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OPTIMIZATIOM OF THE REMOVAL OF DIVALENT LEAD IONS, FROM AQUEOUS SOLUTIONS USING SUGARCANE BAGASSE AS THE ADSORBENT

CHARMANE MAKALANI

B224459B

SUPERVISOR: Mr. G. KATENGEZA

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APPROVAL FORM

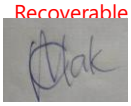
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OPTIMIZATIOM OF THE REMOVAL OF DIVALENT LEAD IONS, FROM AQUEOUS SOLUTIONS USING SUGARCANE BAGASSE AS THE ADSORBENT

Submitted by Charmane Makalani B224459B

In partial fulfilment of the requirements for the Bachelor of Science Honours Degree in Chemical Technology

Recoverable Signature



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student signature

Signed by: trust_50a78e96-a3be-4cb8-b9f9-473e90f3bc1b

X 20/04/2026

supervisor signature

signature of chairperson

ABSTRACT

Divalent lead ions pose a severe environmental and health risks particularly in resource limited regions. This study focused on the optimization of Pb^{2+} ions adsorption using sugarcane bagasse, evaluating the best operational parameters of particle size and contact time. Fourier-Transform Infrared Spectroscopy (FTIR) was utilized to characterize the SCB before the uptake lead to find the functional groups responsible for the uptake of the metal.

The FTIR spectrum of the sugarcane bagasse confirmed a typical lignocellulosic composition, highlighting broad O-H stretching from 3300 to 3500 cm^{-1}, aliphatic C-H stretching from 2920 to 2850 cm^{-1} and lastly the carbonyl C=O stretching from 1700 to 1730 cm^{-1}. Batch experiments were conducted using four particle sizes which were 0.5, 1, 2 and 4mm. To find the best contact time samples were taken across contact time from 30minutes to 360 minutes. Atomic Absorption Spectroscopy (AAS) analysis revealed 68.59%, 78.65%, 66.62% and 65.74% percentage removal of lead by 0.5, 1, 2 and 4 mm respectively. This showed that 1mm particle is the best for the removal of lead between the particle sizes that I used. Kinetic analysis revealed rapid initial uptake within 30 minutes to 60 minutes with equilibrium reached at 120 to 180 minutes for the fine fraction. At 120 minutes contact time was identified as optimal.

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DEDICATION

I dedicate this project to the Muchakachi family. When my world was turned upside down by my parents' divorce, you opened your hearts and home for me. Your unconditional love and support provided the strength I needed to keep moving forward. I would not be standing here completing this degree without your care and belief in me. Thank you for being my anchor during the storm and for showing me what true family means. This achievement belongs to you as much as it does to me.

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CHAPTER 1: INTRODUCTION

The availability of heavy metals in receiving water is a concern because of their bioaccumulation, persistence and toxicity to the aquatic life and the environment (Reda et al., 2025). Lead (Pb) is known as one of the top three most toxic heavy metals followed by mercury (Hg) and cadmium (Cd) and its toxicity creates many human health effects to dysfunction of many human systems such as nerve, blood, tissue, reproductive, digestive, respiratory and many diseases such as anemia, paralysis, barren and cancer (Sharma et al., 2024). The adsorption method is an interesting choice for heavy metal removals because it is an effective and eco-friendly method, easy operation, low operation cost and low amount of sludge is created after treatment (Elias et al., 2022; Genet et al., 2022 and Msimango et al., 2025). In addition, various adsorbents such as activated carbon, chitosan, zeolite, silica, resin, nanocomposite, tomato peels, shrimp shells, coconut shells or husk, oil palm shells, banana peels, corn stalk, rice husk, sawdust, bagasse, bagasse fly ash are available choices for eliminating specific target metal ions in wastewater (Iwuozor et al., 2022; Nata et al., 2024 and Su et al., 2024). However, this study will focus on agricultural wastes because of their benefits as low-cost adsorbents used for improving water quality along with reducing waste volumes in terms of waste management.

1.1 BACKGROUND

Toxic heavy metals are among the most harmful types of contaminations associated with water pollution and at high levels they present a risk to many forms of life including humans (Ajala et al., 2025 and Reda et al., 2025). Industrialization and urbanization have all the limits to sustain a healthy and peaceful life on the earth. Aquatic pollution caused by release of various heavy metals from different anthropogenic activities is one of the major environmental concerns (Genet et al., 2022). The heavy metals have the bioaccumulation tendency, non-biodegradable nature and may contaminate the food chain threatening the existence of living beings (Msimango et al., 2025). The main source of the Pb^{2+} ions pollution are battery manufacturing industries, mines, paint industries, chemical manufactures, surfactants etc. (Elias et al., 2022). Lead is a common heavy metal element and it causes brain damage, kidney disease, liver damage and blood disease (Su et al., 2024). When the contamination of lead in soil reaches a certain degree, it will have a large impact on the growth and quality of plants. High concentrations of lead will inhibit the germination of plant seeds and the growth of seedlings, reduce the content of chlorophyll in plant leaves, resulting in the decline of plant photosynthesis and affect plant growth of seedlings, reduce the content of chlorophyll in plant leaves, resulting in the decline of plant photosynthesis and affect plant growth and fruit yield (Sharma et al., 2024 and Ajala et al., 2025). The recommended concentration level of lead ions, by the Environmental Protection Agency (EPA) is 0.015 and 0.05mg/L in drinking and wastewater, respectively (Elias et al., 2022 and Genet et al., 2022). Adsorption is a surface phenomenon which depends on a number of parameters like pH, contact, adsorbent dose, initial metal concentration, pore size, temperature, surface area. Various researchers have used the by-product of sugarcane,

which is the bagasse adsorption for different pollutants including heavy metals, dyes. It is an easily available waste which can be collected from different sugar mills and juice shops. Pb^{2+} and Cd^{2+} are listed by the World Health Organization (WHO) among the top ten contaminants posing risks to public health (Elias et al., 2022). This caused a higher demand for the development of greener and lower cost techniques for the removal of toxic metals from water and wastewater, highlighting biosorption as a technique that can comply with important aspects of a bio-based economy. Biosorbents obtained from different types of biomasses have been reported to remove a wide variety of pollutants. Raw sugarcane bagasse has been used to remove various types of contamination from water and wastewater, such as dyes. Selection of the appropriate reaction parameters for the production of a suitable biosorbent to remove a specific contaminant requires a detailed investigation. In addition, one of the main problems related to most routine adsorption studies published in the literature is the lack of research aimed at optimizing the reaction conditions for the preparation of a suitable adsorbent, rather than only optimization of the adsorption process itself. A suitable adsorbent must be based on a readily available, mechanically and biologically stable, low-cost material that can be chemically modified to provide fast adsorption kinetics and high adsorption capacity, with capability for reuse in multiple adsorption and desorption cycles (Reda et al., 2025; Msimango et al., 2025 and Sharma et al., 2024)

1.2 PROBLEM STATEMENT

Lead contamination in Zimbabwe's water system poses serious health risks. It originates primarily from mining operations, industrial activities, battery recycling and also vehicles that use leaded petrol, release lead ion particles in the environment. Divalent lead ions enter the human body through multiple routes which includes inhalation, drinking water and food chain bioaccumulation. Contaminated drinking water is the primary route in most communities. Bioaccumulation is another way in which lead is introduced in the food chain. Inhalation, is another way in which lead enters human bodies. Conventional methods of coagulation–flocculation, chemical precipitation, reverse osmosis, membrane filtration, ion exchange, and electrochemical are used for eliminating heavy metals in wastewater; however, these methods have limitations of incomplete heavy metal removals, complicated operations with expensive cost, toxic sludges with requiring disposal (Elias et al., 2022). Sugarcane bagasse is an abundant agricultural residue from Zimbabwe sugar industry, contains functional groups that are capable to adsorb lead ions from water (Nata et al., 2024). It offers a sustainable cheaper method to remove ions from water. The biosorption of sugarcane bagasse remains inadequately optimized. This research investigates optimal operational parameters in which lead ions are absorbed the best, looking at contact time and particle size. By optimizing sugarcane bagasse absorption, this research will provide practical knowledge for accessible water remediation solutions tailored to Zimbabwe's industrial and rural communities, contributing to both environmental protection and circular economy principles through utilization of agricultural waste.

1.3 JUSTIFICATION

Lead metal ions are very toxic both to humans and the environment even at low concentration therefor, removing them is very essential process. Other methods of lead ions removal are either expensive or insufficient and generate secondary waste (Ajala et al.,2025), by using sugarcane bagasse which is cheaper and eco-friendly we will be saving money and our environment. We cannot solve a problem by creating another therefor using sugarcane bagasse is good, since it is eco-friendly.

1.4 AIM OF THE RESEARCH

To optimize the use of sugarcane bagasse as Pb ion absorbent from drinking water and using AAS to measure the amount of lead ions in water before and after using sugarcane bagasse.

1.5 SPECIFIC OBJECTIVES

I. Characterization of the adsorbent, sugarcane bagasse using Fourier Transform Infrared Spectroscopy (FTIR).
II. To determine the optimal adsorption parameters, contact time and particle size, for maximum lead removal.
III. To quantify the amount of Pb^{2+} ions in before and after adsorption by sugarcane bagasse using AAS.

1.6 SCOPE OF STUDY

This research cover from preparation of sugarcane bagasse as a natural Pb^{2+} ion absorber. The research cover pretreatment and characterization of sugarcane bagasse using FTIR spectroscopy to identify functional groups responsible for adsorption. Different conditions were used for absorption to find the most suitable conditions that have the highest lead absorption. Different particle sizes were used to determine the most suitable particle size. Atomic Adsorption Spectrometer was used to measure the amount of Pb^{2+} ions in water before and after using sugarcane bagasse absorbent.

CHAPTER 2: LETIRATURE REVIEW

2.1 INTRODUCTION

Contamination of industrial wastewater by heavy metals remains a challenging matter. Conventional treatment methods such as chemical precipitation, ion exchange etc., are very

expensive and they also generate secondary pollution (Sharma et al., 2024). Removal of heavy metals using agricultural residue has emerged as a sustainable alternative. Among the agricultural residues that are being used there is sugarcane bagasse, which is a lignocellulosic byproduct of the sugar industry, it has attracted attention due to its abundance, low cost and its structural properties (Iwuozor et al., 2022). Sugarcane bagasse is composed of cellulose, hemicellulose and lignin with a porous structure that can be chemically modified to enhance adsorption (Nguyen et al., 2024). While there are more studies that focused on the adsorption capacity, isotherm modeling and chemical modifications, operational parameters such as contact time and particle size have often been treated as secondary variables rather than systematically studied on their own.

2.2 HISTORICAL CONTEXT OF SUGARCANE BAGASSE ADSORPTION

The use of agricultural residues for wastewater treatment is becoming very common, with sugarcane bagasse emerging as one of the most used lignocellulosic materials. Early researchers emphasized its role as a low-cost adsorbent due to its abundance in sugar-producing countries. Over time, studies shifted from simple batch adsorption experiments to more sophisticated approaches that involve chemical modification. Iwuozor et al. (2022) reviewed a comprehensive review of sugarcane bagasse applications in heavy metals mitigation, they also highlighted how the initial studies focused on raw bagasse before moving towards modified forms such as biochar. This progression reflects a broader trend in adsorption research, starting with raw agricultural waste, then enhancing performance through chemical or physical modification. Sharma et al. (2024) traced the advancements in bagasse biochar and noted that the field has evolved from basic adsorption trials to engineered materials with enhanced surface chemistry, including alkali modification and co grafting with functional groups. The history also showed that diversification in target contaminants. While early studies focused on Pb^{2+} and Cd^{2+} later work expanded to Ni^{2+}, Zn^{2+}, Cu^{2+}, Cr^{3+} and even ammonium (Nguyen et al., 2024). These expansions demonstrated the versatility of sugarcane bagasse as a biosorbent. Genet et al. (2022) emphasized on the economical preparation of adsorbents for Zn^{2+} removal reflecting a shift towards cost effective and scalable solutions. Recently, Ajala et al. (2025) explained how bagasse has been integrated into a composite system for industrial wastewater remediation and showed that material has adapted across decades of research. Although there are many researches that were done, operational parameters such as contact time and particle size remains underexplored.

2.3 ENVIRONMENTAL AND INDUSTRIAL RELEVANCE

Sugarcane bagasse is not just a laboratory curiosity; it has direct implications for industrial wastewater treatment and environmental sustainability. Heavy metals such as Pb^{2+}, Cd^{2+}, Ni^{2+} and Zn^{2+} are very common in effluents from mining, battery manufacturing etc. Their persistence and toxicity necessitate effective removal strategies. Ajala et al. (2025) review the remediation of leadacid battery wastewater using bagasse composites and highlighted its relevance to one of the

most hazardous industrial effluents. Reda et al (2025) also showed effective elimination of Pb^{2+} and Cd^{2+} from industrial wastewater using agricultural residues, this reinforced the material's applicability to real life contexts. Msimango et al. (2025) extended this relevance to Ni^{2+} remediation comparing kinetic and isotherm models to evaluate performance in industrial scenarios. Besides heavy metals, sugarcane bagasse adsorbent have been used on diverse contaminants. Nata et al. (2024) explored the simultaneous adsorption of Cr^{3+} and other pollutants using bagasse composites, while Nguyen et al. (2024) reviewed ammonium removal this expanded the scope of bagasse applications beyond metals. Valorizing sugarcane bagasse addresses two challenges simultaneously which are waste management and water pollution. As Sharma et al. (2024) and Gupta et al. (2024) noted, agricultural residue represents a sustainable feedstock for adsorbent production, this reduces the reliance on costly synthetic materials. Furthermore, Singh et al. (2026) emphasized that agricultural waste derived materials contribute to a broader sustainability goal, that aligns with clean water and climate action initiatives. Briao et al. (2025) also highlighted the potential of lignocellulosic biomass hydrogels for toxic metal uptake, situating bagasse within a wider family of sustainability adsorbents.

2.4 LEAD ION (Pb^{2+}) TOXICITY

Lead is one of the most studied heavy metals due to its higher levels of toxicity and widespread occurrence in industrial effluents. Pb^{2+} are not biodegradable and are bioaccumulative, posing risks to ecosystems and human health. Chronic exposure can lead to a neurological damage, kidney dysfunction and developmental disorders in children (Reda et al., 2025). Industrial sources of lead include mines and battery manufacturing. Ajala et al. (2025) addressed lead-acid battery wastewater, which is one of the most concentrated sources of Pb^{2+}. Their study shows the agency of developing effective adsorbents for lead removal. Raimondi et al. (2022) compared sugarcane press mud and bagasse for Pb^{2+} adsorption in mining areas, this highlighted the relevance of bagasse in mitigating contamination from attractive industries. The toxicity of lead explains why many studies prioritize on Pb^{2+} in adsorption experiments. Elias et al. (2022) optimized bagasse biosorbents for Cd^{2+} and Pb^{2+} removal, but Patel et al. (2025) reviewed Pb^{2+} remediation using sugar industrial waste-derived mesoporous silica. All these studies reflect the centrality of lead in adsorption research due to its environmental and health impacts. Despite all these extensive researches, the role of operational parameters such as contact time and particle size Pb^{2+} adsorption remains underexplored

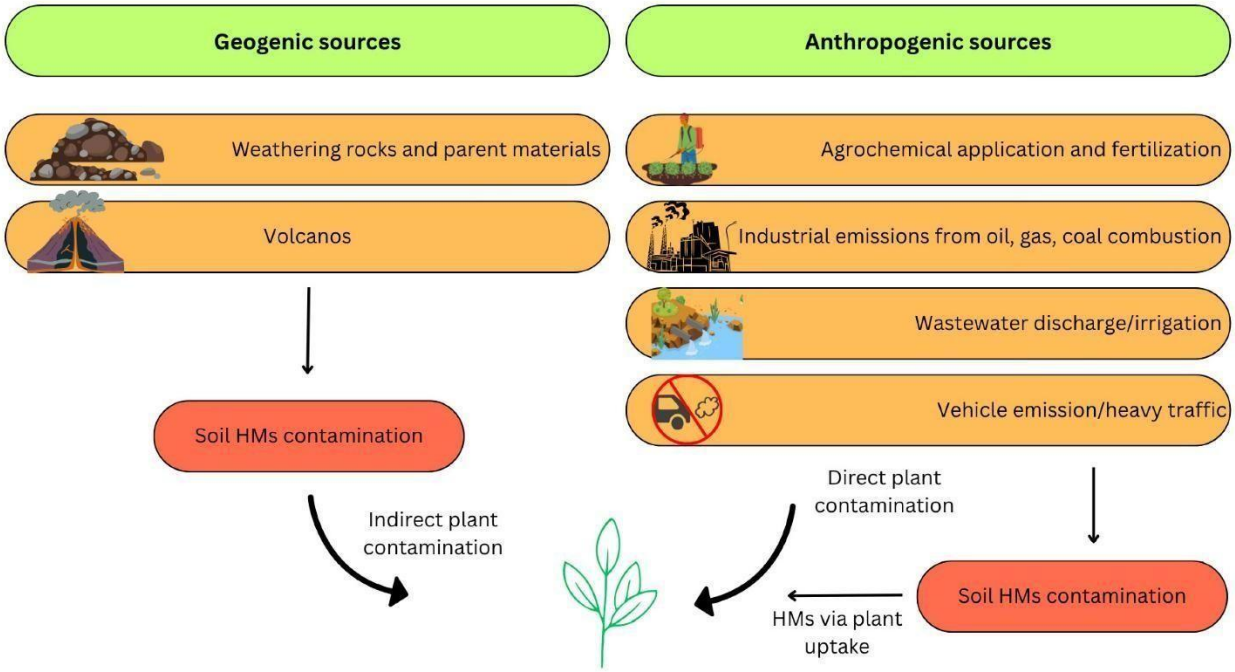


Figure 1 2.4 sources of lead

2.5 CONTACT TIME IN ADSORPTION STUDIES

One of the critical factors in adsorption processes is determining how quickly is equilibrium being reached and the extent of ion uptake. Iwuozor et al (2022), their study provided a broad review that noted that most studies fit pseudo second order kinetics, implying chemisorption. They also observed that contact timed is often reported only as a supporting parameter rather than as a variable of interest. Ajala et al. (2025) studied the removal Pb^{2+} ions using sugarcane bagasse modified with α-alumina derived from aluminum waste cans. They also reported that equilibrium is within 60-90 minutes but their emphasis was on material modification rather than systematically varying contact time. Teodoro et al. (2022) they compared the batch and continuous adsorption of Cu^{2+} and Zn^{2+}. On their study they found out that systems reached equilibrium faster but again contact time was not isolated as the primary factor. Msimango et al. (2025) did a study on Ni^{2+} adsorption with kinetic modeling confirming equilibrium times varied with chemical modification but they did not explore how different contact times independently influenced adsorption. Elias et al. (2022) applied multivariate optimization for Cd^{2+} and Pd^{2+} removal, identifying contact time as statistically significant. Yet, their focus was on optimization rather than mechanistic exploration. Across all these studies, contact time is acknowledged but it was not isolated to be studied. Most researches assume a fixed time to equilibrium and focus on material modification or isotherm fitting. This leaves a gap in understanding how varying contact times influence adsorption kinetics across different divalent ions.

2.6 PARTICLE SIZE IN ADSORPTION STUDIES

Particle size affects the surface area directly and it also affect pore accessibility and diffusion pathways; this makes it a crucial operational parameter. Smaller particles generally increase adsorption efficiency but systematic quantification is limited. Genet et al. (2022) developed an economical adsorbent from bagasse for Zn^{2+} removal. They reported higher efficiency with smaller particle sizes, attributing this to increased surface area. Sharma et al. (2024) studied bagasse biochar applications, noting that fine grinding enhanced adsorption by exposing all the micropores. However, all the conclusions were generalized rather than experimentally quantified. Reda et al. (2025) combined particle size reduction with chemical modification, this achieved a high Pb^{2+} and Cd^{2+} uptake. Yet the dual modification made it difficult to isolate particle size effects. Raimondi et al. (2022) compared press mud and bagasse for Pb^{2+} and Zn^{2+} adsorption. They found out that finer bagasse fractions outperformed larger particles but they did not extent findings to other ions. Nata et al. (2024) showed that composite adsorbents with reduced particle size improved Cr^{3+} uptake, this reinforced the general trend. While smaller particle sizes consistently improve adsorption, few studies quantify the relationship between particle size and adsorption capacity. Most researcher treated particle size reduction as a preparatory step rather than a variable worthy of systematic investigation.

2.7 MECHANISTICAL CONSIDERATION

The influence of contact time and particle size can be further explained mechanistically. Longer contact time allows ions to diffuse into internal pores and form stronger bonds. Rapid equilibrium in modified adsorbents suggests surface functionalization reduces diffusion barriers (Su et al., 2024). Smaller particle sizes increase the surface area to volume ratio; this exposes more active sites. They also reduce diffusion pathways, facilitating faster equilibrium. However, excessive fined particles may cause agglomeration or clogging in continuous systems (Teodoro et al., 2022). These mechanisms highlight why both parameters deserve systematic study, independent of chemical modification.

2.8 RESEARCH GAP

Literature reviewed that contact time and particle size are acknowledged but not rigorously isolated variables in sugarcane bagasse adsorption studies. Moat researches emphasize on chemical modification, isothermal modeling or thermodynamics with operational parameters treated as secondary. This leaves clear gaps which are systematic investigation of contact time on the adsorption of Pb^{2+} ions, quantitative analysis of particle size distribution and its direct impact on adsorption capacity and equilibrium behavior and also integration of both parameters to find out whether optimization of contact time and particle size alone without chemical modification can significantly help enhance adsorption efficiency

CHAPTER 3: METHODOLOGY

3.1 INTRODUCTION

This chapter reviews the experimental procedure of removal of divalent lead ions from aqueous solutions using sugarcane bagasse as the adsorbent focusing on contact time and particle size, to find the best parameters for maximum removal of lead ions.

3.2 EQUIPMENT, INSTRUMENTATION AND CHEMICALS

APPARATUS

- Beakers
- Stop watch
- Volumetric flask
- Graduated cylinder
- Conical flask
- Filter paper
- Spatula
- Dropper

INSTRUMENTS

- FTIR
- AAS
- pH meter
- Mechanical shaker
- Centrifuge
- Balance

CHEMICALS

- lead nitrate

- Nitric acid

3.3 MATERIALS AND ADSORBENT PREPARATION

Sugarcane bagasse was obtained from a local market place, Bindura town. The raw sugarcane bagasse was washed thoroughly with distilled water to remove adhering dirt and water-soluble impurities, then dried at 105°C in an oven until constant weight was achieved, following the procedures similar to Iwuozor et al. (2022) and Sharma et al. (2024). After drying, the material was grounded using a mechanical grinder and sieved to obtain different particle sizes which were 0.5mm, 1mm, 2mm and lastly 4mm. Each size fraction was stored in sealed containers at room temperature to prevent moisture absorption from the atmosphere (Ajala et al. 2025).

3.4 CHARACTERIZATION OF ADSORBENT

The prepared bagasse was characterized using Fourier Transform Infrared Spectroscopy (FTIR). A spirit Qatr-s FTIR spectroscopy was used. FTIR was performed to identify functional groups capable of forming chemical bonds with lead ions, using a spectrophotometer in the wavenumber range 400-4000 cm^{-1} following the approach of Elias et al. (2022) and Su et al. (2024).

3.5 PREPARATION OF LEAD STOCK SOLUTION

A lead standard solution was prepared by dissolving 0.598g lead nitrate ($Pb(NO_3)_2$) in distilled water to obtain an initial concentration of 1000 mg/L. Working solutions at various initial lead concentrations (50, 100, 250, and 500 mg/L) which were prepared by serial dilution. All solutions used, were prepared using analytical-grade chemicals and ultrapure distilled water (Ajala et al. 2025 and Reda et al. 2025). The pH of all solutions was adjusted to 5.0 ± 0.1 using nitric acid, as this pH range is essential for preventing lead hydroxide precipitation while ensuring effective biosorption (Patel et al. 2025).

3.6 EFFECT OF CONTACT TIME

Batch adsorption experiments were to determine the optimal contact time for lead removal using sugarcane bagasse. In these experiments, 0.5 g of bagasse particle size 0.5mm, were added to 50 mL of lead solution with initial concentration 250 mg/L, pH 5.0 in 100 mL conical flasks. The flasks were agitated at 200 rpm using a mechanical shaker at room temperature (Ajala et al., 2025). Samples were withdrawn at predetermined time intervals: 30, 60, 120, 180, 240, and 360 minutes. At each interval, samples were centrifuged at 3000 rpm for 10 minutes to separate the solid adsorbent from the liquid phase (Msimango et al., 2025).

The supernatant was filtered using filters paper and analyzed for residual lead concentration using Thermo Scientific iCE 3000 series Atomic Absorption Spectrometer (AAS) following the EPA Method 7000B standards. All measurements were performed in triplicate to ensure reproducibility, accuracy and minimize errors (Sharma et al., 2024). The amount of lead adsorbed at time, t was calculated using the following mass balance equation:

$q_t = \left(\frac{co-ct}{m}\right) v$

C_0 is the initial lead concentration (mg/L), C_t is the lead concentration at time t (mg/L), V is the volume of solution in liters and m is the mass of the adsorbent in grams.

The removal percentage will be calculated as

Removal% = $(\frac{c0-ct}{c0})100$

Adsorption kinetic data was analyzed using pseudo-first-order and pseudo-second-order kinetic models to determine the rate-controlling mechanism as applied by Genet et al. (2022) and Su et al. (2024)

Pseudo-first-order model: $\log (q_e - q_t) = \log q_e - \frac{k1}{2.303} t$

Pseudo-second-order model: $\frac{t}{qt} = \frac{1}{k2qe^2} = \frac{t}{qe}$

where q_e is the amount of lead adsorbed at equilibrium (mg/g), k_1 is the pseudo-first-order rate constant (min^{-1}) and k_2 is the pseudo-second-order rate constant (g/mg·min)

3.7 EFFECT OF PARTICLE SIZE

A series of experiments was conducted using different particle sizes which were 0.5 mm, 1.0 mm, 2.0 mm and 4.0 mm to determine the optimal particle size for lead adsorption. For each particle size, 0.5 g of adsorbent was mixed with 50 mL of lead solution (250 mg/L, pH 5.0) and agitated at 200 at room temperature and pressure. Samples were withdrawn after 2 hours. After centrifugation and filtration, residual lead concentrations were determined by Thermo Scientific iCE 3000 series AAS (Reda et al., 2025). The amount of lead adsorbed at time, t was calculated using the following mass balance equation: $qt = (\frac{c0-ct}{m})v$

C_0 is the initial lead concentration (mg/L), C_t is the lead concentration at time t (mg/L), V is the volume of solution in liters and m is the mass of the adsorbent in grams.

The removal percentage will be calculated as

Removal% = $(\frac{c0-ct}{c0})100$

The effect of particle size was evaluated by comparing adsorption capacities and kinetic parameters across all sizes being used. A linear relationship between particle size and adsorption capacity were determined using regression analysis (Genet et al., 2022).

CHAPTER 4 RESULTS AND DISCUSSION

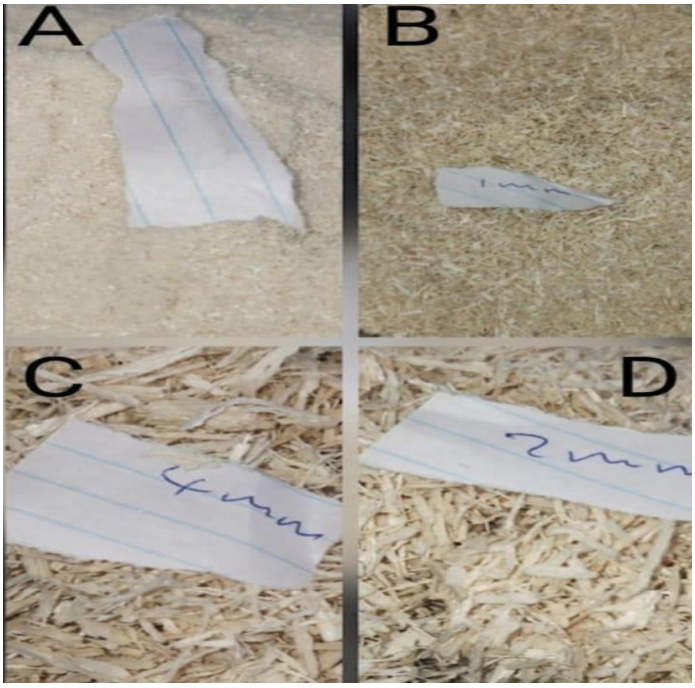


Figure 2 4.0 particle size A= 0.5mm, B=1mm, C= 4mm and D= 2mm

4.1 CHARACTERIZATION RESULTS

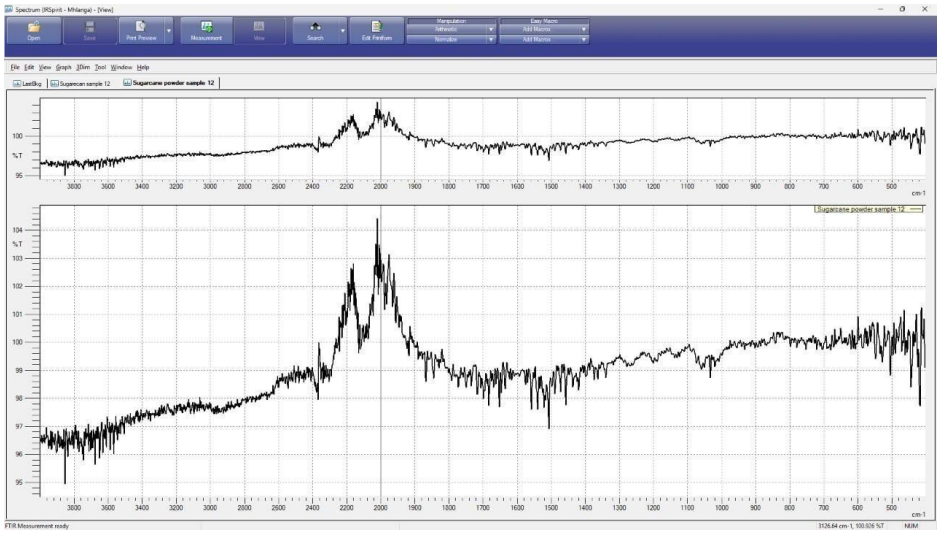


Figure 3 4.1 spectrum of sugarcane bagasse

Lignocellulosic material like sugarcane bagasse is rich in biopolymers like cellulose, lignin and hemicellulose these polymers are the one responsible for the provision of functional groups that can absorb lead from water by forming chemical bonds with it (Iwuozor et al., 2022). There was a region that was stretching from 3300 to 3500 cm^{-1}, a highly intense band was observed around 3339cm^{-1}. This band caused by the presence of the O-H functional group, which is involved in the internal and external hydrogen bonding in the cellulose and lignin backbones (Elias et al., 2022). There was also a minor sharp peak around 2918 cm^{-1} which represented the presence of the C-H stretching vibrations which belongs to the CH_2 and CH_3 functional units of the carbohydrates on the structure. There was a 1700 to 1730 cm^{-1} region, a sharp well-defined peak at 1732cm^{-1} was caused by the C=O from the ester groups or acetyl which are in hemicellulose as well as carboxylate groups in carboxylic acids (Genet et al., 2022). There was a secondary sharp band around 1604 cm^{-1} which corresponds to the availability of the C=C vibrations, this confirms the rigid structure which is contributed by the aromatic rings of the lignin component (Msimango et al., 2025). The region which was stretching from 1200 to 1000 cm^{-1} has highly dense and intense fingerprint peaks centered near 1035 cm^{-1} indicates the availability of the C-O-C or the C-O stretching vibrations, this shows the ether linkages and the alcohol structure within the cellulose. This spectrum showed that sugarcane bagasse has more oxygen containing functional groups which are -OH and -COOH that are highly localized negative charge centers making sugarcane bagasse an excellent substrate ready for cation binding (Sharma et al., 2024)

4.2 CONTACT TIME AAS RESULTS

Table 1 4.2 CONTACT TIME AAS RESULTS

Time (mins)	30		60	120	180	240	360

Sample 1 concentration (mg/L)	78.2337		62.4231	53.2992	51.7978	49.4110	47.8833
Sample 2 concentration (mg/L)	78.1243		62.3212	53.3001	51.8013	49.4321	47.9000
Sample 3 concentration (mg/L)	77.9871		62.2340	53.3121	51.7871	49.4221	47.8601
Average concentration (mg/L)	78.12 ± 0.12		62.32 ± 0.10	53.304 ± 0.007	51.795 ± 0.007	49.404 ± 0.008	47.88 ± 0.02

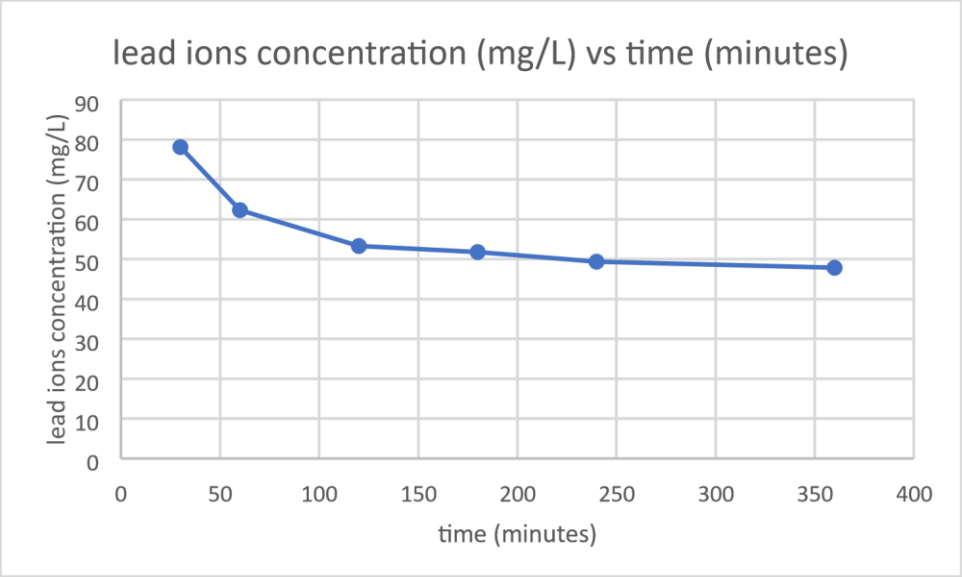


Figure 4 4.2 graph of concentration of lead against time

The effect of contact time revealed a classic biphasic kinetic curve, which is typical for plant-based biosorbents (Sharma et al., 2024; Ajala et al., 2025 and Msimango et al., 2025). During the initial time of the experiment, 30 to 60 minutes there was a rapid adsorption of the metal. This was due

to the higher availability of the metal to adsorb onto the sugarcane bagasse and also the availability of vacant functional groups that are responsible for the adsorption of the metal on the sugarcane bagasse. (Elias et al., 2022 and Reda et al., 2025). As the contact time progress towards 120 minutes and above the rates of the reaction decreased due to the scarce of the vacant active spots and also repulsive electrostatic barrier that develops between heavy metals that have already bound to the matrix and those remaining in the solution (Genet et al., 2022 and Nata et al., 2024). This causes the reaction to flatten out into an equilibrium plateau. This fixes the optimal contact time on the 120 minutes, which provides an excellent compromise for scaledup operations, maximizing lead recovery without wasting energy on extended agitation cycles.

The amount of lead adsorbed at time, t

$$qt = (\frac{c0-ct}{m})v$$

Mass of adsorbent was 0.5g

Initial lead concentration was 20mg/L

Volume of solution was 0.005 liters

Concentration at time, t

The removal percentage will be calculated as

$$\text{Removal\%} = (\frac{c0-ct}{c0})100$$

AT 30 MINUTES

$$q_t = (\frac{250-78.12}{0.5})0.05$$

= **<u>17.18mg/g</u>**

$$\text{The percentage removal} = (\frac{250-78.12}{250})100$$

= **<u>68.71%</u>**

AT 60 MINUTES

$q_t = (\frac{250-62.32}{0.5})0.05$

= <u>18.76mg/g</u>

The percentage removal = $(\frac{250-62.32}{250})100$

= **<u>75.03%</u>**

AT 120 MINUTES

$q_t = (\frac{250-53.30}{0.5})0.05$

= **<u>19.67mg/g</u>**

The percentage removal = $(\frac{250-53.30}{250})100$

= **<u>78.68%</u>**

AT 180 MINUTES

$q_t = (\frac{250-51.80}{0.5})0.05$

= **<u>19.82mg/g</u>**

The percentage removal = $(\frac{250-51.80}{250})100$

= **<u>79.28%</u>**

AT 240 MINUTES

$q_t = (\frac{250-49.40}{0.5})0.05$

= **<u>20.06mg/g</u>**

The percentage removal = $(\frac{250-49.40}{250})100$

= **<u>80.24%</u>**

AT 360 MINUTES

$q_t = (\frac{250-47.88}{0.5})0.05$

= **<u>20.21mg/g</u>**

The percentage removal = $(\frac{250-47.88}{250})100$

= **<u>80.85%</u>**

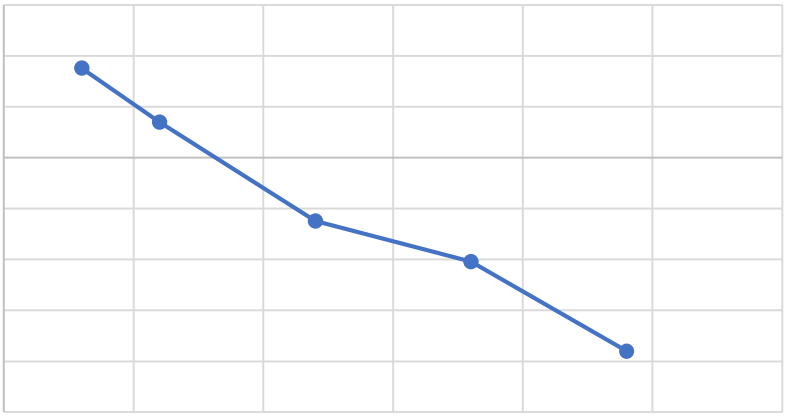
Pseudo-first-order model: $\log (q_e - q_t) = \log q_e - \frac{k1}{2.303} t$

The q_e value is the q_t at 360 minutes which is 20.21mg/g

PSEUDO FIRST ORDER TABLE

Table 2 4.2 PSEUDO FIRST ORDER

Time (minutes)	Q_t(mg/g)	In(q_e-q_t)
30	17.8	0.88
60	18.76	0.35
120	19.67	-0.62
180	19.82	-1.02
240	20.06	-1.90
360	20.21	0



Y= -0.0127x + 1.1409

R^2 = 0.9821

Slope = -K_1 Slope

= -0.0127 K_1

=0.0127 min^{-1}

In (q_e) = intercept

Q_e= 4.09mg/g

Figure 5 4.2 pseudo first order graph

PSEUDO FIRST ORDER RESULTS TABLE

Table 4 4.2 PSEUDO FIRST ORDER RESULTS

Adsorbent size (mm)	Experimental q_e (mg/g)	PFO K_1 (min^{-1})	PFO calculated q_e (mg/g)	PFO R^2
0.5	20.21	0.0127	4.09	0.9821

The pseudo first order model assumes that adsorption is controlled by the physisorption, where the rate depends on the number of unoccupied sites and weak van der Waals forces dominate. This model failed to predict actual equilibrium capacity for biosorbents like sugarcane bagasse. The pseudo first order model underestimates the adsorption capacity and yields lower R^2 values, indicating poor correlation with experimental data (Genet et al., 2022; Elias et al., 2022 and Sharma et al., 2024). Physisorption does not adequately describe the complex interactions between Pb^{2+} ions and lignocellulosic functional groups, which involve stronger chemical bonding.

Pseudo-second-order model: $\frac{t}{qt} = \frac{1}{k2qe^2} + \frac{t}{qe}$

where q_e is the amount of lead adsorbed at equilibrium (mg/g), k_1 is the pseudo-first-order rate constant (min^{-1}) and k_2 is the pseudo-second-order rate constant (g/mg·min) PSEUDO-SECOND-ORDER MODEL TABLE

Table 5 4.2 PSEUDO SECOND ORDER

Time (minutes)	Q_t (mg/g)	t/q_t (g/mg·min)
30	17.8	1.69
60	18.76	3.37
120	19.67	6.74
180	19.82	10.11
240	20.06	13.48
360	20.21	20.22

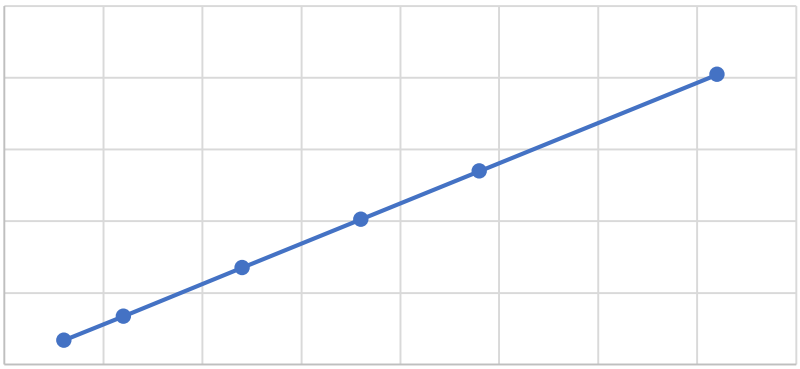


Figure 6 4.2 pseudo second order graph

Y = 0.0562x + 0.0023

$R^2 = 1$

Slope = 0.0562

$Q_e = \frac{1}{slope}$

$Q_e = \frac{1}{0.0562}$

Q_e = 17.80 mg/g

Pseudo rate constant $k_2 = \frac{1}{intercept \times qe^2}$

$k_2 = \frac{1}{0.0023 \times 17.80^2}$

k_2 = 1.37 (mg/g·min)

The R^2 value on the graph is 1 and the one that I had calculated is 1.37. The pseudo second order model R value is 1 this proves that my system follows the chemisorption mechanism. The pseudo second order kinetic model is considered as the best fit for describing adsorption of Pb^{2+} ions onto the sugarcane bagasse adsorbent due to its ability to accurately represents chemisorption, where adsorption occurs through valence forces involving electron sharing or exchange between the adsorbent and adsorbate (Ajala et al., 2025)

4.3 PARTICLE SIZE AAS RESULTS

Table 6 4.3 PARTICLE SIZE AAS RESULTS

Particle size (mm)	0.5	1.0	2.0	4.0
Sample1 conc (mg/L)	78.5778	68.4885	83.4491	85.6273
Sample 2 conc (mg/L)	78.4876	68.2131	83.4312	85.6321
Sample 3 conc (mg/L)	78.5312	68.4321	83.5113	85.6721
Average conc (mg/L)	78.53 ± 0.05	68.38 ± 0.15	83.46 ± 0.04	85.64 ± 0.02

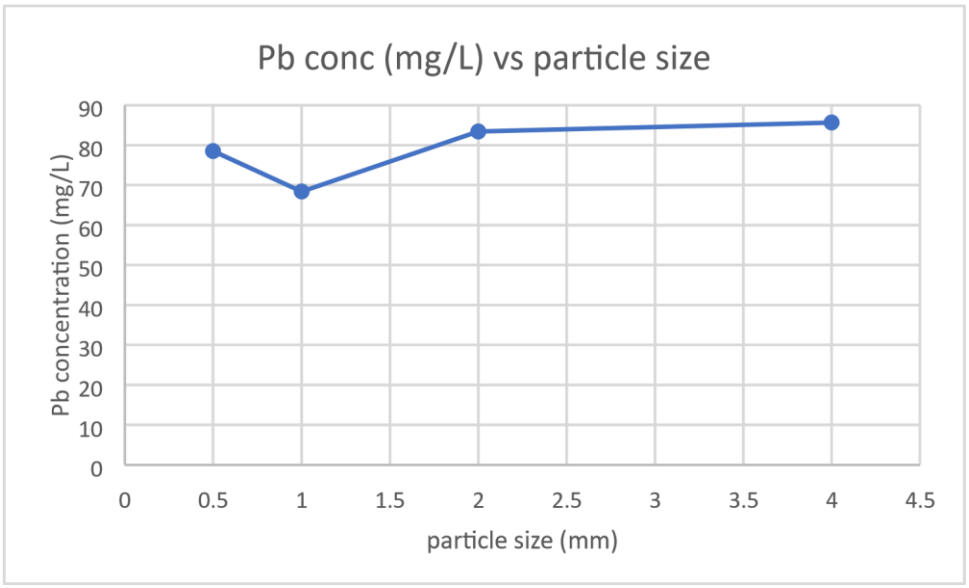


Figure 7 4.3 particle size against lead concentration

The graph of the particle size in mm against the lead concentration in mg/L

The amount of lead adsorbed at time, t

$$\text{qt} = \left(\frac{c0-ct}{m}\right) v$$

Mass of adsorbent was 0.5g

Initial lead concentration was 250mg/L

Volume of solution was 0.05 liters

Concentration at time, t

The removal percentage will be calculated as

$$\text{Removal\%} = \left(\frac{c0-ct}{c0}\right) 100$$

PARTICLE SIZE 0.5mm

$$q_t = \left(\frac{250-78.53}{0.5}\right) 0.05$$

$$= \mathbf{17.15}$$

$$\text{Removal\%} = \left(\frac{250-78.53}{250}\right) 100$$

$$= \mathbf{68.59\%}$$

PARTICLE SIZE 1.0mm

$q_t = \left(\frac{250-68.38}{0.5}\right) 0.05$

=**18.16**

Removal% = $(\frac{250-68.38}{250})100$

= **78.65%**

PARTICLE SIZE 2.0mm

$q_t = \left(\frac{250-83.46}{0.5}\right) 0.05$

= **16.65**

Removal% = $(\frac{250-83.46}{250})100$

= **66.62%**

PARTICLE SIZE 4.0mm

$q_t = \left(\frac{250-85.64}{0.5}\right) 0.05$

=**16.45**

Removal% = $(\frac{250-85.64}{250})100$

= **65.74%**

In the liquid to solid adsorption process, classical mass transfer models assumes that by reducing the particle size you will be increasing surface area therefor a linear increase in heavy metal uptake must be observed. However, in this study there was a non-linear trend on the recovery percentage.

1.0 mm (78.65%) > 0.5 mm (68.59%) > 2.0 mm (66.62%) > 4.0 mm (65.74%)

There was a reduced recovery percentage on the larger particle size, 2.0mm and 4.0mm which had 66.62% and 65.74% recovery percentages respectively was due to the suppressed surface area. Large particle sizes restrict diffusion of Pb^{2+} ions into the lignocellulosic matrix, this resulted into a higher internal pore diffusion resistance and slower transfer (Ajala et al., 2025 and Reda et al., 2025). Therefor the active functional groups that are not exposed will the unutilized. The performance dropped when reducing the particle mesh from 1.0 mm to 0.5mm, they had recovery percentages of 78.65% and 68.59% respectively this demonstrated a well-known physical phenomenon called particle agglomeration. When raw lignocellulosic agriculture residue is over pulverized into fine particles which are less than or equal to 0.5 mm there will be particle agglomeration. When the particles that have an elevated surface energy are in contact with water, they will be forced to clump together (Nata et al., 2024). This clumping causes a mud like

boundary layer that locks away the functional groups that are responsible for the uptake of the heavy metal from water. Additionally fine particle sizes often cause fluid channeling during agitation; this will prevent uniform physical contact across the aqueous solution profiles. This makes the 1.0 mm particle size the best size to use because it provides a higher surface area for adsorption while avoiding aggregation and fluid channeling boundaries (Sharma et al., 2024).

CHAPTER 5

5.1 RECOMMENDATION

Industrial wastewater processing is a large-scale process it requires continuous flow fixed bed column; this will increase the rate of removal of lead from wastewater. The column of the fixed bed has to be packed with 1mm sugarcane bagasse which I had found most effective during my research. This will determine essential large-scale engineering parameters, such as breakthrough curves, exhaustion time and optimal volumetric flow rates under realistic hydrodynamic conditions (Ajala et al., 2025 and Reda et al., 2025). Although smaller particle size theoretically has higher surface area, this study proved that the 0.5 mm particle size have a low percentage recovery than 1mm due to agglomeration. They have to be an investigation of the deployment of mild, eco-friendly surfactants during the aqueous pre-treatment of ultra-fine biomass. This will help in preventing particle agglomeration in water, which could help unlock the hidden, dense surface are of the 0.5 mm and potentially push recovery rates past the 1.0mm benchmark (Nata et al., 2024). The FTIR data confirmed that carboxyl and hydroxyl functional groups that are essential in the removal of Pb^{2+} ions from water. Chemical modifications specifically on the optimal 1.0mm particle size using citric acid esterification or alkaline saponification which is sodium hydroxide washing. This will increase the density of oxygen-bearing functional groups onto the SCB matrix increasing the binding sites and push the recovery efficiency from 78.65% closer to 95 to 100% (Elias et al., 2022 and Msimango et al., 2025). For the adsorbent to be commercially viable, it must be able to have a long lifecycle to minimize operating and waste disposal costs. There must be conducted systematic stripping and elution tests using mild acidic eluents, such as dilute nitric acid, hydrochloric acid or ethylenediaminetetraacetic acid. This will help evaluate desorption kinetics and to determine exactly how many adsorption-desorption cycles the 1.0mm sugarcane bagasse can undergo before experiencing severe degradation of the functional groups (Genet et al., 2022). Industrial waste water in most times it contains many ionic species and this will cause adsorption competition, therefor a selective binding affinity of sugarcane bagasse must be established and also document how competing ions affect its lead removal efficiency in complex chemical environments (Sharma et al., 2024).

5.2 CONCLUSION

Inconclusion this project successfully optimized the adsorption of divalent lead ion from aqueous solutions using sugarcane bagasse, proving that sugarcane bagasse can be used in removal of lead from drinking and waste water. For optimal removal of lead metal 1mm particle size and contact time of 120 minutes is the best with removal percentage of 78.65%. Over-pulverization to a 0.5 mm particle size limits performance, 68.59% recovery due to particle agglomeration and active site blocking. Large particle size like 2.0 mm and 4.0 mm underperforms due to severe internal pore diffusion resistance. FTIR evaluations proved that lead uptake is a chemisorption process. It is driven by covalent surface complexation and inner-sphere coordination bonding involving the hydroxyl and carbonyl functional domains intrinsic to the lignocellulosic matrix of sugarcane bagasse.

APPENDIX

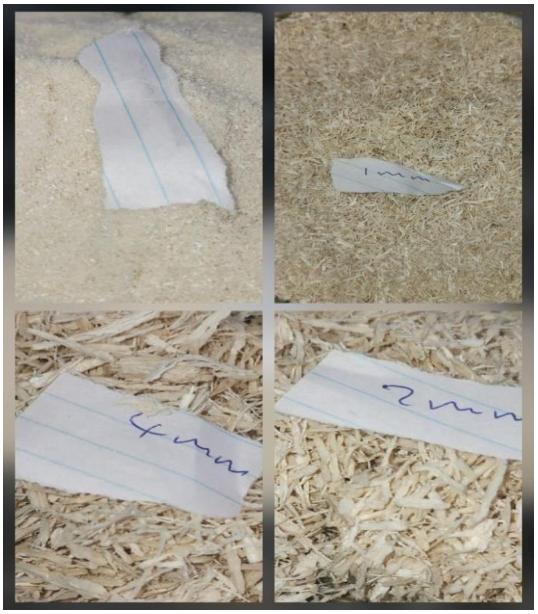


Figure 8 PARTICLE SIZES USED



Figure 9 IMAGE OF FILTRATION AND CONICAL FLASKS ON THE MECHANICAL SHAKER



Figure 10 PREPARATION OF REQUIRED LEAD CONCENTRATION AND LEAD STANDARD USED DURING MEASURING OF LEAD IONS USING AAS

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