

# Preparation of Cement Waste–Derived Biochar for Efficient Pb (II) Removal from Aqueous Solutions

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**Abstract** — *The contamination of water bodies with lead (Pb<sup>2+</sup>) poses serious environmental and health risks, requiring efficient and low-cost remediation strategies. In this study, cement waste was converted into a functional biochar through controlled thermal treatment and evaluated as an adsorbent for Pb(II) removal from aqueous solutions. The prepared cement waste–derived biochar (CWDB) was characterized using basic physicochemical analyses including pH measurement, moisture and ash content determination, Fourier Transform Infrared (FTIR) spectroscopy, and Scanning Electron Microscopy (SEM) to examine surface morphology and functional groups. Batch adsorption experiments were performed to study the effects of pH, contact time, initial metal concentration, and adsorbent dosage on Pb(II) removal efficiency. The results showed that CWDB exhibited significant adsorption capacity, particularly under slightly alkaline conditions. The removal mechanism was primarily attributed to surface adsorption and precipitation facilitated by the alkaline nature of cement waste. Adsorption data followed the Langmuir isotherm model and pseudo-second-order kinetics, indicating favorable monolayer adsorption behavior. The findings demonstrate that cement waste–derived biochar can serve as a simple, cost-effective, and sustainable material for lead-contaminated wastewater treatment.*

**Index Terms** — Cement waste Biochar; Lead (Pb<sup>2+</sup>) removal; Heavy metal adsorption; Wastewater treatment; Waste valorization.

## I. INTRODUCTION

Heavy metal contamination in water bodies has become a critical environmental concern due to rapid industrialization and urban development. Among various toxic metals, lead (Pb<sup>2+</sup>) is particularly hazardous because of its persistence, non-biodegradability, and bioaccumulative nature. Exposure to lead-contaminated water can cause severe health problems, including neurological disorders, kidney damage, and developmental impairments. Major sources of lead pollution include battery manufacturing, metal plating,

mining activities, pigments, and industrial effluents. Therefore, the development of efficient, economical, and sustainable methods for Pb(II) removal from aqueous systems is of significant importance.

Conventional treatment methods such as chemical precipitation, ion exchange, membrane filtration, and electrochemical processes have been widely employed for heavy metal removal. However, these techniques often involve high operational costs, complex procedures, and secondary sludge generation. In recent years, adsorption has emerged as a promising alternative due to its simplicity, cost-effectiveness, and high removal efficiency. Biochar, a carbon-rich material obtained from the thermal conversion of biomass or waste materials under limited oxygen conditions, has attracted considerable attention as an eco-friendly adsorbent owing to its porous structure, surface functional groups, and tunable physicochemical properties.

Simultaneously, the cement industry generates large quantities of solid waste, including kiln dust and construction debris, which pose disposal and environmental challenges. Cement waste is typically alkaline and rich in calcium, silica, and alumina phases, making it a potential precursor or composite material for adsorbent development. Converting cement waste into biochar-based materials not only addresses waste management issues but also enhances the adsorption performance through synergistic mechanisms such as surface complexation and precipitation.

In this study, cement waste was valorized into a functional biochar through controlled thermal treatment and evaluated for the removal of Pb(II) from aqueous solutions. The physicochemical properties of the prepared material were examined using basic characterization techniques, and batch adsorption experiments were conducted to assess the effects of operational parameters. The study aims to provide a simple and sustainable approach for transforming industrial waste into an effective adsorbent for lead-contaminated wastewater treatment.

## II. MATERIALS AND METHODS

### 2.1 Materials

Cement waste was collected from local construction debris and cement handling residues. The collected material was air-dried, manually cleaned to remove impurities such as stones and plastics, and sieved to obtain a uniform particle size. Lead nitrate [Pb(NO<sub>3</sub>)<sub>2</sub>] of analytical grade was used to prepare the Pb(II) stock solution. All solutions were prepared using distilled water. Hydrochloric acid (HCl) and sodium hydroxide (NaOH) solutions (0.1 M) were used for pH adjustment.

### 2.2 Preparation of Biochar

The dried cement waste was ground into fine powder and placed in a ceramic crucible. Thermal treatment was carried out in a muffle furnace under limited oxygen conditions at 500–600 °C for 2 hours. After cooling to room temperature, the obtained material was washed with distilled water to remove soluble impurities and dried at 105 °C. The final product was ground and stored in airtight containers for further use.

### 2.3 Characterization of Biochar

Basic physicochemical properties of the prepared biochar were analyzed as follows:

- **pH Measurement:** A suspension of biochar in distilled water (1:10 w/v) was stirred for 24 hours, and pH was measured using a digital pH meter.
- **Moisture and Ash Content:** Determined by standard gravimetric methods.
- **Fourier Transform Infrared Spectroscopy (FTIR):** Used to identify surface functional groups before and after Pb(II) adsorption.
- **Scanning Electron Microscopy (SEM):** Used to observe surface morphology and porosity changes after adsorption.

### 2.4 Preparation of Pb(II) Solution

A stock solution of 1000 mg/L Pb(II) was prepared by dissolving an appropriate amount of lead nitrate in distilled water. Working solutions of desired concentrations (e.g., 25–200 mg/L) were obtained by dilution.

### 2.5 Batch Adsorption Experiments

Batch adsorption studies were conducted in 250 mL conical flasks containing 100 mL of Pb(II) solution and a known amount of biochar. The flasks were agitated using a mechanical shaker at room temperature (≈25 °C).

The influence of the following parameters was investigated:

- **Effect of pH:** Adjusted between 2 and 7
- **Contact Time:** 10–180 minutes
- **Initial Pb(II) Concentration:** 25–200 mg/L
- **Adsorbent Dosage:** 0.1–1.0 g

After equilibrium, the mixtures were filtered, and the residual Pb(II) concentration was determined using Atomic Absorption Spectroscopy (AAS) (or ICP-OES, if available).

The removal efficiency (%) and adsorption capacity (q<sub>e</sub>) were calculated using standard equations:

$$\text{Removal Efficiency (\%)} = (C_0 - C_e / C_0) \times 100$$

## III. RESULTS AND DISCUSSION

### 3.1 Physicochemical Characteristics of Cement Waste-Derived Biochar

The cement waste-derived biochar (CWDB) exhibited alkaline characteristics, with a pH typically above 9, which is favorable for Pb(II) removal due to enhanced metal precipitation and surface interaction. The ash content was relatively high, attributed to the mineral-rich composition of cement waste, particularly calcium and silica phases.

FTIR analysis revealed the presence of functional groups such as –OH, Si–O–Si, and carbonate groups, which play an important role in metal binding. After Pb(II) adsorption, noticeable shifts in peak positions and intensity reductions were observed, indicating interaction between Pb(II) ions and surface functional groups.

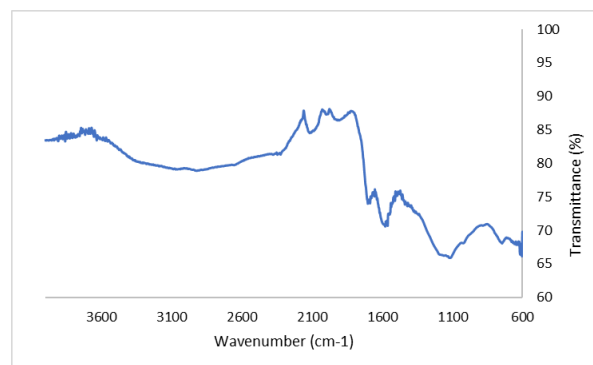


Fig. 1 FTIR of Biochar

SEM images showed a heterogeneous and irregular surface morphology with visible pores and cracks. After adsorption, the surface appeared relatively smoother and partially covered, suggesting deposition or attachment of Pb(II) onto the biochar surface. These results confirm that the prepared

material possesses suitable surface characteristics for adsorption applications.

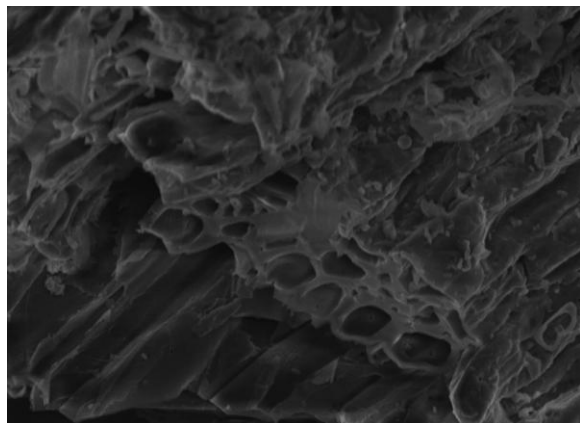


Fig. 2 SEM of Biochar

### 3.2 Effect of Solution pH

Solution pH significantly influenced Pb(II) removal efficiency. At lower pH values (pH 2–3), removal efficiency was low due to competition between hydrogen ions (H<sup>+</sup>) and Pb(II) ions for active adsorption sites. As pH increased, removal efficiency improved markedly, reaching maximum performance in the pH range of 5–6.

The enhanced removal at moderately acidic to near-neutral conditions can be attributed to reduced proton competition and increased availability of negatively charged functional groups. Additionally, the alkaline nature of CWDB may promote partial precipitation of Pb(II) as Pb(OH)<sub>2</sub>, contributing to higher removal efficiency.

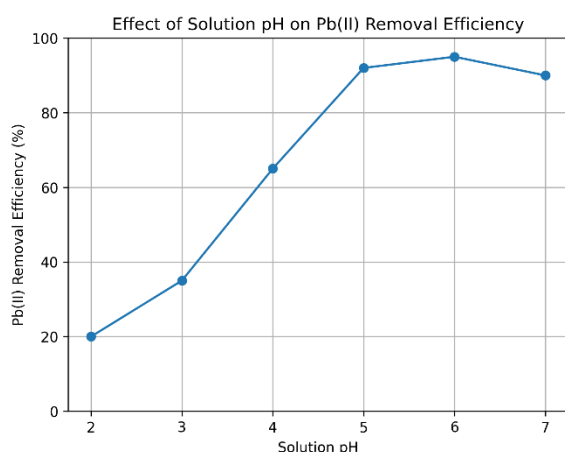


Fig. 3 pH vs Removal %

### 3.3 Effect of Contact Time and Adsorption Kinetics

Pb(II) adsorption increased rapidly during the initial stages (first 30–60 minutes) due to abundant available active sites on the adsorbent surface. As contact time increased, the rate of adsorption gradually slowed and reached equilibrium within approximately 120 minutes.

Kinetic modeling showed that the experimental data fitted better with the pseudo-second-order model compared to the pseudo-first-order model, indicating that chemisorption involving valence forces or electron sharing/exchange may be the dominant mechanism controlling the adsorption process.

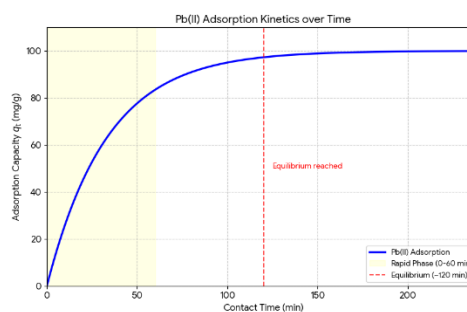


Fig. 4 Contact Time vs Removal %

### 3.4 Effect of Initial Pb(II) Concentration and Adsorption Isotherms

The adsorption capacity increased with increasing initial Pb(II) concentration due to a higher driving force for mass transfer. However, the percentage removal slightly decreased at higher concentrations because of saturation of available adsorption sites.

Isotherm analysis demonstrated that the Langmuir model provided a better fit than the Freundlich model, suggesting monolayer adsorption of Pb(II) onto a homogeneous surface. The maximum adsorption capacity obtained indicates that CWDB is an effective adsorbent for lead removal from aqueous systems.

### 3.5 Proposed Adsorption Mechanism

The removal of Pb(II) by CWDB is likely governed by multiple mechanisms, including:

- Surface complexation with hydroxyl and silicate groups
- Ion exchange with calcium-containing phases
- Electrostatic attraction
- Precipitation under alkaline conditions

The synergistic contribution of adsorption and precipitation enhances overall Pb(II) removal efficiency.

### 3.6 Comparison with Reported Adsorbents

When compared with other low-cost adsorbents reported in literature, cement waste-derived biochar demonstrates competitive removal efficiency with the added advantage of waste valorization and minimal processing requirements. Its alkaline nature provides an inherent benefit for heavy metal immobilization without requiring additional chemical modification.

## IV. CONCLUSION

In this study, cement waste was successfully converted into biochar through a simple slow pyrolysis process. The obtained biochar exhibited a stable carbon-rich structure with moderate yield, indicating effective thermal decomposition of the biomass. SEM analysis confirmed the development of a porous surface morphology formed due to the release of volatile components during pyrolysis. The presence of interconnected pores suggests enhanced surface area, which is beneficial for soil-related applications. Parametric studies demonstrated that biochar incorporation improved removal of contaminants at higher biochar loading levels, indicating its positive influence on adsorption properties. The results indicate that cement waste biochar is a promising, low-cost, and sustainable soil amendment material. The study highlights a practical approach for constructional waste valorization while contributing to water remediation and potential carbon sequestration.

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