This study demonstrated that modified mahogany sawdust is an efficient, eco-friendly adsorbent for treating lead-contaminated water. The findings provide valuable insights for the optimization of mahogany sawdust for practical heavy metal ions removal.

Keywords: Mahogany sawdust, Lead ion, Aqueous Solution, Adsorption

INTRODUCTION

Heavy metal pollution in aqueous solutions is a growing concern worldwide due to its detrimental effects on human health and the environment. Heavy metal ions in industrial wastewater constitute a major cause of pollution for groundwater sources (Muya *et al*., 2016). The presence of heavy metals in wastewater has been increasing with the growth of industry and human activities, such as the plating and electroplating industry, batteries, pesticides, the mining industry, metal rinse processes, the anning industry, the textile industry, petrochemicals, paper manufacturing, and electrolysis applications (Qasem *et al*., 2021). Unlike organic wastes, heavy metals are non-biodegradable and they can be accumulated in living tissues, causing various diseases and disorders; hence the need for removal before discharge.

Research interest into the production of cheaper adsorbents to replace costly wastewater treatment methods such as chemical precipitation, ion- exchange, electro flotation, membrane separation, reverse osmosis, electrodialysis, and sand solvent extraction is attracting the attention of scientists (Ngah and Hanafiah, 2008). Among these methods, adsorption has been recognized as a promising approach for the efficient removal of heavy metals, even at low concentrations (1-100 mg/L) due to the limitations of other techniques. Extensive research has been conducted on various adsorbents for metal ions from water. These include the use of polymeric adsorbents, industrial by-product adsorbents, natural mineral-based adsorbents, and chelating resins. Polymeric adsorbents have shown effectiveness in heavy metal removal (Zaimee *et al*., 2021). Industrial by-product adsorbents, such as lignin, bark, chitosan, clay, and zeolite, have also been utilized for this purpose (Gupta *et al*., 2021).

In recent years, industrial by-product adsorbents, specifically wood sawdust, have emerged as sustainable and cost-effective materials for heavy metal removal (Tripathi and Ranjan, 2015). This is because the sorption capacity of wood materials which is rich in lignocellulosic content, is typically attributed to adsorption mechanisms (Demcak *et al*., 2017). Various methods, including chemical and physical modifications, have been employed to enhance the adsorption properties of sawdust. For instance, acid treatment has been utilized to increase the presence of functional groups that interact with heavy metal ions, leading to improved adsorption (Meez *et al*., 2021). Alkaline treatment, on the other hand, has been employed to enhance the surface area and porosity of sawdust, resulting in an increased adsorption capacity (Demcak *et al*., 2019). Studies have shown that sawdust of several trees both modified and unmodified is a potential solution for heavy metal removal from aqueous media (Muya *et al*., 2016). However, there is a need to further explore alternative sawdust adsorbents that are cost-effective and readily available for the removal of heavy metal ions from water. Hence, this study is intended to prepare and modify sawdust obtained from mahogany using bo, th, a,cid, an,b, and ase, and thereafter using them for the removal of lions fromfrom aqueous solution.

MATERIALS AND METHOD

Preparation and modification of Mahogany Wooden Sawdust (Adsorbent preparation)

The Mahogany Wooden Sawdust was bought from Bori Timber market in Khana Local Government Area of Rivers state, Nigeria. It was filtered with a 2.0 mm sieved mesh and washed in a beaker with deionised water to remove dust and other dirt particles. The sample was placed in an oven at a temperature of 85 ^{o} C for 24 hours to dry, then it was stored in an airtight container. 30g each of the dried sample was modified separately using 0.1 M HCl and 0.1 M NaOH. It was soaked for 24hours in the acid and alkaline solution after which it was washed with distilled water repeatedly to remove soluble impurities. The pH was monitored with a pH meter. The sample was oven dried again at 50 ^{o}C according to the method given by Djilali *et al*., (2012).

Adsorbate preparation (Preparation of Lead solution)

A stock solution with a concentration 1000ppm of the lead nitrate ion was prepared by dissolving 1.6g of the metal salt (Lead Nitrate) into a 1000ml volumetric flask and distilled water was added to the flask till it reached the given mark on the volumetric flask. Various adsorbate concentrations were obtained from the stock solution (100ppm-500ppm) by appropriate dilution of the stock with distilled water using the formula

$$C_1V_1= C_2V_2. \qquad 1$$

Where, C_1 = concentration of stock solution in ppm

C_2 = concentration of the working solution in ppm

V_1 = volume of working solution to be taken from the stock solution in ml

V_2 = volume of measuring cylinder used in ml.

Batch Adsorption Studies

Batch adsorption studies were conducted using 100ml beakers into which the Lead Nitrate solution and the weighed Mahogany Wood Sawdust adsorbents were added. pH (2.0, 4.0, 6.0, 8.0, and 10.0), dosage (0.5, 1.0, 1.5, 2.0, and 2.5g), contact time (30, 60, 90, 120, and 150 mins), and different lead ion solution concentrations (100, 200, 300, 400, and 500 ppm) were all examined. The beakers were agitated on an electric orbital shaker at a constant speed of 200 rpm. The samples were withdrawn and filtered using Whatman No. 1 filter paper, the filtrates were then analyzed for residual Lead Nitrate concentrations using an Atomic Absorption Spectrophotometer (AAS) (Bulut and Tez, 2007).

Data Analysis

The percentage of Lead ion removed by the Mahogany Wooden Sawdust adsorbents was calculated from the difference between the initial Lead Nitrate concentration (C_o) and the final Lead Nitrate concentration (C_f) with the formula below.

$$\% \text{ Removal} = \frac{C_o - C_f}{C_o} \; x\ 100 \qquad (2)$$

Amount of metal ion bound by the adsorbent:

The amount of lead ion (q_e) bound by adsorbents was calculated by the expression in the equation below

$$q_e = \frac{V[C_i - C_f]}{m} \qquad (3)$$

where; m = mass of the adsorbent and V = volume of adsorbate

Pseudo First Order Kinetic Model Equation:

$$Log\ (q_e - q_t) = -\left[\frac{K_1}{2.303}\right] t + Log q_e \qquad (4)$$

Where, q_e = Equilibrium adsorption capacity q_t = Amount adsorbed at time, t, k_1 = Model constant

Pseudo-Second Order Kinetic Model Equation:

$$\frac{t}{qt} = \frac{1}{K_2 qe^2} + \frac{1}{qt}\ t \qquad (5)$$

Where, K_2 = Model constant q_t = Amount adsorbed at time, t, q_e= Equilibrium adsorption capacity

Adsorption Isotthe the herm

Langmuir and the Freundlich adsorption isotherms were used to analyze experimental equilibrium sorption. Langmuir equation according to Ozacar *et al.,* 2005 was employed. The equation is represented thus:

Langmuir Model

$$\frac{C_f}{q_e} = \frac{1}{q_{max}}\ C_f + \frac{1}{K_a q_{max}} \qquad (6)$$

Where, q_{max} = maximum metal uptake under given conditions, K_a = constant related to affinity between adsorbent and sorbate, C_f = Final concentration of metal in filtrate, q_e = Equilibrium adsorption capacity.

Freundlich Model

$$Log\ q_e = \frac{1}{n}\ Log\ C_f + Log K_f \qquad (7)$$

Where, k_f = Model constant n = Adsorption intensity q_e = Equilibrium adsorption capacity.

RESULTS AND DISCUSSION

Effect of variables on removal efficiency:

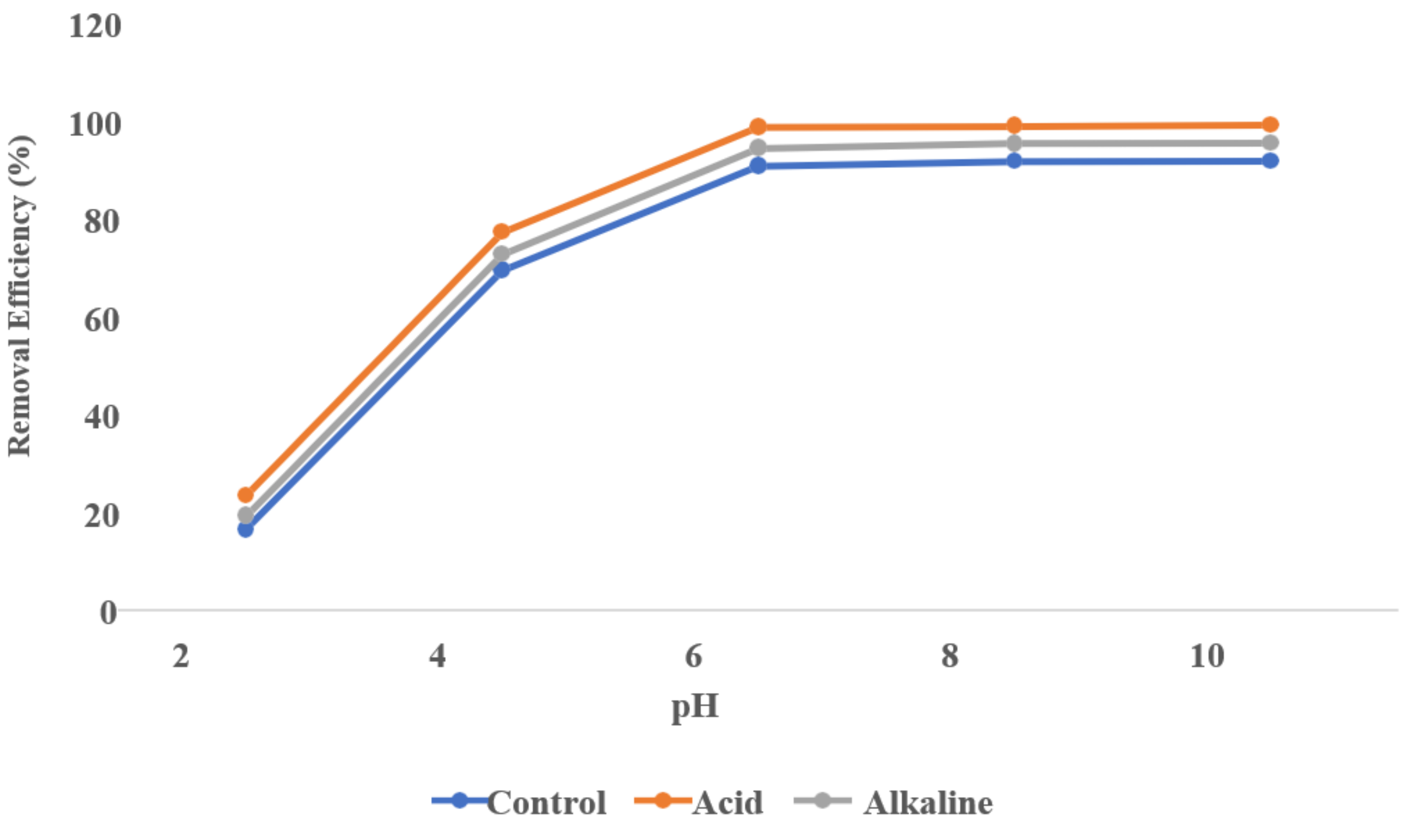

Figure 1: Plot of % Removal of lead using acid and alkaline modified adsorbent at varying pH.

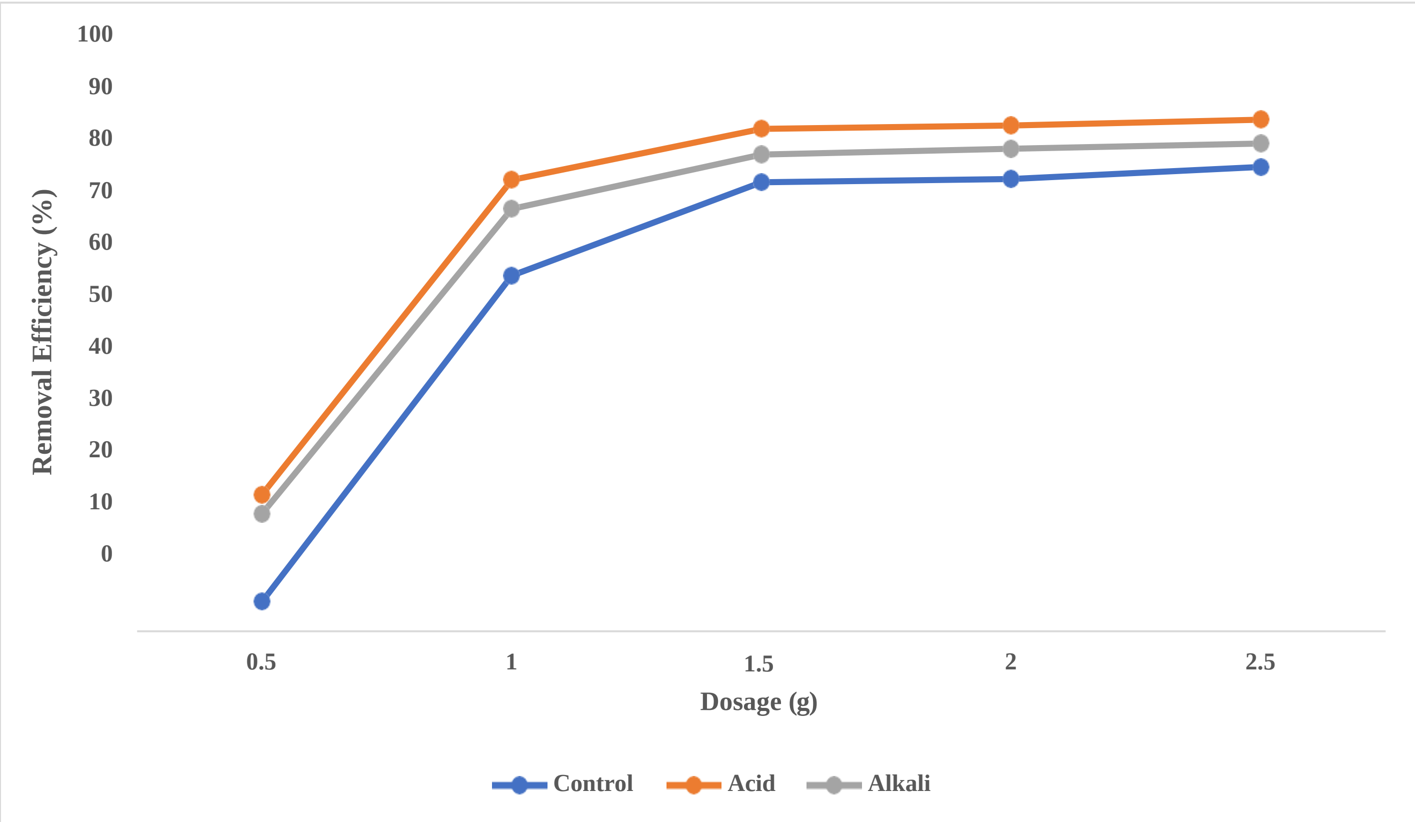

Figure 2: Plot of % Removal of lead using control, acid, and alkaline modified adsorbent at varying adsorbent doses.

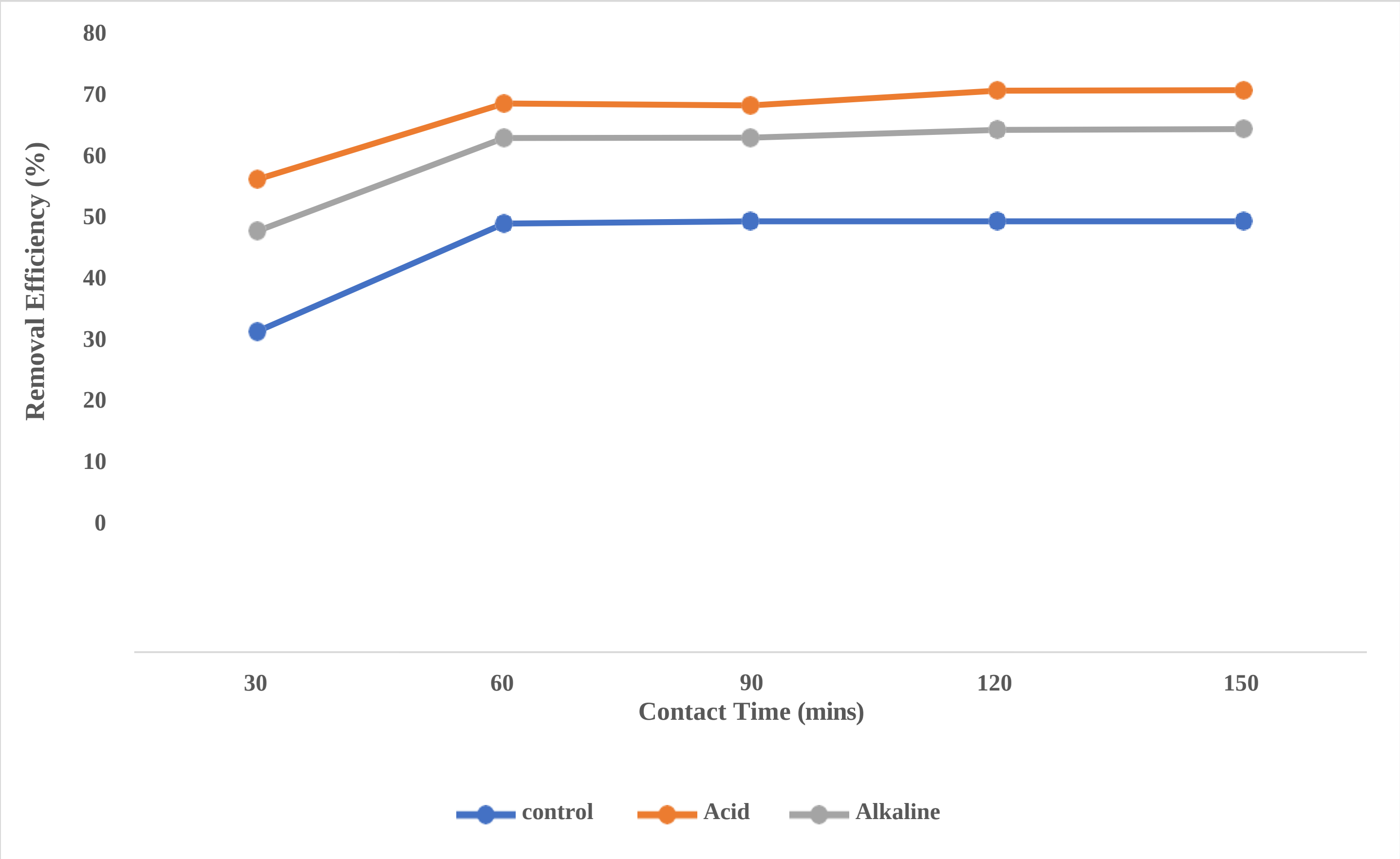

Figure 3: Plot of % Removal of lead using control, acid, and alkaline modified adsorbent at varying contact time.

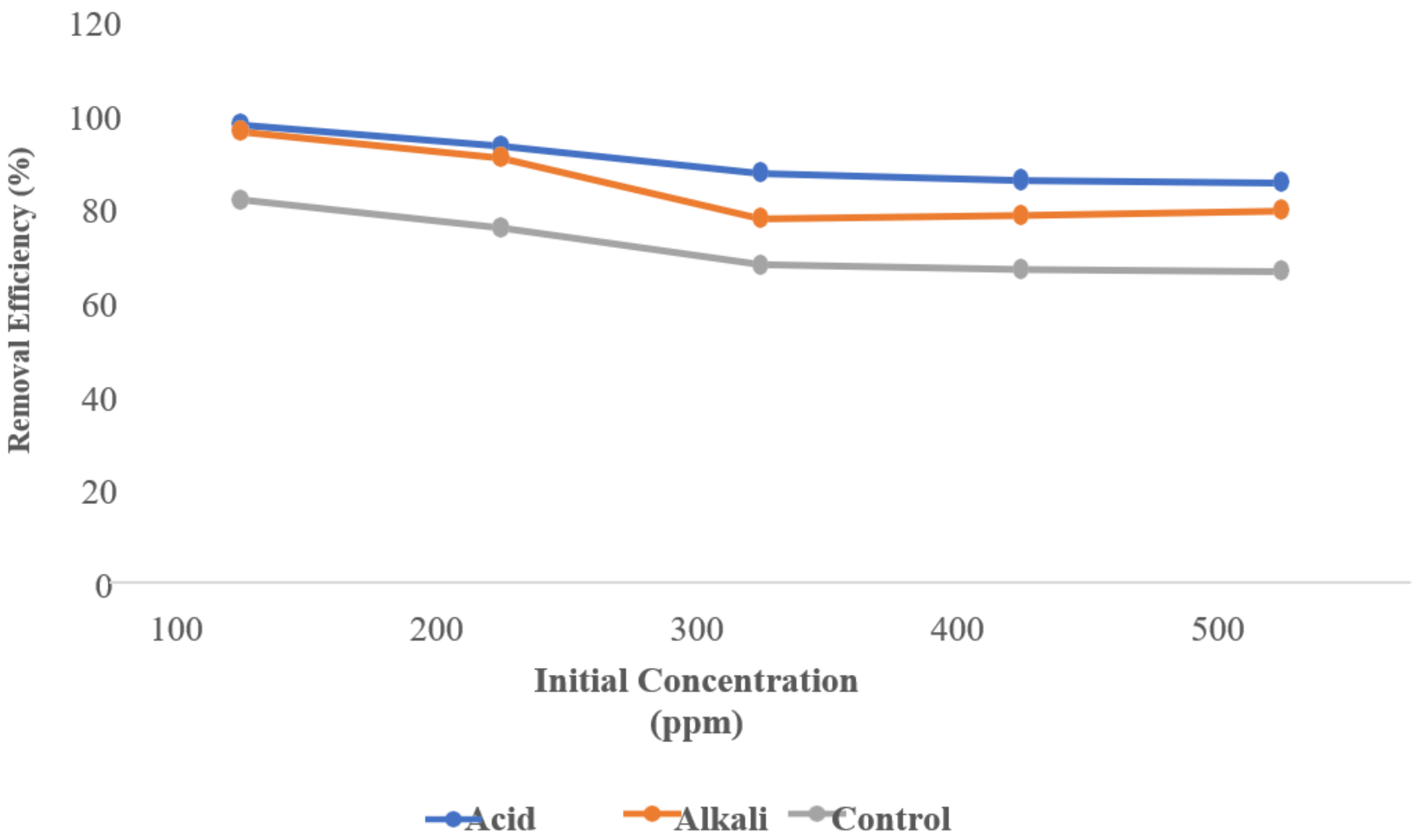

Figure 4: Plot of % Removal of lead using control, acid, and alkaline modified adsorbent at varying adsorbate initial concentrations.

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS |Volume XI Issue I January 2026

Sorption Kinetics

Table 1: Kinetic Parameters of lead ion adsorption onto modified and unmodified adsorbent

First-order	Parameter	Acid-modified	Acid-modified sawdust	Alkaline Modified sawdust
First-order kinetics	q_e.cal (mg/g)	1.693	1.508	1.697
	k_1 (1/min)	0.011	0.018	0.017
	R^2	0.797	0.907	0.928
Second-order kinetics	q_e cal (mg/g)	3.011	3.812	3.583
	K_2 (g/mg min)	0.037	0.044	0.040
	R^2	0.995	0.999	0.999

Adsorption Isotherm

Table 2: Langmuir and Freundlich Isotherms parameters of Lead ion adsorption onto acid-modified and unmodified adsorbent.

Isotherm	Parameter	Unmodified sawdust	Acid-modified sawdust	Alkaline Modified sawdust
Freundlich	K_f (mg/g). (L/mg)$^{1/n}$)	3.329	3.953	3.357
	1/n	0.276	0.39	0.358
	R^2	0.897	0.977	0.972
Langmuir	Qe (mg/g)	14.662	24.272	21.322
	K_L (L/mg)	0.021	0.070	0.050
	R^2	0.985	0.901	0.855

DISCUSSION

Effects of operating conditions

Effects of pH

Figure 1 dddemonstrates thatb^{2+} adsorption by the control (unmodifie saw dust), aci,, an d alkali modified sawdust was highly dependent on pH, with removal efficiencies increasing from 6.75% to 91.01%,14.56% to 99.28% a nd 6.75% to 91.01% respectively for the various adsorbents when pH was raised from 2 to 10 with an optimal seen at 6.5. This phenomenon can be explained by the surface charge of the adsorbent and the H^+ ions present in the solution. The lower adsorption at acidic pH may be due to the competition between protonated surface sites and Pb^{2+} cations thereby diminishing binding on the adsorbents. Lim *et al*., (2008), gave a similar report from their study. As reported by Rahman and Islam (2009), at higher pH values, deprotonation of functional groups on the adsorbent's surface enhanced Pb^{2+} uptake due to reduced electrostatic repulsion and greater attraction to negatively charged sites. In comparison, the acid-modified sawdust achieved consistently high removals above 98% from pH 6-10, suggesting the introduction of functional groups tolerant to pH changes as suggested by Gad *et al*., (2013).

Effects of adsorbent dosage

Figure 2 showed that increasing dosage from 0.5 g to 2.5 g resulted in an increase in Pb^{2+} removal efficiency from 4.99% to 78.02% for the control, 22.98% to 86% for acdmdified n d 19.79% to 82% for alkali-modified sawdust with recorded at 1.5 g. This is attributed to greater availability of surface binding sites and larger surface area at higher adsorbent doses, similar observation has been made earlier by Meena *et al*., (2008). However, the rate of improvement in removal efficiency was not linear, with smaller incremental enhancements observed at higher doses. This indicates that beyond a certain dosage, the additional binding sites did not contribute significantly to more Pb^{2+} uptake (El-Hajam *et al*., 2020). In comparison, the control showed a slower increase in removal. This contrasts with the acid-modified sawdust which showed a steeper increase in removal efficiency. The slower rate of enhancement for both the alkaline-modified and the control indicates that their additional binding sites were less effective for lead uptake compared to the acid-modified.

Effects of contact time

Figure 3 showed that Pb^{2+} adsorption on the control, acid, and alkali modified sawdust approached equilibrium after 60 minutes with 41.669% to 55.69%, 61.43% to 72.997%, and 56.013% to 67.991% removal. The result showed that the adsorption percentage of Pb ions increases with time until it becomes stable at around 120 min. It is also notable that adsorption increased rapidly in the early contact time within a few minutes, after which the increase became gradual. Similar observations were found for the removal of lead by ne sawdust in the study carried out by Semerjian, (2018). Other studies on sawdust by Bulut and Tez (2007) and Meena *et al.*, (2008) have reported similar rapid adsorption kinetics, reaching equilibrium within 30-60 minutes. The high adsorption rate at early contact time is attributed to the availability of large binding sites on the adsorbents which reduces with time because of adsorption until it reaches equilibrium. The maximum removal efficiency reached was lower for the alkaline modified and the control compared to 72.997% for the acid modified sawdust under the same conditions. This suggests that more binding sites were available and accessible on the acid-modified adsorbent.

Effects of Adsorbate Initial Concentration

As shown in Figure 4, the removal efficiency of the control, acid, and alkali modified sawdust decreased from 94.35% to 52.03%, 98.4% to 87.97%, and 97.22% to 82.98% as the initial concentration increased from 100 ppm to 500 ppm. This may be because at lower concentrations, sufficient binding sites are available on the adsorbent surface to adsorb the Pb^{2+} ions. However, at higher concentrations, the binding sites become saturated, resulting in a marginal decrease in removal efficiency as reported by earlier researchers, Meena *et al.*, (2008). A similar trend has been reported in a study by Bozic *et al.*, (2009) on sawdust adsorbents, where the percent removal dropped with increasing initial metal ion concentrations due to saturation. This observation also aligns with the findings of Khan *et al*., (2015), who investigated the impact of initial concentration on the use of acid-modified bamboo stem for lead removal. The observations that neither the alkaline modification nor the control process significantly enhanced the adsorptive efficiency for metal binding sites compared to the acid-treated adsorbent.

Sorption Kinetics

Table 1 showed the results for Pseudo first and second order kinetics for the control sample, acid, and alkaline modified ssamples The higher adsorptive capacity, qe, 3.011 mg/g, 3.812 mg/g and 3.583 mg/g as well as the correlation coefficient, R^2 0.995, 0.999 and 0.999 recorded for the control, acid and alkaline modified adsorbents for the pseudo second order model against the lower values recorded for pseudo first order model showed that the data fitted better to the pseudo second order model than the first order model. The pseudo-second order model assumes that chemisorption, which involves valency forces through sharing or exchange of electrons between sorbent and sorbate, is the rate-limiting step in the adsorption process (Hubbe *et al*., 2019). This is consistent with other adsorption studies on biosorbents that reported the suitability ofthe pseudo-secondd order kinetic model in analyzing adsorption data (Lim *et al*., 2008). Among the samples, acid and alkaline modified sawdust showed higher adsorption capacities than the control based on the qe values from the pseudo-second order model. This is because acid and alkali treatments introduce more functional groups on sawdust, enhancing its affinity for Pb^{2+} ions through increased chemisorption sites available for interaction (Meena *et al*., 2008).

Adsorption Isotherm

As seen in Table 2, the Freundlich constant K_f was highest for the acid-modified sawdust (3.953) followed by alkaline-modified sawdust (3.357) and unmodified sawdust (3.329). The K_f value is an indicator of adsorption capacity, so the acid-modified sawdust had the greatest capacity. The intensity of adsorption, 1/n, values were <1 for all samples, indicating a favorable adsorption. The Langmuir constants, q_m, indicating maximum adsorption capacity, were also highest for acid-modified sawdust (24.272 mg/g) compared to 21.322 mg/g and 14.662 mg/g for alkaline and the control respectively. The trend shows that no modification reduces the adsorption capacity compared to modified sawdust. The Langmuir constant K_L relates to binding strength, and was lower for the control, suggesting weaker binding before modification. The data better fit the Freundlich model (R^2 0.897-0.977) compared to the Langmuir model (R^2 0.855-0.985) implying that heterogeneous adsorption is more applicable than monolayer coverage. This may be due to the complex and variable nature of binding sites on the sawdust surface.

CONCLUSION

Modification improves the efficiency of adsorbents. Acid-modified sawdust exhibited higher lead removal efficiency and maximum adsorption capacity than the alkaline-modified and control samples. The kinetics data obtained fitted well with pseudo second order model which suggests chemisorption as did the Langmuir isotherm model which supportedthe Freundlich model. The study demonstrated that modified mahogany sawdust is an efficient, eco-friendly adsorbent for treating lead-contaminated water compared to the unmodified.

REFERENCES

1. Božić, D.S., Stanković, V.D., Gorgievski, M., Bogdanović, G., and Kovačević, R. (2009). Adsorption of heavy metal ions by sawdust of deciduous trees. *Journal of hazardous materials*, 171 1-3, 684-92.
2. Bulut, Y., and Tez, Z. (2007). Removal of heavy metals from aqueous solution by sawdust adsorption. *Journal of Environmental Sciences*, 19 2, 160-6.
3. Demcak, S., Balintova, M., and Demcakova, M. (2017). Study of heavy metals removal from model solutions by wooden materials. *IOP Conference Series: Earth and Environmental Science*, 92, 012008.
4. Demcak, S., Balintova, M., Demcakova, M., Csach, K., Zinicovscaia, I., Yushin, N., and Frontasyeva, M. (2019). Effect of alkaline treatment of wooden sawdust for the removal of heavy metals from aquatic environments. *Desalination and Water Treatment*, 155, 207-215.
5. Djilali, Y., Elandaloussi, E.H., Aziz, A., and De Ménorval, L. (2012). Alkaline treatment of timber sawdust: A straightforward route toward effective low-cost adsorbent for the enhanced removal of basic dyes from aqueous solutions. *Journal of Saudi Chemical Society*, 16(4), 381- 387.
6. El-Hajam, M., Idrissi, K.N., Plavan, G.-I., Halim, H.A., Mansour, L., Boufahja, F., and Zerouale, A. (2020). Pb2+ ions adsorption onto raw and chemically activated Dibetou sawdust: application of experimental designs. *Journal of King Saud University - Science. Advance online publication*. Retrieved 12th September, 2023 from doi:10.1016/j.jksus.2020.02.027.
7. Gad, H.M., Omar, H.A., Khalil, M.H., and Hassan, M.R. (2013). Factors Affecting Sorption of Pb(II) from Aqueous Solutions Using Sawdust-Based Activated Carbon. *The Journal of American Science*, 9(10), 95-106.
8. Gupta, A., Sharma, V., Sharma, K., Kumar, V., Choudhary, S., Mankotia, P., Kumar, B., Mishra, H., Moulick, A., Ekielski, A., and Mishra, P. K. (2021). A Review of Adsorbents for Heavy Metal Decontamination: Growing Approach to Wastewater Treatment. *Materials (Basel, Switzerland)*, 14(16), 4702.
9. Hubbe, M. A., Azizian, S., and Douven, S. (2019). "Implications of apparent pseudo-second-order adsorption kinetics onto cellulosic materials: A review," *Bioresource*. 14(3), 7582-7626.
10. Khan, M.A., Alemayehu, A., Duraisamy, R., and Berekete, A.K. (2015). Removal of lead ions from aqueous solution by Bamboo activated Carbon. *International Journal of Water Resources*, 5, 33-46.
11. Lim, J., Kang, H.-M., Kim, L.-H., and Ko, S.O. (2008). Removal of Heavy Metals by Sawdust Adsorption: Equilibrium and Kinetic Studies. *Environmental Engineering Research*, 13(2), 79-84.
12. Meena, A.K., Kadirvelu, K., Mishra, G., Rajagopal, C., and Nagar, P.N. (2008). Adsorptive removal of heavy metals from aqueous solution by treated sawdust (Acacia arabica). *Journal of hazardous materials*, 150 3, 604-11.
13. Meez, E., Rahdar, A., and Kyzas, G. Z. (2021). Sawdust for the Removal of Heavy Metals from Water: A Review. *Molecules (Basel, Switzerland)*, 26(14), 4318.
14. Muya, F. N., Sunday, C. E., Baker, P., and Iwuoha, E. (2016). Environmental remediation of heavy metal ions from aqueous solution through hydrogel adsorption: a critical review. *Water science and technology: Journal of the International Association on Water Pollution Research*, 73(5), 983–992.
15. Ngah, W.S.W. and Hanafiah, M.A.K.M. (2008) Removal of Heavy Metal Ions from Wastewater by

Chemically Modified Plant Wastes as Adsorbents: A Review. *Bioresource Technology*, 99, 3935-3948.

16. Ozacar, M. and Sengil, I. A. (2005). Adsorption of metal complex dyes from aqueous solutions by pine sawdust. *Bioresource Techno (l*96), 791-795.
17. Qasem, N.A.A., Mohammed, R.H., and Lawal, D.U. (2021). Removal of heavy metal ions from wastewater: a comprehensive and critical review. *Npj Clean Water*, 4(1), 36.
18. Rahman, M.S. and Islam, M.R. (2009) Effects of pH on Isotherms Modeling for Cu (II) Ions Adsorption Using Maple Wood Sawdust. *Chemical Engineering Journal*, 149, 273-280.
19. Semerjian, L. (2018). Removal of heavy metals (Cu, Pb) from aqueous solutions using pine (Pinus halepensis) sawdust: Equilibrium, kinetic, and thermodynamic studies. *Environmental Technology and Innovation*. Retrieved 30th September, 2023 from doi:10.1016/j.eti.2018.08.005
20. Tripathi, A., and Ranjan, M.R. (2015). Heavy Metal Removal from Wastewater Using Low-Cost Adsorbents. *Journal of Bioremediation and Biodegradation*, 6, 315.
21. Zaimee, M.Z.A., Sarjadi, M.S., and Rahman, M.L. (2021). Heavy Metals Removal from Water by Efficient Adsorbents. *Water*, 13(19), 2659.