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Variation in Metal Removal from Contaminated Water Using Activated Charcoal, Charred and Uncharred Plant Materials, Eggshells and Oxalic Acid

Lovell Agwaramgbo[1], Shalin Bell[2] and Christopher Alisa[3]

1. Chemistry Department, Dillard University, New Orleans, LA 70122, USA

2. Biology Department, Dillard University, New Orleans, LA 70122, USA

3. Chemistry Department, Federal University of Technology Owerri, PMB 1526, Owerri, Nigeria

Abstract: In today's economy, determining accessible and affordable techniques to remove Heavy Metals (HMs) from wastewater is crucial. Activated carbon is highly effective in adsorbing HMs due to its large surface area and porous structure. It works by attracting and binding HM ions to its surface. Okoubaka is known for its medicinal properties and some studies suggest it has detoxifying effects. However, its specific role in HM removal would likely involve binding mechanisms like other plant-based materials. This study examines the efficiency of activated charcoal, charred versus uncharred Okoubaka plant materials, eggshells and oxalic acid to remove HMs like copper, lead, and zinc from contaminated water.

Key words: Oxalic acid, HM remediated, plant materials, Okoubaka plant, metal contamination.

1. Introduction

Water contamination has intensified over the past years as the world's population and industrial activities have grown. HMs (Heavy Metals) are among the environmental contaminants commonly found in water and wastewater [1]. Generally, the HMs are present in the wastewater at low concentrations and adsorption is suitable even when the metal ions are present at concentrations as low as 1 mg/L. This makes adsorption an economical and favorable technology for HM removal from wastewater [2]. Adsorption is a commonly proposed technique since it is highly effective in the extraction process and is easy to apply; adsorbents are available in different ranges and are cheaper in cost [3]. Therefore, it is important to develop low-cost, feasible, and sustainable wastewater metal removal technologies. Various methods for the removal of HMs from wastewater have been extensively studied in recent years [2-4]. Liu et al. [5] highlighted the effectiveness of various adsorption methods for removing copper ions from wastewater, noting that low-cost, natural adsorbents have shown promising results in metal removal from contaminated water systems. Kumar and Roy [6] demonstrated that oxalic acid-modified activated carbon significantly enhances the removal of HMs from contaminated water, suggesting that chemical modification of adsorbents can improve their efficiency. Agwaramgbo, Alisa, and Sardin also reported that Oxalic Acid was very effective in removing copper, lead and zinc from contaminated water due to its bonding to the metals [7]. Research reports by Agwaramgbo and his group also suggested that adsorbent charge plays a role in HM removal, showing that adjusting the charge of adsorbents can influence their ability to remove contaminants from aqueous solutions [8-9] Furthermore, speciation of HM into various forms will affect their removal due to their accumulation, sequestration,

Corresponding author: Lovell Odili Agwaramgbo, Ph.D., Chair Scholl of STEM & Professor of Chemistry, research fields: organic and environmental chemistry.

migration and localization in the ecosystem upon entering the environment [2, 10, 11].

2. Materials and Methods

2.1 Material Preparations

Standard metal solutions of 1,000 ppm of (Zn (II), Pb(II) and Cu(II)) were respectively prepared using equivalent amount of the corresponding nitrate salt dissolved in 1,000 mL of solution, respectively, using deionized water.

Okoubaka plant materials were washed, air dried, ground into fine powder, and sieved to a homogeneous powder. The charred plant material was prepared by heating each Okuobaka plant material at high temperature until charred. Eggshells were washed with distilled water, dried, crushed into a fine powder, and sieved. Oxalic acid and activated charcoal were purchased from Fisher Scientific and used without further purification.

2.2 Treatment of Contaminated Water with the Adsorbents

Duplicate samples of 2.0 g of each adsorbent (activated charcoal, charred and uncharred Okoubaka plant materials (fruit, and seed), eggshell, and oxalic acid) were weighed and placed in different labeled centrifuge tubes for zinc, lead and copper, respectively. To each set of duplicate centrifuge tubes for each adsorbent was added 40 mL of the corresponding metal contaminated water sample. Each resulting mixture was vortexed for 30 s. The sample tubes were then placed on a shaker and agitated for 16 h. After the agitation period, the sample tubes were removed from the shaker and were centrifuged for 10 min at 3,000 rpm. The supernatant of each sample was decanted into a new centrifuge tube. The resulting samples were analyzed for metal ion concentration using Environmental Protection Agency (EPA) Method 6010 (ICP-AES).

3. Results and Discussion

Fig. 1 below demonstrates that oxalic acid removed more than 96% of each metal from the contaminated water sample and is more effective in metal removal than the other adsorbents. It is also worthy to note that all the charred Okoubaka plant materials were more effective in removing metals from contaminated water than commercial activated charcoal. Additionally, charred Okoubaka seed was more effective in metal removal than the charred Okoubaka fruit. Eggshell was the least effective in metal removal except for Pb when compared to other adsorbents. The order of metal removal is: oxalic acid > charred Okoubaka seed > charred Okoubaka fruit > activated charcoal > eggshell (with the exception of Pb).

Fig. 2 below suggests that once again oxalic acid is the most effective in metal removal compared to all other adsorbents and across all metals except for lead removal by eggshell (99.9%). It is interesting to note the varying degree of metal removal by each of the adsorbents which could be explained by factors such as metal and adsorbent type.

Fig. 3 illustrates that charring significantly enhances metal removal efficiency across all Okoubaka-derived adsorbents, likely due to increased surface area and porosity following thermal modification. Among all adsorbents, OA (Oxalic Acid) exhibited the highest removal efficiency, consistently achieving ~ 99% removal for Zn, Pb, and Cu. In contrast, ES (Eggshells) showed the lowest adsorption capacity, particularly for Cu (21.2%), indicating limited effectiveness for copper remediation. CC (Commercial Charcoal) also displayed moderate efficiency, comparable to some uncharred Okoubaka materials.

A direct comparison between charred and uncharred Okoubaka samples reveals that charred materials removed significantly higher percentages of metals. For instance, OFC (Charred Okoubaka Fruit) achieved Zn, Pb, and Cu removal rates of 87.0%, 85.0%, and 81.6%, respectively, whereas its OF (Uncharred Counterpart) exhibited lower efficiencies at 72.9%, 63.7%, and 56.8%. Similar trends were observed for other Okoubaka components, reinforcing the positive impact of charring on adsorption potential.

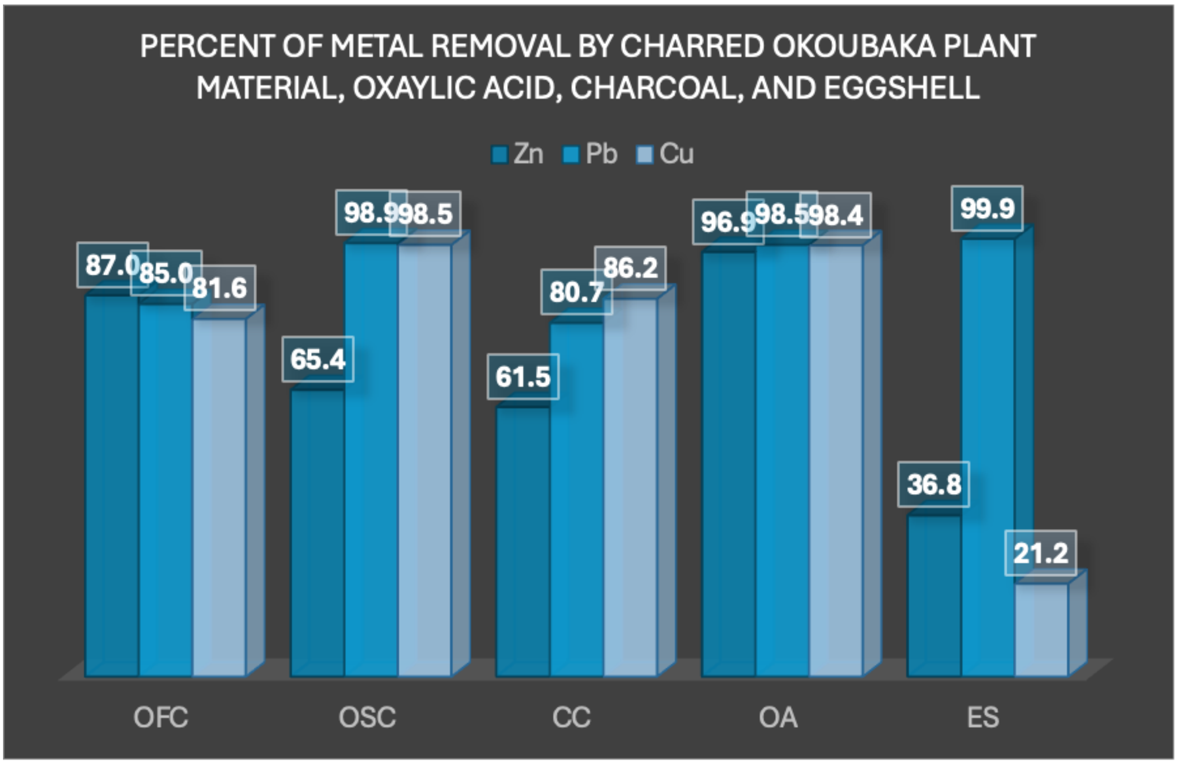

Fig. 1 Percent metal removal by oxalic acid, eggshell and charred Okoubaka seed & fruit.
OFC = Charred Okoubaka fruit; OSC = Charred Okoubaka seed; CC = Charcoal; OA = Oxalic acid; ES = Eggshell.

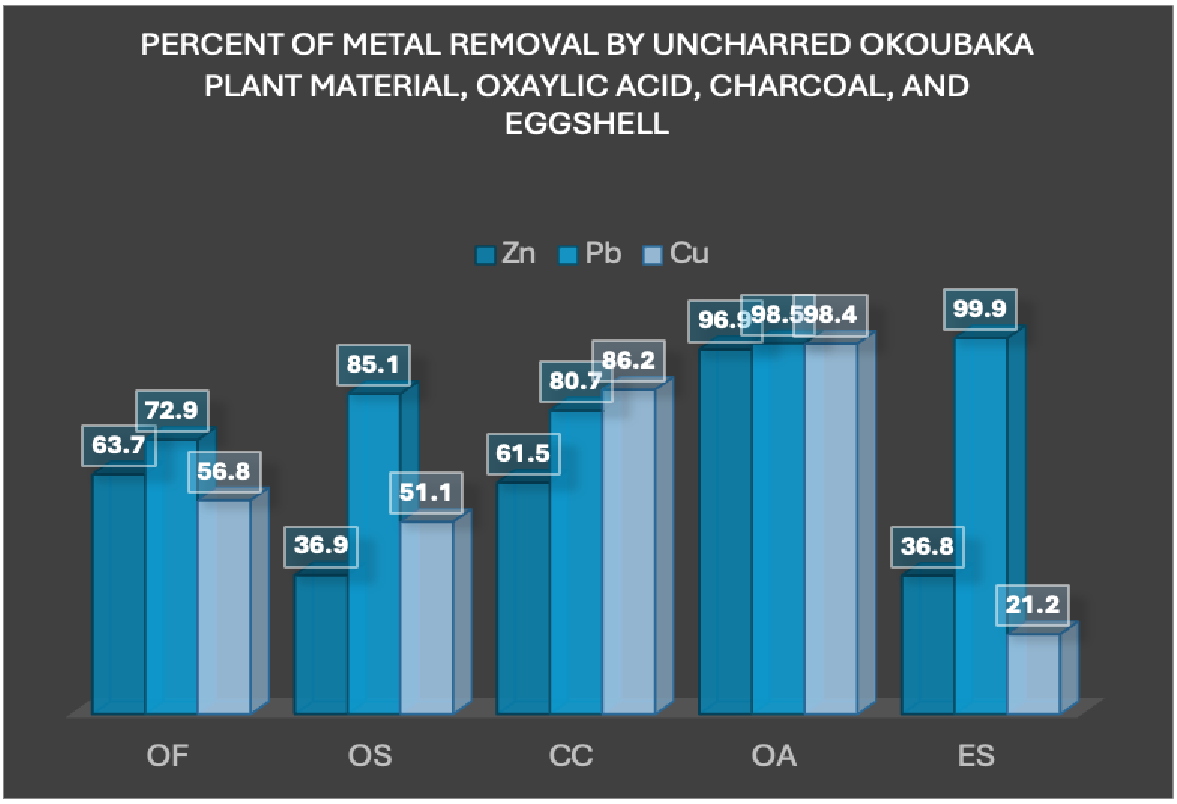

Fig. 2 Percent metal removal by oxalic acid, eggshell and uncharred Okoubaka fruit & seed.
OF = Okoubaka fruit; OS = Okoubaka seed; CC = Charcoal; OA = Oxalic acid; ES = Eggshell.

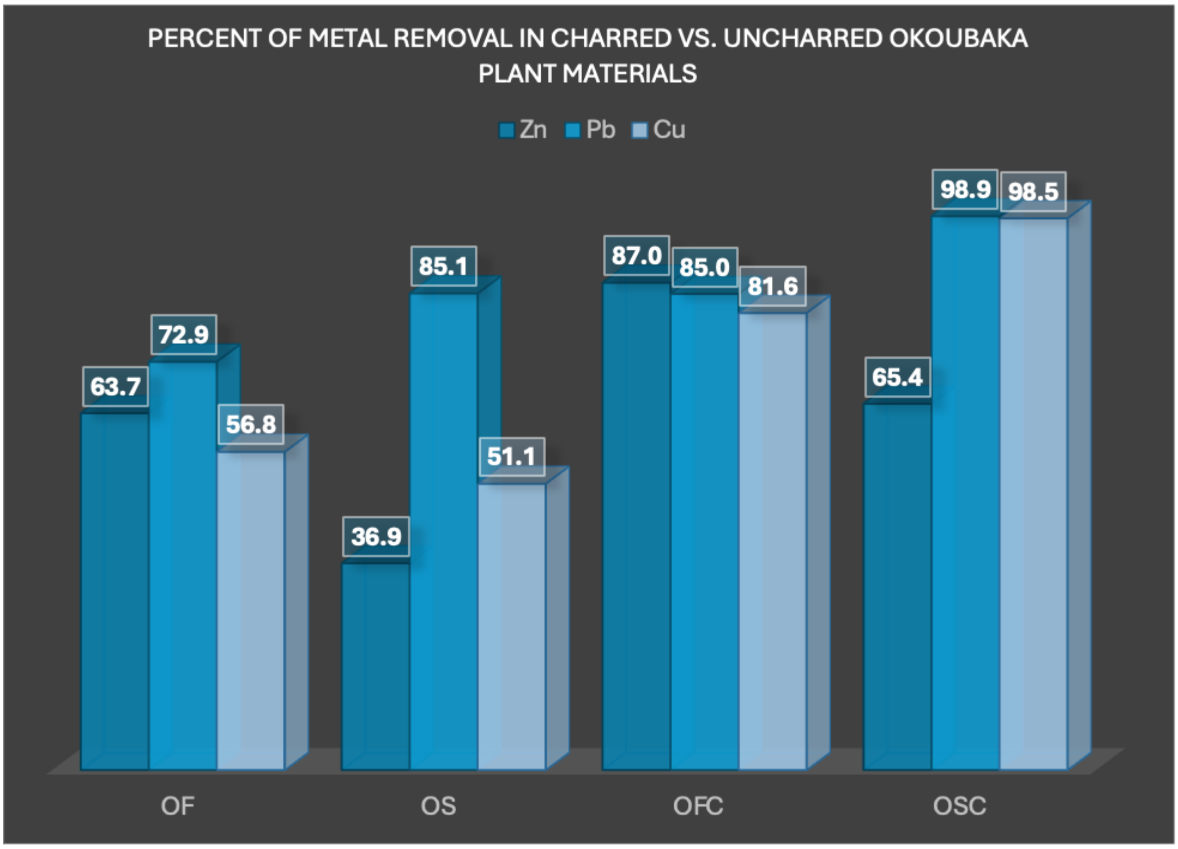

Fig. 3 Percent metal removal by charred and uncharred Okoubaka fruit & seed.
OF = Okoubaka fruit; OS = Okoubaka seed; OFC = Charred Okoubaka fruit; OSC = Charred Okoubaka seed.

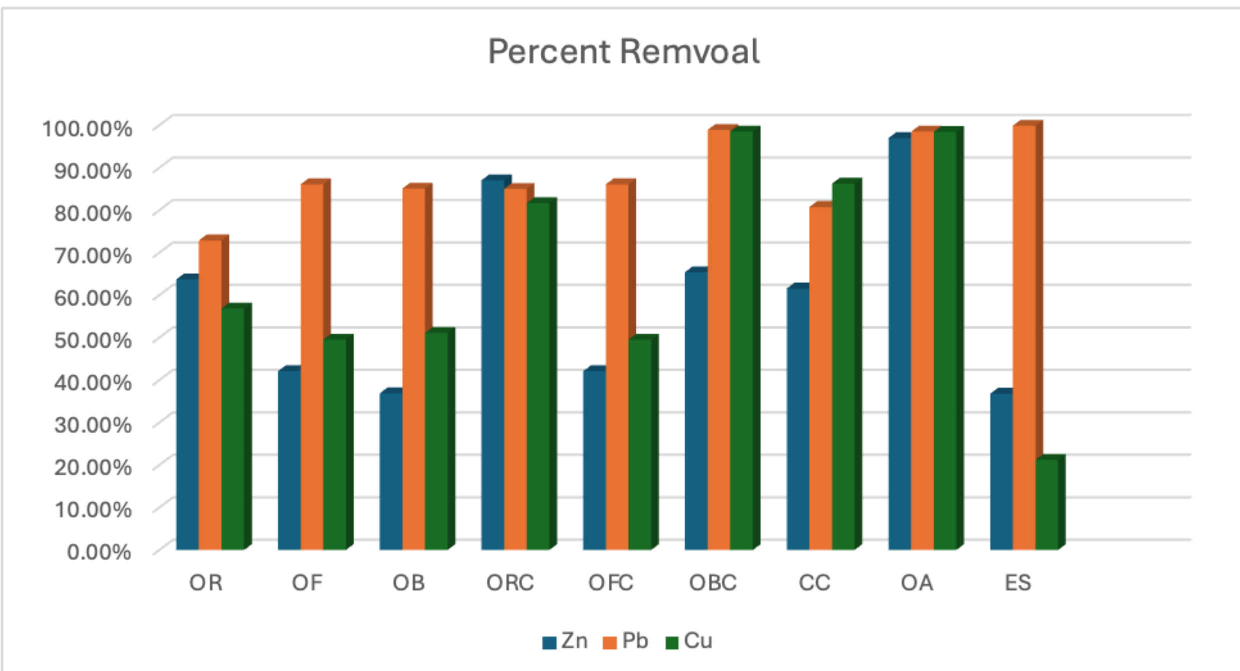

Fig. 4 Percent removal of Zn, Pb, and Cu from contaminated water using various adsorbents. OR = Okoubaka root, OF = Okoubaka fruit, OB = Okoubaka bark, ORC = Charred Okoubaka root, OFC = Charred Okoubaka fruit, OBC = Charred Okoubaka bark, CC = Commercial Charcoal, OA = Oxalic Acid, ES = Eggshell. Oxalic acid achieved the highest removal across all metals, followed by charred Okoubaka materials. Eggshells showed high Pb removal but low for Zn and Cu.

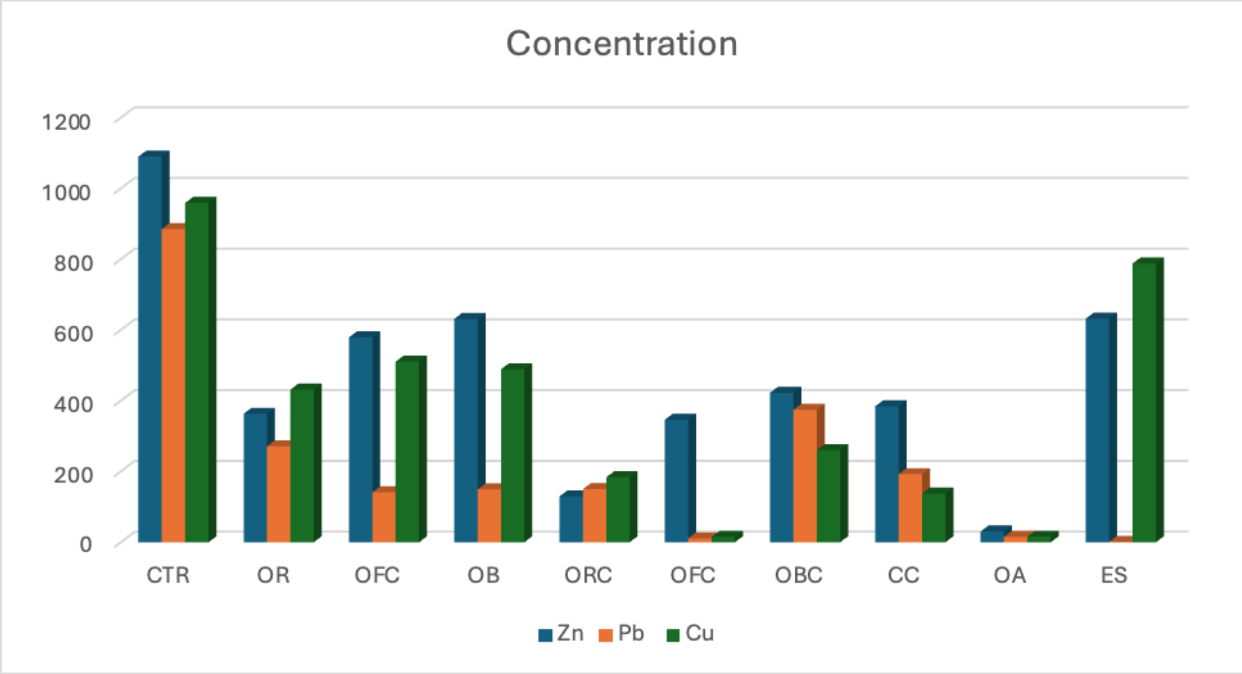

Fig. 5 Post-treatment concentrations of Zn, Pb, and Cu remaining in solution after exposure to each adsorbent. CTR = Control (untreated), all other labels as defined above. Oxalic acid-treated samples exhibited the lowest residual concentrations for all metals, demonstrating its superior efficiency. Charred Okoubaka samples showed significantly improved performance compared to their uncharred counterparts.

Furthermore, lead (Pb) and zinc (Zn) were generally removed at higher efficiencies compared to copper (Cu), suggesting a preferential adsorption mechanism or differences in metal ion interactions with the adsorbent surfaces. These findings suggest that charred Okoubaka plant materials have promising applications as low-cost, sustainable adsorbents for HM remediation, particularly in wastewater treatment. Future research should focus on optimizing charring conditions and investigating the regeneration potential of these materials for long-term environmental applications.

4. Discussion

This study demonstrates that activated charcoal is the most efficient adsorbent for removing HMs from contaminated water, followed by charred plant materials (biochar) and eggshells. Uncharred plant materials and oxalic acid were less effective but still showed potential for certain applications. The effectiveness of these materials can be further optimized by adjusting pH, contact time, and adsorbent dose. This research provides valuable insights into the use of sustainable, low-cost materials for water treatment and suggests that biochar and eggshells could be viable alternatives for HM remediation in regions where activated charcoal is not economically feasible.

Activated charcoal exhibited the highest removal efficiency for all three metals, with lead showing the highest removal at 95%. This is likely due to the large surface area and high adsorption capacity of activated charcoal, which allows for extensive physical and chemical adsorption of metal ions. Okoubaka root, fruit, and bark charred and uncharred materials demonstrated a moderate to high removal efficiency, with a maximum of 83% for lead. This suggests that pyrolysis increases the metal adsorption capacity by enhancing the surface area and introducing functional groups. Uncharred plant materials were the least effective, with removal efficiencies ranging from 53% to 61%. The lower surface area and lack of heat treatment may explain this lower performance. Eggshells removed up to 78% of lead, likely through ionic exchange and precipitation as calcium-metal complexes. Oxalic acid also showed high removal efficiencies, the removal was less efficient compared to activated charcoal but still significant.

5. Conclusion

The experiment successfully demonstrates the variation in metal removal from contaminated water using different adsorbents. Activated charcoal was the most efficient material for metal removal, followed by charred plant materials and eggshells. Uncharred plant materials showed the least effectiveness. Oxalic acid also contributed to the removal of certain metal ions, likely due to complexation. This study provides valuable insight into the potential use of natural and waste materials in water purification, offering cost-effective and environmentally friendly alternatives for HM remediation.

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