EFFICIENCY OF THE PORTABLE BIOSORBENT CARTRIDGE FILTERFOR THE REMOVAL OF HEAVY METALS FROM LABORATORY WASTEWATER

Dr. Rowena P. Calasara[1]
[1]*Iloilo Science and Technology University*
La Paz, Iloilo City 5000, Philippines
rowena.calasara@isatu.edu.ph
Orcid # 0009-0000-3056-1755

Abstract
Green engineering is emerging as a critical technology for reducing pollution and minimising environmental risks while maintaining economic efficiency. This study designed and evaluated a portable biosorbent cartridge filter unit (PBCFU) to remove heavy metals from laboratory wastewater using agricultural wastes like rice hull, bagasse, banana peel, oyster shells, and scallop shells. These agricultural wastes were utilised as unmodified and modified to determine the efficiency of the medium. The PBCFU, constructed from a 64-inch steel pipe, was tested with unmodified and modified biosorbents. The modified biosorbents underwent pyrolysis and acid treatment. Synthetic wastewater containing lead, copper, and zinc was treated in 11 ways. Results showed that unmodified rice hull, carbonised rice hull, carbonised bagasse, and oyster shells achieved 100% removal of the metals, meeting regulatory standards. The PBCFU demonstrated adequate adsorption capacity and removal efficiency, making it a viable solution for wastewater treatment.
Keywords: Portable biosorbent cartridge filter unit (PBCFU), Adsorption capacity, Adsorption isotherm, Agricultural wastes, Heavy metals, Wastewater treatment, Pyrolysis, Acid treatment, Synthetic Wastewater, Removal efficiency

1. INTRODUCTION

Hazardous waste, often generated in research and academic laboratories, poses significant risks due to its toxicity, non-degradability, and potential to harm humans and the environment(Abou-elela; Ibrahim, 2019). Improper handling, especially liquid waste containing heavy metals, can lead to serious environmental and health hazards. Although the volume of waste from educational institutions is small, it can include highly toxic compounds, making proper disposal essential(de Souza Nascimento, Filho; 2010).While effective, traditional methods for removing heavy metals are costly and impractical for many laboratories (Kumar et al., 2009), thus prompting the need for cost-effective alternatives. This study proposes using agricultural wastes with natural biosorption capabilities to develop a portable cartridge filter for treating laboratory wastewater. This approach addresses the need for safe wastewater treatment and helps reduce solid waste by repurposing agricultural by-products. The project aims to create an effective, affordable solution for heavy metal removal, contributing to environmental sustainability.

2. SYNTHESIS

The study examines the unavoidable generation of wastewater from human activities, emphasising the presence of various hazardous pollutants. These pollutants pose significant environmental and health threats by altering the natural characteristics of water bodies.

Crab shells have been studied for their effectiveness in heavy metal removal among biological waste materials. Vijayaraghavan and Yun (2008) found that crab shells and *Sargassum* sp. outperformed other sorbents in this capacity. Similarly, Ogunsuyi et al. (2006) investigated oyster shells and discovered they exhibited the highest potential for copper ion sorption compared to agricultural by-products. Massie, Dean, and Sanders (2014) observed that adsorption using waste biomass, such as peanut skin extracts, shows promise in removing contaminants. Peanut hulls and chitosan cross-linked beads were also evaluated as adsorbents, with some demonstrating strong adsorption capacities for Cd, Cu, Pb, Zn, and Ni. Rice husks, a low-value agricultural by-product, have been developed into sorbent materials for heavy metal removal. The biosorption process involves chemisorption, complexation, surface adsorption, pore diffusion, and ion exchange (Acharya & Rafi, 2018). Additionally, Kwong et al. (2003) research revealed that tartaric acid-modified rice husks (TARH) exhibited the highest binding capacities for Cu and Pb.

In the study by Mqehe-Nedzivhe et al., batch adsorption experiments were performed using 50 mL plastic bottles. A fixed mass of adsorbent with a predetermined particle size was mixed with arsenic standard solutions, and the bottles were sealed and agitated at 200 rpm with a mechanical shaker until equilibrium was reached. Afterwards, the samples were filtered and analysed using inductively coupled plasma optical emission spectroscopy (ICPOES). Similarly, Ashraf et al. conducted experiments in which 100 mL of solution was placed in a conical flask and thoroughly mixed with 0.5 g of biosorbent, with particle sizes ranging from 255 to 355 microns at 30°C. The mixtures were shaken at 100 rpm for 12 hours, the equilibrium period established by previous studies. The biomass was separated from the solution through filtration using filter paper after agitation.

In previous experiments, solutions and biosorbents were mixed in 50-ml plastic bottles or conical flasks. The containers were sealed and agitated in a mechanical shaker until equilibrium was reached. The mixtures were filtered using filter paper, and the filtrates were analysed. However, due to the limited availability of filtration devices for treating wastewater with agricultural waste-based biosorbents, this study aims to design and construct a filtration system that minimises human contact, ensuring safer and more effective treatment.

3. RESEARCH SIGNIFICANCE

This phase is significant because it addresses the critical issue of heavy metal pollution in wastewater, mainly from industrial and institutional laboratory sources. It highlights the limitations of conventional heavy metal removal methods, which are costly and environmentally detrimental due to the production of toxic sludge.

The study's focus on biosorption as an alternative solution is significant because it introduces a cost-effective, eco-friendly approach that utilises natural, abundant, and renewable materials like agricultural waste. By exploring the use of materials such as rice hull, bagasse,banana peel, oyster, and scallop shell as biosorbents, the study contributes to the development of sustainable wastewater treatment technologies. Additionally, the design of the Portable Biosorbent Cartridge Filter Unit (PBCFU) is noteworthy for its practicality and versatility. It offers a scalable and adaptable solution that can be easily implemented in various settings, including remote or resource-limited areas, making it a valuable innovation in environmental protection and public health. This technology addresses the immediate issue of heavy metal contamination and provides a sustainable and accessible method for long-term wastewater management.

4. OBJECTIVES OF THE STUDY

This study sought to evaluate the efficiency of PBCFUinremoving heavy metals from laboratory wastewater.

Specifically, it aimed to:

1. Design and construct a PBCFU;
2. Evaluate the efficiency of unmodified agricultural wastes, which include (A) rice hulls, (B) bagasse, (C) banana peels, (G) oyster shells, and (H) scallop shells as biosorbents based on the percent removal of lead, zinc, and copper metals from laboratory wastewater;
3. Evaluate the efficiency of carbonised agricultural wastes, which include (D) rice hulls, (E) banana peels, and (F) bagasse as biosorbents based on the percent removal of lead, zinc, and copper metals from laboratory wastewater and

4. Evaluate the efficiency of chemically treated agricultural wastes, which include (I) chemically treated rice hulls, (J) Chemically treated bagasse, and (K) chemically treated banana peel shells as biosorbents based on the percent removal of lead, zinc, and copper metals from laboratory wastewater.

5.DESCRIPTION OF THE STUDY

5.1 Design. Criteria

The project utilised an experimental design to develop, construct, and evaluate a portable cartridge filter to remove heavy metals from laboratory wastewater. There were five (5) unmodified and six (6) modified treatments, with five (5) replicates per treatment, tested at 30-minute intervals. The unmodified treatments included rice hull (A), bagasse (B), banana peel (C), oyster shell (G), and scallop shell (H), while the modified treatments consisted of biochar rice hull (D), banana peel (E), and bagasse (F), and the chemically-treated with HCl versions of rice hull (I), bagasse (J), and banana peel (K). The influent used was synthetic wastewater with controlled concentrations of heavy metals.

The project procedure was divided into seven (7) significant stages. The first stage involved gathering materials. The second stage focused on designing and constructing the PBCFU. The third stage covered the preparation of biosorbents. The fourth stage included the preparation of a stock solution containing heavy metals. The fifth stage involved testing the PBCFU. The sixth stage consisted of water sample analysis. Finally, the seventh stage evaluated the data collected. These steps are outlined in Figure1.

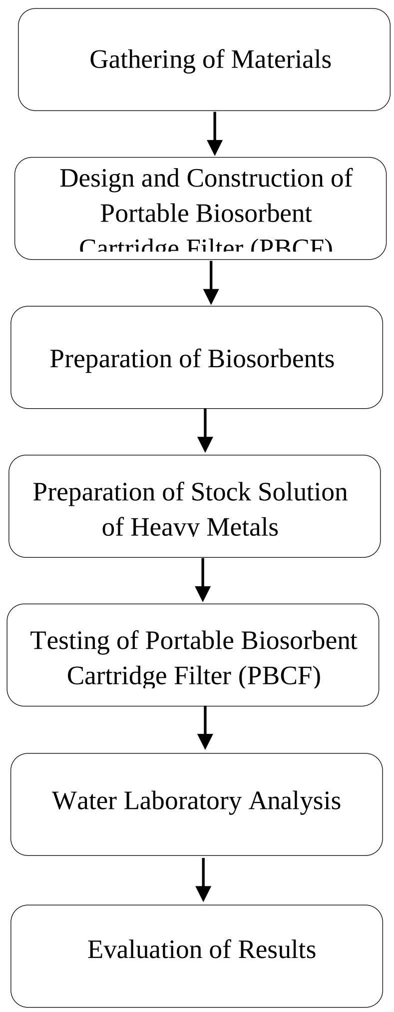


Figure 1.*Process Flow Diagram for the Design, Construction, and Evaluation of Portable Biosorbent Cartridge Filter for the Removal of Heavy Metals from Laboratory Wastewater*

5.1.1. Gathering of Materials

This study used five (5) different types of agricultural waste collected from various municipalities in Iloilo Province, where these wastes are commonly found. The agricultural wastes included rice hulls, bagasse, banana peels, oyster shells, and scallop shells.

5.1.2.PBCFU System

The PBCFU is a compact and mobile filtration system designed to remove heavy metals from wastewater using biosorption. Biosorption is a process where natural, organic materials (biosorbents) bind and remove contaminants like heavy metal ions, especially from wastewater.The unit uses biosorbents—natural materials such as agricultural waste (e.g., rice hulls, bagasse, banana peels, oyster shells, and scallop shells)— believed to capture heavy metals from wastewater effectively. The filter is designed to be portable and can be easily transported and deployed in various locations, including remote or resource-limited areas. The unit is designed to minimise direct human contact with the toxic wastewater, enhancing safety during operation.Due to its modular design, the unit can be scaled to meet different needs, from small laboratory settings to larger industrial applications.It can be used in various environments, including laboratories, making it adaptable to wastewater treatment contexts.The PBCFU represents an innovative and sustainable approach to managing heavy metal pollution in wastewater, combining the principles of environmental protection, cost-effectiveness, and practicality.

5.1.3.Components of the PBCFU System

The PBCFUcomprises several key components designed to facilitate the efficient removal of heavy metals from wastewater using biosorption. The Filter Systemis composed of;

Filter Columns. As noted by HIFI Water and Filters, cartridge filtration is highly versatile. This study'sfilter columns are constructed from stainless steel Schedule 40, which was chosen for its corrosion resistance. Stainless steel materials are known for their ability to endure corrosive substances. The design includes four vertically aligned stainless steel pipes, segmented into upper, middle, and lower sections. A breathing space is incorporated inside each segment in the column to maintain proper airflow and balance during filtration. These columns are designed to accommodate filter media and efficiently manage and process liquid waste.

*Coupling System.*A coupling system connects different filter system parts, ensuring the components work together as a cohesive unit while allowing fluid transfer. Stainless steel is used for all materials in contact with wastewater to resist corrosion. Flanges secure the connections between filter column sections with rubber sealants to prevent leaks. A mesh between sections ensures even liquid distribution and keeps the filter media in place. The column cap reduces and directs the flow of filtered liquid, while a ball valve at the bottom controls the flow rate into beakers.

*Metal Stand.*This metal stand is constructed from 3/16" flat bars and angle bars made of mild steel, providing sufficient strength to support the system as both legs and framework. The top metal platform holds the filter system and connects to the upper section of the filter columns. The legs and metal frame offer structural stability for the entire unit. Rubber footings are also included to enhance stability and minimise disturbances during operation.

Beaker Holder Platform. The beaker holder platform is a specially designed structure that securely holds beakers in place as they collect filtered liquid during filtration. It features a series of precisely sized holes or cutouts, each tailored to fit the dimensions of the beakers, ensuring they remain stable and do not tip over while the liquid is being collected. This platform is typically made from lightweight plastic materials, which makes it easy to handle, move, and transfer as needed within the system.

Beakers. Beakers are essential containers for collecting and holding filtered liquid samples. They are made of cylindrical glass with a flat bottom and a graduated scale for measuring filtered volumes.

5.1.4. Device Construction

PBCF was constructed with a 2 x 64 in Sch 40 steel pipe to accommodate the two-litre sample. To avoid over and faster saturation at the topmost part of the filter and for easier regeneration of the biosorbent, the PBCF was divided into three (3) portions. These were 24”, 22”, and 18” high for the topmost, middle, and bottom parts. However, every portion only contained a 10” high biosorbent, where the remaining part served as an open space to accommodate the faster flow. The flange connected every portion, which also functioned as a packing support and access manway for packing removal during regeneration time. Stainless steel was used for construction since it is a corrosion-resistant alloy that is environmentally neutral and inert, and its longevity ensures it meets sustainable construction needs.

6. DESCRIPTION OF TECHNOLOGY

The PBCF system comprises a filter assembly, beakers, a beaker holder platform, and a metal stand. The filter assembly is securely mounted on the top metal platform of the stand, with the beakers positioned on the beaker holder platform. The holder has holes that match the outer diameter of the beakers, allowing them to collect the filtered liquid from the system.

The filter system contains filter media and four vertically arranged, equally spaced filter columns. These columns are made of schedule 40 stainless steel pipes with a 5.08 cm internal diameter and a height of 162.56 cm. They are designed to hold two (2) litres of liquid waste and 76.2 cm of filter media.

The column height is mathematically calculated using the formula $V=\pi r^2 h$. Each column is divided into three sections: an upper section (60.96 cm), a middle section (55.88 cm), and a lower section (45.72 cm). The upper section is attached to the top metal platform and joined to the middle section using a 3” x 4” stainless steel flange with UNC 5/6” bolts and nuts. The middle and lower sections are connected using a 3” x 3” flange with the same type of bolts and nuts.

The total height (h_T) of the filter system is the sum of the height of the filter media (h_F) and the breathing space (h_B), expressed as $h_T = h_F + h_B$.

A ball valve is connected to the lower section of each column using a 3” x 3” flange and UNC 5/6” bolts and nuts. The ball valve controls the flow of the filtered liquid and is mounted on the column cap, guiding the liquid to the beakers. It can be opened or closed using a gate lever. The filter media filters the liquid samples inside each filter column.

The PBCF beaker platform comprises a metal housing that securely holds the beakers containing the filtered liquid samples. The metal stand includes legs, a frame, a top platform, and rubber footings for stability. The legs are attached to the top platform with metal supports, and the top platform has several holes to hold and secure the filter columns.

7. PREPARATION OF THE MEDIA

7.1. Filter Media.

These materials capture heavy metals from liquid waste and can be sourced from unmodified or modified agricultural residues, including rice hulls, bagasse, oyster shells, and scallop shells. Initially, these materials undergo water cleaning and sun drying for 72 hours, followed by additional drying in a machine dryer at 200°C for two hours. Unmodified filter media are cleaned, dried, and ground into powder using a ball mill. The ground materials were then sieved through a Tyler screen with a 4/100 mesh, producing a particle diameter of less than 4.7mm, as shown in Figure 2.

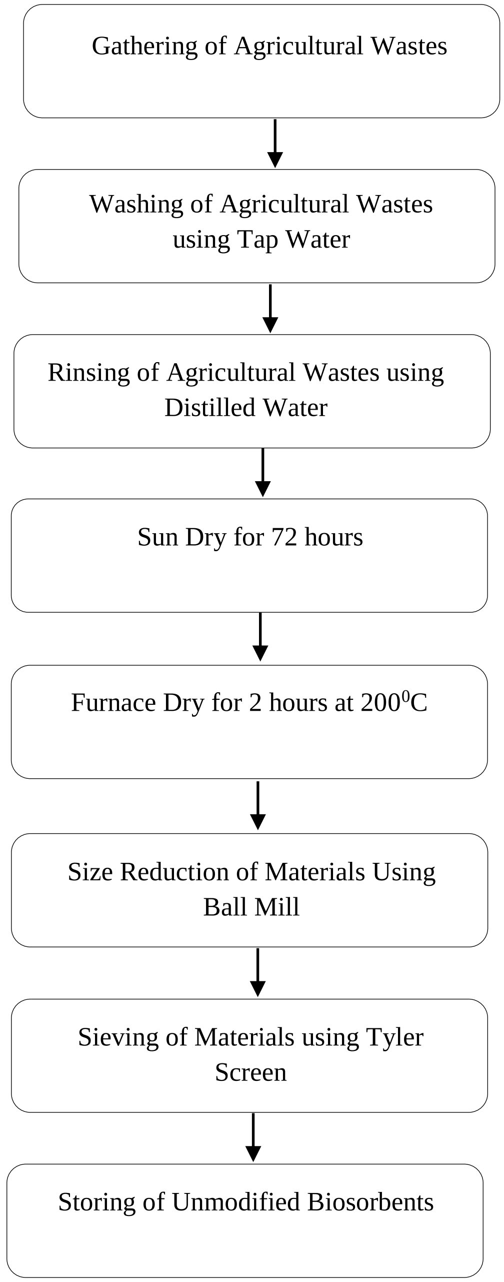
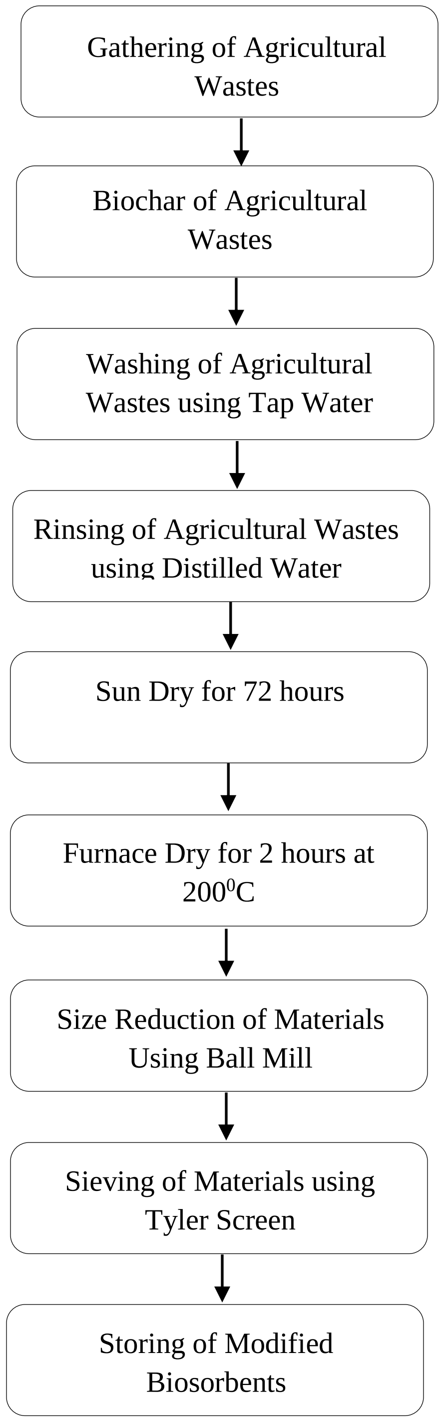


Figure 2.*Process Flow Diagram of Unmodified Biosorbent Preparation.*

Figure 3 below illustrates the steps in producing modified biochar biosorbents. The preparation process is similar to unmodified biosorbents, with the primary difference being pyrolysis. First, the gathered materials were sorted to remove foreign matter and then placed in a fabricated biochar device for pyrolysis. Afterwards, the biochar was washed, sun-dried, and dried in a furnace. The dried biochar was ground using a ball mill and sieved through a Tyler screen with a 4/100 mesh, resulting in particles with a diameter of less than 4.7 mm, which were then stored for future use.



,

Figure 3.*Process Flow Diagramof Modified Biosorbent (Biochar)Preparation.*

Figure 4 below illustrates the steps involved in producing chemically treated biosorbents. The preparation process utilises 1M Hydrochloric acid as a treatment and cleaning agent for the gathered materials. Initially, the collected materials were sorted to remove foreign matter, then washed, sun-dried, and dried in a furnace. The dried biosorbents were ground using a ball mill and sieved through a Tyler screen with a 4/100 mesh, resulting in particles smaller than 4.7 mm. The biosorbents were soaked in 1M HCl (pH 4.5) for 24 hours. After soaking, the biosorbents were rinsed several times with distilled water, air-dried for 24 hours, and subsequently stored for future use.

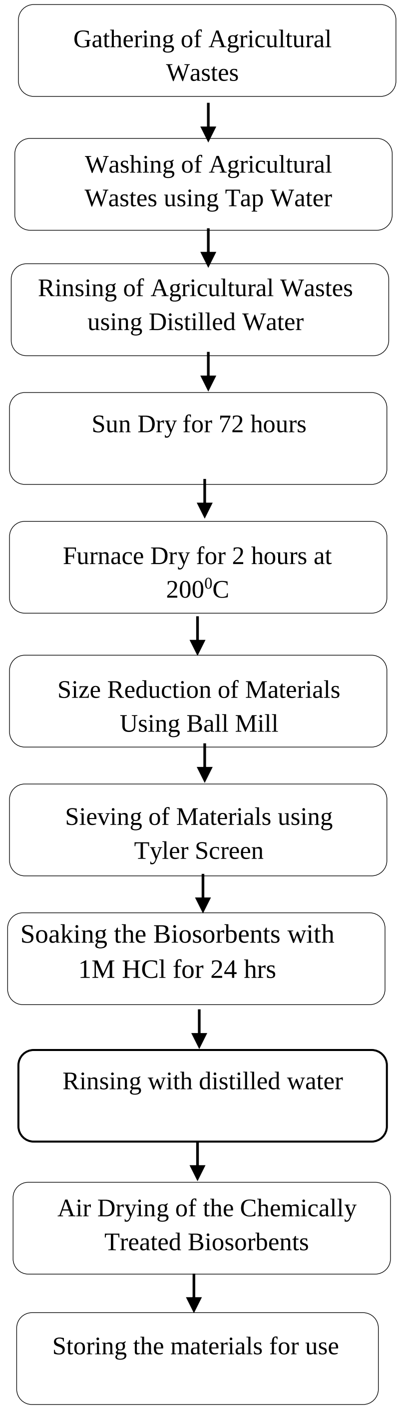


Figure 4.*Process Flow Diagram of Chemically Treated Biosorbent Preparation.*

7.2.Preparation of Stock Solution of Heavy Metals

The wastewater was synthesised to control the metal concentration in each treatment. Researchers wore appropriate personal protective equipment (PPE) to ensure safety when handling the heavy metals. Only three (3) heavy metals were studied: copper(II) nitrate trihydrate, lead(II) nitrate, and zinc(II) nitrate hexahydrate. Using stoichiometric calculations, 11.4059 g of copper, 4.7954 g of lead, and 13.6406 g of zinc compounds were dissolved and diluted in 30 L of distilled water for each respective metal.

8. Testing of Portable Bio-sorbent Cartridge Filter

The prepared biosorbents were compacted inside the PBCF to a height of 10 inches. For each sampling period, 2 L of influent was poured into the PBCF. Samples were collected every thirty (30) minutes over five sampling periods to ensure sufficient contact time. The collected samples were stored in sampling bottles for analysis.

9. INTERPRETATION OF DATA

The copper, lead, and zinc concentrations in the influents and effluents were analysed at the CPU Water Laboratory. Pre- and post-treatment results for removing these heavy metals were recorded at 30-minute intervals over five sampling periods. A consistent two-litre volume of wastewater was used for all treatments, designed specifically for the PBCF. The particle size of the biosorbents, separated using a Tyler screen, ranged from Tyler Mesh 100 (149 microns) to Tyler Mesh 4 (4699 microns). Wastewater concentrations were 28.956 mg/L for Cu, 45.140 mg/L for Pb, and 102.670 mg/L for Zn.

AAS results were used to calculate the most efficient biosorbent for removing the three heavy metals. The removal efficiency of each sorbent material was expressed as a percentage, calculated using the formula:

$$\%R = \frac{C_{in} - C_{out}}{C_{in}} x\ 100$$

Where:

- %R = percent removal efficiency,
- C_{in} = concentration of the influent,
- C_{out}= concentration of the effluent."

9.1.Unmodified Biosorbents

Treatment A: Unmodified Rice Hull

Treatment A removed copper, lead, and zinc almost 100%, indicating that this medium is an effective sorbent for these heavy metals, as shown in Table 1.

Table 1

Pre and Post Treatment Results for the Removal of Copper (Cu), Lead (Pb), and Zinc(Zn) at Different Timeusing Treatment A

Time (mins)	Effluent Standard (ppm)			Pre-treatment sample (ppm)			Post-treatment Sample (ppm)			Per cent Removal (%)		
	Cu	***Pb***	***Zn***	***Cu***	***Pb***	***Zn***	***Cu***	***Pb***	***Zn***	***Cu***	***Pb***	***Zn***
0	0.040	0.100	4.000	28.956	45.140	102.670	28.956	45.140	102.700	0.000	0.000	0.000
30							0.000	0.040	1.491	100.000	99.914	98.548
60							0.000	0.000	0.987	100.000	100.000	99.039
90							0.000	0.000	0.567	100.000	100.000	99.448
120							0.000	0.000	0.483	100.000	100.000	99.530
150							0.000	0.000	0.029	100.000	100.000	99.972

Treatment B: Unmodified Bagasse

Table 2 shows that Treatment B removed almost 100% of copper and lead, while the removal of zinc averaged 94.40%.

Table 2

Pre- and Post-Treatment Results for the Removal of Copper (Cu), Lead (Pb), and Zinc (Zn) at Different Times using Treatment B.

Time (mins)	Effluent Standard (ppm)			Pre-treatment sample (ppm)			Post-treatment Sample (ppm)			Per cent Removal (%)		
	Cu	***Pb***	***Zn***	***Cu***	***Pb***	***Zn***	***Cu***	***Pb***	***Zn***	***Cu***	***Pb***	***Zn***
0	0.040	0.100	4.000	28.956	45.140	102.670	28.956	45.140	102.67	0.000	0.000	0.000
30							0.010	0.050	12.7861	99.966	99.8892	87.546
60							0.000	0.020	8.0412	100.000	99.9557	92.168
90							0.000	0.010	6.6555	100.000	99.9778	93.518
120							0.000	0.000	4.8079	100.000	100.000	95.317
150							0.000	0.000	3.4642	100.000	100.000	96.626

Treatment C: Unmodified Banana Peel

This treatment was excluded from the sample analysis because the effluent emerged very slowly, dripping out due to its highly viscous nature, significantly delaying collection from the PBCF.

Treatment G: Unmodified Oyster Shell

The PBCF achieved almost 100% removal of all three heavy metals in terms of percent removal using treatment G, as shown in Table 3.

Table 3

Pre- and Post-Treatment Results for the Removal of Copper (Cu), Lead (Pb), and Zinc (Zn) at Different Times using Treatment G.

Time (mins)	Effluent Standard (ppm)			Pre-treatment sample (ppm)			Post-treatment sample (ppm)			Per cent Removal (%)		
	Cu	***Pb***	***Zn***	***Cu***	***Pb***	***Zn***	***Cu***	***Pb***	***Zn***	***Cu***	***Pb***	***Zn***
0	0.040	0.100	4.000	28.956	45.140	102.670	28.956	45.140	102.67	0.000	0.0000	0.000
30							0.2588	0.030	0.5952	99.1061	99.9335	99.4203
60							0.0706	0.000	0.0934	99.7562	100.0000	99.909
90							1E-05	1E-05	0.0682	100.000	100.0000	99.9335
120							1E-05	1E-05	0.0472	100.000	100.0000	99.954
150							1E-05	1E-05	0.0346	100.000	100.0000	99.9663

Treatment H: Unmodified Scallop Shell

Nearly 100% removal for the three heavy metals, Cu, Pb, and Zn, as shown in Table 4.

Table 4

Pre- and Post-Treatment Results for the Removal of Copper (Cu), Lead (Pb), and Zinc (Zn) at Different Times using Treatment H.

Time (mins)	Effluent Standard (ppm)			Pre-treatment sample (ppm)			Post-treatment sample (ppm)			Per cent Removal (%)		
	Cu	***Pb***	***Zn***	***Cu***	***Pb***	***Zn***	***Cu***	***Pb***	***Zn***	***Cu***	***Pb***	***Zn***
0	0.040	0.100	4.000	28.956	45.140	102.670	28.956	45.140	102.67	0.000	0.0000	0.000
30							0.2337	0.000	0.1375	99.1929	100.0000	99.8661
60							0.3011	0.281	0.1228	98.9601	99.3779	99.8804
90							0.3124	0.2496	0.064	98.9213	99.4471	99.9376
120							0.2562	0.2184	0.0367	99.1153	99.5162	99.964
150							0.3236	0.3276	0.0346	98.8825	99.2743	99.9663

9.2. Carbonized Biosorbents

Treatment D: Carbonized Rice Hull

Using treatment D, the percentage of copper, lead, and zinc removal was almost 100%, as shown in Table 5.

Table 5

Pre- and Post-Treatment Results for the Removal of Copper (Cu), Lead (Pb), and Zinc (Zn) at Different Times using Treatment D.

Time (mins)	Effluent Standard (ppm)			Pre-treatment sample (ppm)			Post-treatment sample (ppm)			Per cent Removal (%)		
	Cu	***Pb***	***Zn***	***Cu***	***Pb***	***Zn***	***Cu***	***Pb***	***Zn***	***Cu***	***Pb***	***Zn***
0	0.040	0.100	4.000	28.956	45.140	102.670	28.956	45.140	102.67	0.000	0.0000	0.000
30							0.000	0.040	0.1942	100.000	99.9114	99.8108
60							0.000	0.030	0.1711	100.000	99.9335	99.8333
90							0.000	0.010	0.1648	100.000	99.9778	99.8395
120							0.000	0.000	0.0955	100.000	100.0000	99.907
150							0.003	0.000	0.0871	100.000	100.0000	99.9151

Treatment E: Carbonized Banana Peel

Table 6 shows that PBCF's efficiencies in terms of percent removal using treatment E were almost 100% for all three heavy metals.

Table 6

Pre- and Post-Treatment Results for the Removal of Copper (Cu), Lead (Pb), and Zinc (Zn) at Different Times using Treatment E.

Time (mins)	Effluent Standard (ppm)			Pre-treatment sample (ppm)			Post-treatment Sample (ppm)			Per cent Removal (%)		
	Cu	***Pb***	***Zn***	***Cu***	***Pb***	***Zn***	***Cu***	***Pb***	***Zn***	***Cu***	***Pb***	***Zn***
0	0.040	0.100	4.000	28.956	45.140	102.670	28.956	45.140	102.67	0.000	0.0000	0.000
30							0.3765	0.360	1.9945	98.6999	99.2025	98.0573
60							0.170	0.140	1.0708	99.4129	99.6899	98.9571
90							0.090	0.110	0.7348	99.6892	99.7563	99.2843
120							0.000	0.030	0.3989	100.000	99.9335	99.612
150							0.000	0.030	0.2465	100.000	99.9335	99.7599

9.2.3 Treatment F: Carbonized Bagasse

All three heavy metals were removed at approximately 100% using carbonised bagasse, as shown inTable 7.

Table 7

Pre and Post-Treatment Results for the Removal of Copper (Cu), Lead (Pb), and Zinc (Zn) at Different Times using Treatment F.

Time (mins)	Effluent Standard (ppm)			Pre-treatment sample (ppm)			Post-treatment Sample (ppm)			Per cent Removal (%)		
	Cu	***Pb***	***Zn***	***Cu***	***Pb***	***Zn***	***Cu***	***Pb***	***Zn***	***Cu***	***Pb***	***Zn***
0	0.040	0.100	4.000	28.956	45.140	102.670	28.956	45.140	102.67	0.000	0.0000	0.000
30							0.000	0.080	0.1669	100.000	99.8228	99.8374
60							0.000	0.010	0.1585	100.000	99.9778	99.8456
90							0.000	0.000	0.1417	100.000	100.0000	99.862
120							0.000	0.000	0.1383	100.000	100.0000	99.865
150							0.003	0.000	0.0934	100.000	100.0000	99.909

9.3 Chemically Treated Biosorbents

Treatment I: Chemically-treated Rice Hull

Unlike other treatments that consistently achieved nearly 100% removal, only copper and lead showed close to 100% removal, while zinc exhibited a significantly lower average removal rate of 56.44%, asshown in Table 8.

Table 8

Pre and Post Treatment Results for the Removal of Copper (Cu), Lead (Pb), and Zinc (Zn) at Different Times using Treatment I

Time (mins)	**Effluent Standard (ppm)**			**Pre-treatment sample (ppm)**			**Post-treatment Sample (ppm)**			**Per cent Removal (%)**		
	Cu	***Pb***	***Zn***	***Cu***	***Pb***	***Zn***	***Cu***	***Pb***	***Zn***	***Cu***	***Pb***	***Zn***
0							28.956	45.140	102.67	0.000	0.0000	0.000
30							0.0118	0.000	42.2003	99.9594	100.0000	58.8972
60	0.040	0.100	4.000	28.956	45.140	102.670	0.0471	0.000	42.6202	99.8375	100.0000	58.4882
90							0.2941	0.000	46.8192	98.9843	100.0000	54.3983
120							0.9765	0.000	45.9794	96.6277	100.0000	55.216
150							2.0235	0.000	45.9794	93.0117	100.0000	55.2163

Treatment J: Chemically-treated Bagasse

Chemicallytreated bagasse exhibited relatively low average removal rates of 72.53% for copper and 37.14% for zinc while achieving a higher removal efficiency of 93.56% for lead, as shown in Table 9.

Table 9

Pre- and Post-Treatment Results for the Removal of Copper (Cu), Lead (Pb), and Zinc (Zn) at Different Times using Treatment J.

Time (mins)	**Effluent Standard (ppm)**			**Pre-treatment sample (ppm)**			**Post-treatment Sample (ppm)**			**Per cent Removal (%)**		
	Cu	***Pb***	***Zn***	***Cu***	***Pb***	***Zn***	***Cu***	***Pb***	***Zn***	***Cu***	***Pb***	***Zn***
0							28.956	45.140	102.67	0.000	0.0000	0.000
30							5.8235	2.683	66.1348	79.8883	94.0556	35.5851
60	0.040	0.100	4.000	28.956	45.140	102.670	5.2941	1.545	67.3945	81.7167	96.5784	34.3581
90							7.7059	2.5429	65.295	73.3876	94.3666	36.4031
120							10.529	3.7441	64.4552	63.6365	91.7056	37.221
150							10.412	4.025	59.4163	64.0428	91.0833	42.1288

Treatment K: Chemically-Treated Banana Peel

Table 10 shows that high removal percentages for copper, lead, and zinc were achieved.

Table 10

Pre and Post-Treatment Results for the Removal of Copper (Cu), Lead (Pb), and Zinc (Zn) at DifferentTimes using Treatment K.

Time (mins)	Effluent Standard (ppm)			Pre-treatment sample (ppm)			Post-treatment Sample (ppm)			Per cent Removal (%)		
	Cu	*Pb*	*Zn*	*Cu*	*Pb*	*Zn*	*Cu*	*Pb*	*Zn*	*Cu*	*Pb*	*Zn*
0	0.040	0.100	4.000	28.956	45.140	102.670	28.956	45.140	102.67	0.000	0.0000	0.000
30							1.4353	0.328	7.7892	95.0432	99.2743	92.4134
60							0.6235	0.172	4.388	97.8466	99.6198	95.7261
90							0.2	0.0624	1.1547	99.3093	99.8618	98.8753
120							0.1529	0.0624	1.0708	99.4718	99.8618	98.957
150							0.1412	0.078	0.9448	99.5124	99.8272	99.0798

10. RESULTS AND DISCUSSION

10.1 Performance of the Fabricated Portable Biosorbent Cartridge Filter

The Portable Biosorbent Cartridge Filter was designed and fabricated to effectively treat laboratory wastewater while securely holding biosorbents in place without compromising the integrity of its construction materials. Using subdivided cartridges helped maintain a consistent flow rate by preventing clogging, which could occur from a significant pressure drop if biosorbents were confined to a single cartridge.

10.1.1 Copper Removal

Analysis of samples from different treatments revealed the following findings:Treatments A, B, D, E, F, G, and H achieved a copper removal efficiency ranging from 98% to 100%. In comparison, treatment I achieved a 93.0117% removal rate, Treatment J had a 64.0428% removal rate, and Treatment K reached a 95.0432% removal rate.

10.1.2 Lead Removal

The analysis of samples from different treatments revealed the following findings. For lead removal,treatments A, B, D, E, F, G, H, I, and K achieved a removal efficiency ranging from 98% to 100%

10.1.3 Zinc Removal

The analysis of samples from various treatments revealed the following findings. Only treatments A, D, E, F, G, and H achieved a removal efficiency ranging from 98% to 100% for zinc removal. Treatment B had an87.5465% removal rate, treatment I had a 54.3983% removal rate, Treatment J had a 34.3581% removal rate, and Treatment K had a 92.4134% removal rate.

11. CONCLUSIONS

After thoroughly testing the functionality of the Portable Biosorbent Cartridge Filter and achieving all the objectives set by the proponents, it was concluded that the project was feasible. The sorbents were placed in the filter column and soaked for thirty minutes before starting the operation. Samples were taken at thirty-minute time intervalsthroughout five trials.

Based on the analysis of the results, the following conclusions were drawn:

1. The designed and constructed Portable Biosorbent Cartridge Filter effectively processed and treated laboratory wastewater without any leakage or erosion of the biosorbents inside.

2. Among the agricultural wastes tested, only unmodified rice hull, unmodified bagasse, and oyster shells consistently achieved 98-100 percent removal of copper, which had an average concentration of 30 ppm, across all time intervals. For lead removal, with an average concentration of 45 ppm, unmodified rice hull and unmodified bagasse were the only materials that reached 98-100 percent removal across all time intervals. With an average concentration of 100 ppm for zinc removal, only unmodified rice hull and oyster shells consistently achieved 98-100 percent removal across all time intervals.
3. Among the agricultural wastes tested for copper removal, with an average concentration of 30 ppm, carbonised rice hull and carbonised bagasse achieved 98-100 percent removal across all time intervals. For lead removal, with an average concentration of 45 ppm, carbonised rice hull and carbonised bagasse also achieved 98-100 percent removal across all time intervals. For zinc removal, with an average concentration of 100 ppm, carbonised rice hull, carbonised banana peel, and carbonised bagasse all consistently achieved 98-100 percent removal across all time intervals.
4. Among the agricultural wastes tested for copper removal, with an average concentration of 30 ppm, none of the chemically treated materials achieved 98-100 percent removal across all time intervals. For lead removal, with an average concentration of 45 ppm, a chemically treated rice hull was the only material to achieve 98-100 percent removal across all time intervals. For zinc removal, with an average concentration of 100 ppm, no chemically treated material reached 98-100 percent removal across all time intervals.
5. Among the agricultural wastes tested, only unmodified rice hull, carbonised rice hull, carbonised bagasse, and oyster shells achieved 100% removal of all three heavy metals found in the laboratory wastewater.

12. RECOMMENDATIONS

Based on the substantial findings and conclusions, the following recommendations are made:

1. Unmodified rice hull, carbonised rice hull, carbonised bagasse, and oyster shells were highly effective in removing heavy metals. Therefore, using these agricultural wastes in a series of Portable Biosorbent Cartridge Filters (PBCFs) is recommended.
2. Unmodified bagasse performed exceptionally well in treating wastewater with lead and copper but needed to be more effective for zinc removal. Thus, using unmodified bagasse when treating wastewater with minimal zinc content is advisable.
3. Unmodified, carbonised, and chemically treated banana peels demonstrated minimal effectiveness in reducing heavy metal concentrations and tended to clog the filter, disrupting the natural water flow in the PBCF. Therefore, using other agricultural wastes that do not form a starch-like powder is recommended, which can cause filter blockage.
4. When designing a PBCF for a specific laboratory's wastewater treatment, it is recommended to adjust the height-to-diameter ratio of the PBCF according to the volume of water to be treated periodically.

13. ACKNOWLEDGEMENT

The researchers would like to express their deepest gratitude to the following individuals whose support was instrumental in the completion of this research:

- The researchers are deeply thankful to the ISAT U Administration for their trust and confidence in approving and funding this research;
- To Mr. Hilario S. Taberna, Research Services Division Director, for his valuable comments, sharing his time, talent, expertise, and guidance towards the completion of this study;
- To the ISAT U Center for Natural Science Research and Development for deliberating and accepting this research;
- To the CPU Civil Engineering Department for allowing us to use their Ball Mill to pulverise the samples;
- To the Intellectual Property Management Office through its creative works section’s chair, Dr. Karlo S. Sira, for the efforts to publish my paper;
- To the Research office staff for their patience in providing the needed documents;

- To all those who were not mentioned in one way or another have made significant contributions to this research and
- Above all, I thank Almighty God, the source of everything.

14. REFERENCES

Abou-Elela, S. & Ibrahim, H. (2019). Management of Laboratory Hazardous Wastes: Experience from Egypt. Retrieved from https://www.researchgate.net/publication/ 332980844_Management_of_Laboratory_Hazardous_Wastes_ Experience_from_Egypt.

Acharya,J., Kumar, U. & Rafi, P. (2018). Removal of Heavy Metal Ions from Wastewater by Chemically Modified Agricultural Waste Material as Potential Adsorbent-A Review. Retrieved from chrome-extension://efaidnbmnnnibpcaj.

Ali Redha, A. (2020). Removal of heavy metals from aqueous media by biosorption. Journal of the Association of Arab Universities for Basic and Applied Sciences. 27. 183–193. 10.1080/25765299.2020.1756177.

Ashraf, S. et al. (2019). Phytoremediation: Environmentally sustainable way to reclamation heavy metal polluted soils, Ecotoxicology and Environmental Safety. Retrieved from https://www.sciencedirect.com/science/article/pii/S0147651319302271.

Bailey, S.E., Olin, T.J., Bricka, R.M. & Adrian, D.D. (1999). A Review of Potentially Low-Cost Sorbents for Heavy Metals. Retrieved from https://doi.org/ 10.1016/ S0043 -1354 (98)00475–8.

De Souza Nascimento, E. & Fiho, A.T. (2010). Chemical Waste Risk Reduction and Environmental Impact Generated by Laboratory Activities in Research and Teaching Institutions. Retrieved from https://www.scielo.br/j/bjps/a/VWg4JQyVX7rdL7XdNbPBqXP/ ?lang=en.

Henze, M., & Comeau, Y. (2008). Wastewater characterisation. Biological wastewater treatment: Principles modelling and design, 33-52. Retrieved from https://scholar.google.com.ph/scholar?q=Wastewater+Characterization+Mogens+Henze+and+Yves+Comeau&hl=en&as_sdt=0&as_vis=1&oi=scholart#d=gs_cit&u=%2Fscholar%3Fq%3Dinfo%3AUfIbkTjVUUgJ%3Ascholar.google.com%2F%26output%3Dcite%26scirp%3D0%26hl%3Den.

Massie, B.J. & Sanders, T. & Dean, Lisa. (2015). Removal of Heavy Metal Contamination from Peanut Skin Extracts by Waste Biomass Adsorption. Journal of Food Process Engineering. 38. 10.1111/jfpe.12185. Retrieved from https://www.researchgate.net/publication/270649715_Removal_of_Heavy_Metal_Contamination_from_ Peanut_Skin_Extracts_by_Waste_Biomass_Adsorption

Mqehe-Nedzivhe et.al. (2018). Bio-adsorbents for the Removal of Heavy Metals from Water. Retrieved from https://www.intechopen.com/chapters/59176.

Ogunsuyi et al. (2006). Adsorption of copper ions from aqueous solution using agricultural wastes and oyster shell. Afr. J. Sci., 1(1): 16-12. Retrieved from chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/ viewer.html?pdfurl=https%3A%2F%2Facademicjournals.org%2Farticle%2Farticle1380633846_Opeolu %2520et%2520al.pdf&clen=98191&chunk=true.

Rai, M.K. et al. (2016). Removal of hexavalent chromium Cr (VI) using activated carbon prepared from mango kernel activated with H3PO4. Resource-Efficient Technologies Volume 2 Pages S63-S70. Retrieved from https://doi.org/10.1016/j.reffit.2016.11.011.

Velusamy, S. et al. (2021). A Review on Heavy Metal Ions and Containing Dyes Removal Through Graphene Oxide-Based Adsorption Strategies for Textile Wastewater Treatment. Retrieved from https://doi.org/10.1002/tcr.202000153.

(13) Vijayaraghavan, K. and Yun, Y.S. (2008). Bacterial Biosorbents and Biosorption. Biotechnology Advances, 26, 266-291.
Retrieved from http://dx.doi.org/10.1016/j.biotechadv.2008.02.002pcglclefindmkaj/viewer.html?pdfurl=https%3A%2F%2Finpressco.com%2Fwp-content%2Fuploads%2F2018%2F05%2FPaper6526-530.pdf&chunk=true.

Wong, K & Lee, C.K. & Low, K & Haron, Md Jelas. (2003). Removal of Cu and Pb by tartaric acid-modified rice husk from aqueous solutions. Chemosphere. 50. 23-8. 10.1016/S0045-6535(02)00598-2.

Retrieved from https://www.researchgate.net/ publication/7840668_Removal_of_Cu_and_Pb_by_tartaric_acid_modified_rice_husk_from_aqueous_solutions.