

Optimization of Lead Removal from Aqueous Solution Using Iron Oxide-Modified Alumina Adsorbent Incorporating Sapodilla Leaf Extract

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Abstract

In this study, a novel adsorbent material, alumina beads modified with iron oxide and Sapodilla leaves extract (Fe/C/Al₂O₃), was successfully synthesized and evaluated for its efficiency in remediating lead [Pb (II)] ions from aqueous solutions. To determine the optimal removal conditions, the adsorption performance was investigated under varying operational parameters, including initial Pb (II) concentration, adsorbent dosage, and contact time. The best removal efficiency was achieved at an initial Pb (II) concentration of 60 mg L⁻¹, with an adsorbent dosage of 1.5 g and a contact time of 30 minutes, resulting in a high Pb (II) removal rate of 97.75%. Comprehensive characterization of the Fe/C/Al₂O₃ adsorbent was conducted using X-ray diffraction (XRD) to determine crystalline structure, nitrogen adsorption-desorption analysis (NA) for surface area and porosity evaluation, field emission scanning electron microscopy (FESEM) to observe surface morphology, energy-dispersive X-ray spectroscopy (EDX) for elemental composition analysis, and Fourier transform infrared spectroscopy (FTIR) to identify functional groups involved in adsorption. The adsorption data fit the Langmuir isotherm model, indicating monolayer adsorption with a maximum sorption capacity (q_{max}) of 4.23 mg g⁻¹. Kinetic studies revealed that the Pb (II) uptake process followed a pseudo-second-order kinetic model, suggesting chemisorption as the dominant mechanism. These findings highlight the potential application of Fe/C/Al₂O₃ as an effective and eco-friendly adsorbent for heavy metal removal in wastewater treatment.

Keywords: Adsorption; Alumina Beads; Lead (II); Iron Oxide; Sapodilla Leaves.

Introduction

Rapid development of industrialization and agricultural activities have caused the escalation of water pollution level that can be a serious threat for ecosystem and living creatures, one of most common water pollutant are heavy metal (Fouda-Mbanga et al., 2024; Pandey et al., 2024). This pollutant is not easily breaking down and tend to accumulated in food chain which leads to major health issues in human body (Sibiya et al., 2025). Lead (Pb), a common heavy metal found in environment can enter the human system via the digestive and respiratory systems, subsequently being absorbed into the bloodstream causing disruption to various organs and bodily functions such as kidneys, liver, reproductive and nervous systems, as well as interfere with immune

responses, urinary functions, cellular physiology, and gene regulation (Jomova et al., 2024; Roza Llera et al., 2021). Numerous monitoring studies have revealed that Pb concentrations in rivers, lakes, and coastal waters near industrial zones frequently exceed national and international safety thresholds. Elevated Pb levels have also been detected in rural agricultural areas, primarily due to the leaching of contaminated soils and the use of Pb-containing agrochemicals, indicating that this contamination is not confined to urban or industrial (Mendoza & Rogayan Jr., 2024).

Various techniques have been applied to tackle down the issue of heavy metal pollution in aqueous systems, for instance chemical precipitation, membrane filtration, electrochemical processes, coagulation-flocculation, ion exchange, and adsorption (Aslam et al., 2024; Sibiya et al., 2025). However, adsorption is considered to be one of the most affordable and effective method that can be applied to various water pollutants (Fouda-Mbanga et al., 2024). In this work, Al_2O_3 beads were applied for treating Pb(II) from water because of its good removal capacity, high stability, and low cost processs (Habila et al., 2023; Sadighi et al., 2023). The extract of Sapodilla leaves combined with iron oxide (Fe_2O_3) play roles as coating materials. The extract of sapodilla leaves was utilized as a carbon source, serving as a binder between iron (Fe) and the support material, while also providing functional groups that enhance adsorption capacity. Iron is considered a promising adsorbent because of its abundant availability, environmental friendliness, and strong capacity for removal heavy metal ions (Hegedüs et al., 2020; Zhang et al., 2022).

The aim of this paper was focused on remediation Pb(II) from aquatic system by modified alumina beads ($\text{Fe/C/Al}_2\text{O}_3$). Adsorbent was characterized by X-ray diffraction (XRD), nitrogen adsorption-desorption analysis (NA), field emission scanning electron microscopy (FESEM), Energy dispersive X-ray (EDX), and Fourier transform infrared spectroscopy (FTIR). Batch studies were conducted at several parameters such as initial concentration of Pb(II), adsorbent dosage, and contact time.

Literature Review

In recent years, the presence of heavy metal contaminants in aquatic environments has emerged as a significant concern for both ecosystems and human health (Shi et al., 2018). While certain heavy metals serve as essential micronutrients, excessive concentrations can have severe toxic effects due to their non-biodegradable nature and tendency to accumulate within the environment (Zhou et al., 2018). Industrial activities are a major contributor to heavy metal pollution, as their waste streams often contain substantial quantities of these hazardous elements (Gautam et al., 2014). Common heavy metals detected in wastewater include chromium (Cr), cadmium (Cd), copper (Cu), zinc (Zn), nickel (Ni), mercury (Hg), and lead (Pb), with Pb being considered one of the most toxic. In its inorganic forms, Pb can enter the human body primarily through ingestion of contaminated food and water, as well as inhalation of airborne particles (Ferner, 2001).

To mitigate its risks, several international and national agencies have set maximum permissible Pb concentrations in water systems. The Environmental Protection Agency (EPA) specifies limits of 0.0015 mg L^{-1} for drinking water and 0.05 mg L^{-1} for wastewater (D. Wang et al., 2024). Similarly, the World Health Organization (WHO) recommends a guideline value of 0.01 ppm (Baruah et al., 2025), while Malaysia's Department of Environment allows up to 0.5 mg L^{-1} (Hamdzah, 2018). Nevertheless, field measurements often reveal levels far exceeding these standards. For example, Pb concentrations of 329 mg L^{-1} have been reported in the Selangor River near mining activities (Sakai et al., 2017), 128 mg L^{-1} in Port Klang's industrial zone (Yunus et al., 2020), and between $1.58\text{--}4.50 \text{ mg L}^{-1}$ in Langkawi Island waters (Octavianti & Jaswir, 2017). In another study, Pb levels of 0.60 mg L^{-1} were detected, surpassing permissible thresholds (Mendoza & Rogayan Jr., 2024).

Among the available techniques for removing heavy metals from water, adsorption has been widely recognized as one of the most effective and environmentally sustainable methods (Athapaththu, 2013). This process involves the transfer of contaminants from the liquid phase to the solid surface via physical and/or chemical interactions (Akintola & Yahaya, 2025). Achieving optimal adsorption performance depends on factors such as equilibrium between the solid–liquid phases and the rate of mass transfer (Tripathi & Rawat Ranjan, 2015). Activated carbon is frequently used as a conventional adsorbent; however, its application in industrial wastewater treatment is often limited by high production costs, relatively low removal efficiency for certain metals, and substantial energy requirements for activation (Song et al., 2024). Consequently, there has been growing interest in utilizing biomass- and waste-based materials as alternative adsorbents, with performance further enhanced through metal modification (Lim & Aris, 2014).

Previous studies have demonstrated the effectiveness of metal oxide–modified alumina materials for heavy metal remediation. Mahapatra et al. (2013) synthesized iron oxide–alumina mixed nanocomposite fibers via electrospinning and reported removal efficiencies of 21%, 52%, 67%, and 89% for Cu(II), Pb(II), Ni(II), and Hg(II), respectively. Likewise, Shokati Poursani et al. (2015) examined nano- γ - Al_2O_3 for the adsorption of Cr(II) and Pb(II) at an initial concentration of 20 mg L⁻¹, an adsorbent dosage of 0.2 g, and a contact time of 4 hours, achieving removal efficiencies of 99.99% for Cr(II) and 80% for Pb(II).

Research Method

Materials and Chemicals

Sapodilla leaves were collected from the Faculty of Science, Universiti Teknologi Malaysia. Iron nitrate nonahydrate [$\text{Fe}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$], lead nitrate [$\text{Pb}(\text{NO}_3)_2$], and 3 mm aluminium oxide beads (Al_2O_3) were obtained from Sigma Aldrich. A 1000 mg L⁻¹ Pb(II) stock solution was prepared by dissolving 1.598 g $\text{Pb}(\text{NO}_3)_2$ in 1 L deionized water and diluted to the required concentrations for adsorption experiments.

Adsorbents Preparation

Adsorbent was prepared through wetness impregnation method. 3 g of dried sapodilla leaves powder was subjected to boiling in 100 ml distilled water over a period of 3 h. Afterwards, 10 mL of sapodilla leaves extract was mixed with Fe solution which was obtained by dissolving 5 g of $\text{Fe}(\text{NO}_3)_3$ in 10 ml of water (pH 5.8). The solution then was homogenized in sonicator bath for 30 min. Then, Al_2O_3 beads were underwent immersion in the catalyst solution three times for 15 min. Afterwards, it was dried in oven at 80-90 °C for 24h finalized by calcination at 600 °C for 5 h.

a. Characterization

X-ray Diffraction (XRD)

X-ray diffraction was utilized to examine the chemical composition and crystallographic structure of the adsorbents before and after adsorption process. The patterns of 2θ values were recorded between 20° to 80° and the analysis of given data was carried out using a PC interfaced to the diffractometer through software called Diffrac Plus. The peak positions, intensity, and width were determined according to the Powder Diffraction File (PDF) which was given from the software. Moreover, Scherrer's equation as written below (Equation (1)) was applied to determine the particle size (D_p) of adsorbent.

$$D_p = \frac{k\lambda}{\beta \cos\theta} \quad (1)$$

where D_p represents the size of particles in Å, k is a constant associated the Miller index of

crystallographic planes (assigned a value of 0.9), λ denotes the wavelength of Cu-K α radiation ($\lambda = 1.54060 \text{ \AA}$), β is the full width at half maximum (FWHM), and θ is the Bragg diffraction angle in radian.

Nitrogen Adsorption-Desorption Analysis (NA)

Nitrogen Adsorption analysis was used in order to measure the adsorbents surface area, average pore size, pore diameter, pore type, pore shape and total pore volume. Adsorbent samples were crushed manually into powder using pestle and mortar. The specific surface area was subsequently determined from the Brunauer-Emmett-Teller (BET) method. Meanwhile, the pore size distribution was evaluated from the desorption curve by applying on the Barret-Joyner-Hallender (BJH) method.

Field Scanning Electron Microscope-Energy Dispersive X-ray (FESEM-EDX)

Field emission scanning electron microscopy was carried out to study the surface morphology, size and shape of particles on the surface of the adsorbents. The analysis was conducted using scanning electron microscopy Zeiss Supra 35VP FESEM with energy of 5.0 kV equipped with EDX analyzer

Fourier Transform Infrared Spectroscopy (FTIR)

Fourier-transform infrared spectroscopy (FTIR) was operated to clarify the existence of functional group and other chemical elements in prepared adsorbents. The analysis was conducted on Perkin Elmer 1600 spectrometer with spectral range between 4000 cm^{-1} and 400 cm^{-1} using potassium bromide (KBr) pressed pellet technique.

Adsorption Study

The examination of adsorption behaviour of Pb(II) from aqueous solution was examined through batch technique based on several adsorption parameters including the influence of initial metal concentration, dosage of adsorbent, and time of contact. Initial metal concentrations were set at 20, 40, 60, 80, 100, 150 mg L^{-1} with test was performed using 2 g of adsorbent and 1 h of shaking time. Adsorbent dosage was used in various quantities from 0.5–2.5 g while maintaining the other parameters constant at 1 h shaking duration with Pb(II) concentration is 60 mg L^{-1} . The impact of adsorption contact time that was carried out for 4 h investigated every 5 min at the first 20 min, and at 10 min after that, and at interval 15 min for the next until 60 min, at minute 150 and 90 min after that. Meanwhile, concentration of Pb(II) was set at 60 mg L^{-1} and 1.5 g of adsorbent dosage.

The adsorption performance was done on 100 mL Pb(II) solution in 250 mL Erlenmeyer flask which was agitated at 120 rpm using rotational shaker. The solution then filtered using Whatman (No.2) filter paper and analyzed using *Atomic Absorption Spectroscopy* (AAS) in order to determine Pb(II) concentration remaining in the solution. The AAS data was used to determine percent removal of heavy metal ions based on Equation (2):

$$\% \text{ Removal} = \frac{(C_o - C_e)}{C_o} \times 100\% \quad (2)$$

where C_o and C_e represent the concentration of Pb (II) ions at the start and at equilibrium concentrations of Pb(II) ions in mg L^{-1} , respectively (Mom et al., 2011).

Isotherm Study

The adsorption equilibrium was analyzed by fitting obtained data in isotherm model equations.

The metal uptake capacity was calculated using Equation (3):

$$q_e = \frac{V(C_i - C_e)}{1000W} \quad (3)$$

where q_e denote adsorption capacity in mg g^{-1} , V represents volume of solution (mL), W mass of adsorbent in g, C_i is concentration of metal ions (mg L^{-1}) at initial condition, and C_e is metal ions concentration after reaching equilibrium (mg L^{-1}) (Nawaz & Asif, 2011). The Langmuir model Equation (4) in linear form can be represented as:

$$\frac{C_e}{q_e} = \frac{1}{q_{\max}} \cdot K_L + \frac{C_e}{q_{\max}} \quad (4)$$

Where the capacity of adsorption is represented in q_e (mg g^{-1}), while C_e is the concentration of metal ions after reaching equilibrium (mg L^{-1}), $q_{\max}$ is maximum adsorption capacity and K is Langmuir constants. Freundlich model in linear form are given in Equation (5):

$$\log q_e = \log K_f + \frac{1}{n} \log C_e \quad (5)$$

in which q_e is the adsorption capacity (mg g^{-1}), K_f is Freundlich constant for capacity of adsorption as well as, n is adsorption capacity constant (M. qin Jiang et al., 2010).

Kinetic Study

Lagergren's pseudo-first order kinetic model along with Ho's pseudo-second order kinetic model was the principle for investigating the kinetics of Pb adsorption onto the surface of the adsorbents. Kinetic data were plotted followed Equation (6) for pseudo-first order and Equation (7) for pseudo-second order.

$$\ln(q_e - q_t) = \ln q_e - k_1 t \quad (6)$$

$$\frac{t}{q_t} = \frac{1}{k_2 q_e^2} + \frac{t}{q_e} \quad (7)$$

where q_e (mg g^{-1}) is the maximum adsorption equilibrium capacity, q_t (mg g^{-1}) is the amount adsorption at t (min), k_1 (g/mg min) is pseudo first-order rate constant, and k_2 (g/mg min) is pseudo second-order rate constant.

Results and Discussion

Adsorbent Characterization

X-Ray Diffraction (XRD)

XRD pattern of Fe/C/Al₂O₃ prior to as well as at the end of adsorption of Pb(II) ions from aquatic solution are exhibited in Figure 1. The diffractograms revealed the main peaks appeared at $2\theta = 31.54^\circ$ (220), 37.10° (311), 39.28° (202), 45.81° (200), 67.15° (220) which indicate γ -Al₂O₃ of cubic structure. Moreover, a noticeable peak found at 2θ value 33.00° with (222) is corresponded to Fe₂O₃ in cubic structure.

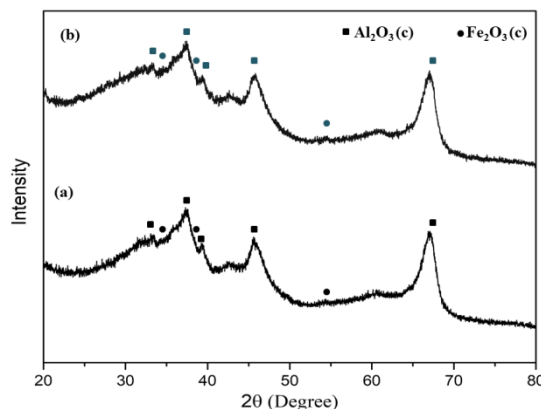


Figure 1. The spectra of XRD adsorbent (a) before and (b) after removal of heavy metal ions from solution

The crystallite size of fresh and used adsorbents was calculated by applying Debye Scherrer equation. Adsorption of Pb(II) ions from system affects the interlaying spacing of adsorbents. The size of Fe/C/Al₂O₃ species is 1.57 nm for Al₂O₃ and 4.71 nm for Fe₂O₃. The crystallite size of all adsorbents species after removal of Pb(II) ions were also determined. Moreover, the size of Al₂O₃ and Fe₂O₃ expanded to 2.97 and 4.95 nm. This suggests that the process adsorption for Pb(II) ions affect the interlayer spacing of the adsorbents (Ibrahim et al., 2022).

Nitrogen Adsorption-Desorption Analysis (NA)

The nitrogen adsorption-desorption isotherms plots of adsorbents before and after removal of Pb(II) ions are displayed in Figure 2. The plot revealed that adsorbent corresponded to typical type IV isotherm plot that represents mesoporous adsorbent. Type IV isotherm describes that the capillary condensation occurs at highest relative pressures (Medeiros-costa et al., 2019). Furthermore, adsorbent can be categorized as H1 type of hysteresis loops that consists of open ended cylindrical pores which have non-uniform size or shape or particles agglomeration (Granados-Pichardo et al., 2020).

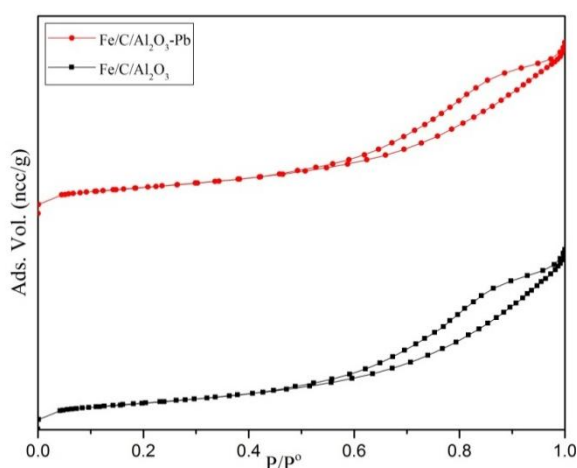


Figure 2. Nitrogen adsorption-desorption isotherms curve for Fe/C/Al₂O₃

In addition, pore diameter of adsorbents was calculated by the Barrett-Joyner-Halenda (BJH) method and the distribution of pore size is plotted in Figure 3. Based on IUPAC standard, classification, pore types can be classified based on the size: (1) micropores which has pore

diameter less than 2 nm; (2) mesopores which lays in the range 2-50 nm; (3) macropores which has size higher than 50 nm (Ngabura, Aslina, et al., 2018).

From the figure, suggesting that pore size distribution of Fe/C/Al₂O₃ for both pre and post of removal process of heavy metal ions has several peaks in range 2-20 nm suggesting that adsorbents consist of mesopores. Additionally, wide pore size distribution (mesopores) plays crucial role as properties of solid adsorbents since it facilitates diffusion of Pb(II) ions containing in the solution to the outer layer of adsorbents as suggested by (Asuquo & Martin, 2016; Ngabura, Hussain, et al., 2018).

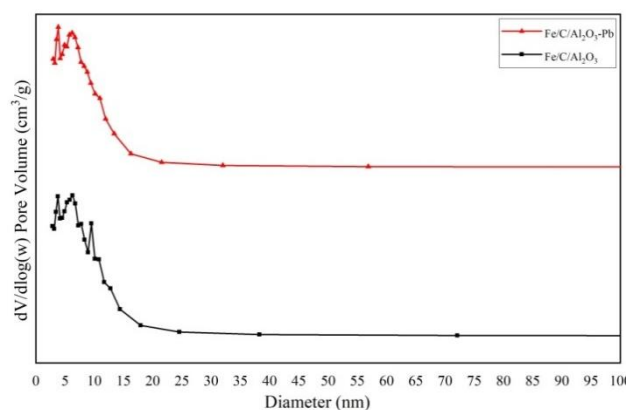


Figure 3. The Size distributions of adsorbent pores over Fe/C/Al₂O₃ adsorbent

The surface area investigated via BET (Brunauer–Emmett–Teller) analysis, exhibited that the adsorbent surface area was about 177 m² g⁻¹, while average pore volume was 0.46 cm³ g⁻¹, and the average pore diameter was 8.14 and increased to 8.32 nm after removal of Pb(II) ions. According to (Chen et al., 2018; Yu et al., 2016), adsorption performance is affected by surface properties in which high surface areas and pores volume as well as wide pores give promising application as adsorbents.

Field Scanning Electron Microscope-Energy Dispersive X-ray (FESEM-EDX)

The morphology of outer layer for fresh and used adsorbents was investigated using Field Scanning Electron Microscope (FESEM). Micrographs of adsorbent pre and post removal of Pb(II) ions are given in the Figure 4. which displayed non-identical structures of aggregation and agglomeration of uneven sphere shape surface with particles with size ranging from 39.70 to 84.70 nm in diameter. The non-uniform and rough surface structure found on Al₂O₃ based adsorbent are expected to facilitate heavy metal removal due to good surface area that increase the number of accessible of active sites (Belhassan et al., 2023). The surface morphology of used adsorbents revealed changes in which more packed surface than fresh adsorbents which was revealed that Pb(II) ions are absorbed onto the surface of adsorbents. The surface with smaller particles size (fresh adsorbent) turned to agglomerated and aggregated on the surface of used adsorbents. Some of cavity disappeared and became collapse to be rough surface morphology.

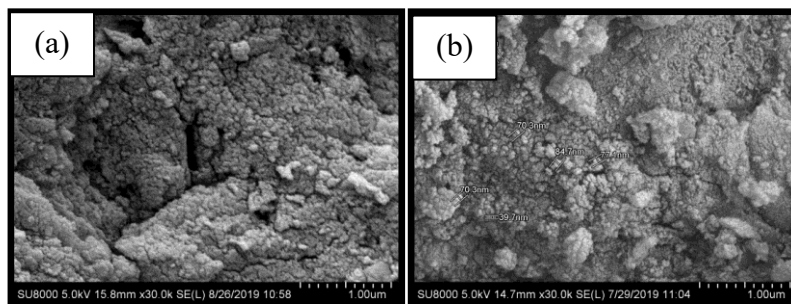


Figure 4. Images for FESEM analysis of (a) fresh and (b) used adsorbent of Fe/C/Al₂O₃

The elemental analysis of fresh and used adsorbents was done using Energy Dispersive X-Ray (EDX) revealed that adsorbent is mainly consisted of Al and O, 44.50% and 42.80%. Meanwhile, small amount of C and Fe was found about 9.60% and 3.10%. The EDX analysis of used adsorbents showed the existence of Pb(II) ions is 0.80% that confirmed the occurrence of Pb(II) adsorption onto the adsorbents.

Fourier Transform Infrared Spectroscopy (FTIR)

Figure 5. showed FTIR spectrum of adsorbent before and after remedial Pb(II) ions from aqueous solution. Overall, some peaks of adsorbents shifted after treating heavy metal solution. The spectra displays a wide peak at 3452.89 cm⁻¹ and shifted to 3469.29 after removal of Pb(II) is believed to be O-H stretching vibration. Meanwhile, strong peak found at 1641.91 which shifted to 1641.97 cm⁻¹ indicate the presence of -OH bending of H₂O adsorbed on the surface of material (K. Wang et al., 2019). The weak peak at 1384.25 cm⁻¹ correspond to C-H stretching vibration (W. Yang et al., 2016). Additionally, some wide peaks also found varying from 1000 to 500 cm⁻¹ which indicate the presence of Al-O stretching vibration in Al₂O₃ (Tabesh et al., 2018).

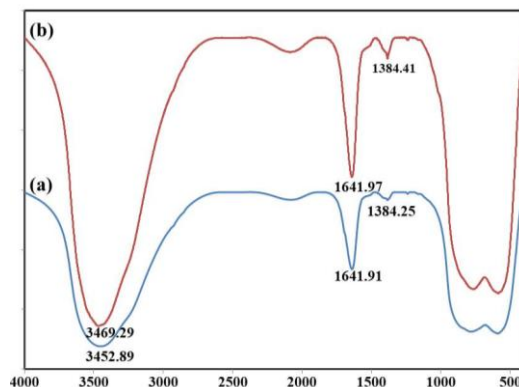


Figure 5. FTIR spectrum for Fe/C/Al₂O₃ adsorbent (a) fresh and (b) used

Adsorption Study

Effect metal concentration

Influence of Pb(II) concentration was investigated to investigate the maximum quantity of Pb(II) that can be removed by prepared adsorbent. Pb(II) concentration used were 20–150 mg L⁻¹ while other parameters were constant at 2 g adsorbent and 1 h of reaction time. The percent efficiency of removal of Pb(II) is displayed in Figure 6. It can be seen that, the removal percentage of Pb(II) using Al₂O₃ based adsorbent decreased slightly from 98.47% at Pb(II) concentration of 20 mg L⁻¹ to 87.16 % at 40 mg L⁻¹, then was constant until 80 mg L⁻¹ and noticeably decline to 54.47% at 150 mg L⁻¹ of Pb(II) concentration. When the concentration of metal ion is low, data showed high

removal of Pb(II) which caused by the wide availability of adsorbent active site as suggested by (Liu et al., 2017). As the concentration increase, there will be more competition between Pb(II) ions to fill active site of adsorbent and lead to saturation of such site when it is fully filled according to (Ahmadi & Izanloo, 2023). Hence, the removal of Pb(II) was low at high concentration of metal.

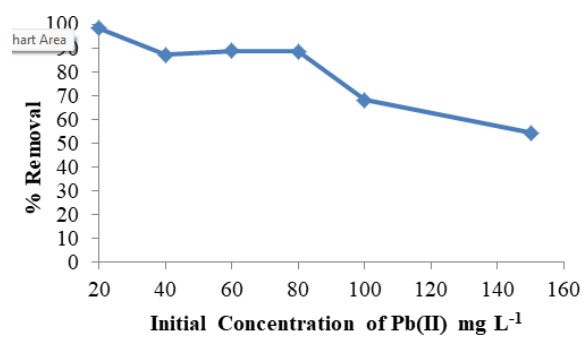


Figure 6. The Pb(II) concentration effect on percent remediation for 1 h of exposure duration with 2 g of adsorbent quantity

Effect of Dosage

The effect of adsorbent dosage was done at 0.5, 1, 1.5, 2, and 2.5 g. Meanwhile, other parameters were kept constant with 60 mg L⁻¹ of Pb(II) concentration and 1 h of adsorption process. The result as in Figure 7 showed that the lowest percentage of Pb(II) removal exhibited at 0.5 g of adsorbent dosage with percent removal 79.75. The percentage then gradually increase to reach the equilibrium at adsorbents dosage of 1.5 g with 89.83%, and it remains plateau as adsorbent dosage increase to 2.5 g. The percent removal of metal rose as the increase of adsorbent dosage. This trend is affected by the wide availability of adsorbent active site at high dosage quantity (Da Silva et al., 2023; Sidiali et al., 2023) (R. Jiang et al., 2015). Hence, the amount of adsorbed Pb(II) will increase as well.

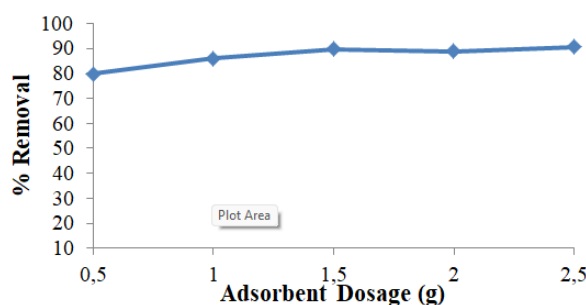


Figure 7. The influence of adsorbent dosage on Pb (II) removal at contact duration of 1 h and 60 mg L⁻¹ of solution concentration

Effect of contact time

Study of contact time is crucial on heavy metal removal as means to investigate the adsorption behaviour. Concentration of metal ion was set at 60 mg L^{-1} with 1.5 g of adsorbent dosage. The contact time was studied up to 4 h at 120 rpm of shaking speed. The plot obtained is displayed in Figure 8. It revealed that the removal percentage of Pb(II) drastically rose up as increase of contact time until reached a point in which the percent removal remain relatively stable. As illustrated by the curve, percent removal of Pb(II) ions showed two different stages. First stage of adsorption showed rapid removal in which the percentage increase from 79.17% at minute 5 to equilibrium point at 97.75% removal in minute 30. Meanwhile, second stage was after 30 minutes of reaction time with efficiency of Pb(II) removal was slowly reduced to 96.08% . The removal of Pb(II) tend to be fast at first of adsorption and relatively unchanged after certain minute. This is caused by the sufficient supply of adsorbents surface area to be occupied by Pb(II) ions at first minutes and become saturated as increase of contact time in which equilibrium point is achieved as suggested by (Mustapha et al., 2023).

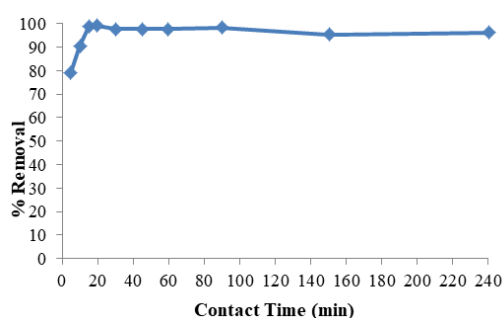


Figure 8. Influence of contact time on Pb(II) removal efficiency under fixed conditions of 1.5 g adsorbent dosage and 60 mg L^{-1} initial concentration

Isotherm Study

Isotherm studies was conducted for the purpose of determining the properties of prepared adsorption process of Pb(II). Isotherm data are given in Table 1. The best fitted isotherm model is determined from the value of the correlation coefficient (R^2) which is the most close to 1. From the plotting of experimental data, revealed that the reducing of Pb(II) from solution is better describing isotherm Langmuir ($R^2 = 0.988$) than Freundlich ($R^2 = 0.875$). Langmuir isotherm model represents to the homogenous surface of adsorbent in identical adsorption surface layer with constant adsorption energy (Xu et al., 2022). Adsorption showed $q_{\max}$ value 4.230 mg g^{-1} .

Table 1. Comparison of Langmuir and Freundlich isotherm parameters for Pb(II) removal

Adsorbent	Langmuir Paramaters			Freundlich Parameters		
	$q_{\max} (\text{mg g}^{-1})$	$K_L (\text{L mg}^{-1})$	R^2	$K_f (\text{mg g}^{-1})$	$1/n$	R^2
Fe/C/Al ₂ O ₃	4.230	4.010	0.988	1.420	0.271	0.875

Kinetic Study

Adsorption efficiency depends on the physical and chemical properties of adsorbents, as well as the transport of solutes from the bulk solution to the adsorbent interface (Asuquo & Martin, 2016).

Thus, kinetic study is investigated to determine mechanism and rate controlling step of adsorption process of Pb(II) from aquatic system to adsorbents. This investigation includes pseudo-first order and pseudo-second order model to understand the type of mechanisms and describe the adsorption process. The kinetic data were then calculated as displayed in Table 3. From the table, correlation coefficient indicates that values (R^2) of pseudo-second order for all adsorbents are higher than R^2 of pseudo-first order. R^2 pseudo-second order is 0.999, while R^2 pseudo-first order is only 0.640. Furthermore, adsorption capacity at equilibrium (q_e) value from pseudo-second order calculation, 3.84 for Al_2O_3 close to q_e value from the experiment which is 3.97 $mg\ g^{-1}$, respectively. Hence, the adsorption of Pb(II) ions to the adsorbents follows pseudo-second order that represent chemisorption process which involves valence force through exchange or sharing of electrons as suggested by (Nezami, 2023).

Table 3. Evaluation of Pseudo-first and Pseudo-second order parameters for the removal of Pb(II)

Adsorbents	Pseudo-first order			Pseudo-second order		
	K_1 (min)	q_e ($mg\ g^{-1}$)	R^2	K_2 (min)	q_e ($mg\ g^{-1}$)	R^2
Fe/C/ Al_2O_3	-0.011	1.227	0.640	-0.790	3.840	0.999

Conclusion

In this study, new adsorbent, Fe/C/ Al_2O_3 was prepared, tested for remediating of Pb(II) from aqueous media, and characterized. The performances of adsorbents are investigated under several conditions such as parameters, reusability and stability, adsorption isotherm, and kinetic. The adsorbents were tested through batch study using 100 mL of Pb(II) metal solution with 120 rpm shaking speed.

In study of effect of metal concentration, increasing the concentration decreased percent removal of Pb(II), while increased adsorption efficiency. Subsequently, adsorbent dosage affects Pb(II) uptake in which percent removal incline as increasing the adsorbents dosage. Also, in contact time study, adsorption efficiency rapidly inclines and remains constant after reaching equilibrium. The percent removal was 97.75% at optimal parameter, 60 $mg\ L^{-1}$ of Pb(II), 1.5 g dosage, and 30 min of contact.

Furthermore, the adsorption isotherm of adsorbents found to be best fit Langmuir for Fe/C/ Al_2O_3 that explain the formation homogenous layer with maximum adsorption capacity was 4.23. Furthermore, the kinetic model results revealed that the adsorption mechanism of adsorbent follows a pseudo second-order model, indicating chemisorption.

In the characterization of prepared adsorbents, XRD analysis showed that Fe/C/ Al_2O_3 adsorbent had polycrystalline structure. Meanwhile NA analysis showed mesopore property of adsorbent as well as good surface area, pore volume, pore diameter. The rough and porous surface morphology of adsorbents were investigated through FESEM. The existence of elements, Al, C, O, Fe, and Pb on the samples was revealed though EDX study. Lastly, FTIR analysis revealed that all adsorbents contain various functional groups. From the result, it can be concluded that Fe/C/ Al_2O_3 can act as potential alternative and inexpensive as adsorbent for treating heavy metal in aqueous medium.

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