

BIOSORPTION OF CU(II) USING COCONUT HUSK IN AQUEOUS SOLUTION



A Project Report

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Abstract

Heavy metal contamination, particularly by copper (Cu(II)), poses a serious threat to aquatic ecosystems and human health due to its toxicity and non-biodegradable nature. Conventional methods for heavy metal removal are often costly, inefficient at low concentrations, and generate secondary waste. In this study, coconut husk, an abundant and low-cost agricultural byproduct, was investigated as a biosorbent for the removal of Cu(II) ions from aqueous solutions. Batch biosorption experiments were carried out to evaluate the influence of operational parameters such as contact time, pH, initial Cu(II) concentration, and biosorbent dosage. The maximum removal efficiency of Cu(II) was found to be 91.99% at a contact time of 60 minutes, with an adsorption capacity of 16.10 mg/g under optimal conditions (pH 5.6, temperature 27°C, 0.4 g biosorbent in 100 mL of 70 ppm solution). Surface characterization using Scanning Electron Microscopy (SEM) revealed changes in the morphology of the coconut husk after biosorption, while Energy-Dispersive X-ray Spectroscopy (EDS) confirmed the presence of copper on the biosorbent surface. The experimental data were best described by the Langmuir isotherm model, indicating monolayer adsorption on a homogeneous surface. The results demonstrate that coconut husk is an effective, sustainable, and eco-friendly biosorbent for Cu(II) removal from contaminated water. This study supports its potential application in wastewater treatment, especially in resource-limited settings where low-cost and environmentally responsible solutions are required.

Chapter 1

Introduction

Uncontaminated and pure waterways are crucial for various reasons, including environmental and health-related reasons. Environmental benefits include aquatic ecosystem health, biodiversity, nutrient cycling, and water quality regulation. Human health benefits include safe drinking water, public health, and economic benefits.

Heavy metals are quietly poisoning our environment—and us. Sure, some of it happens naturally, but let's face it: most of the damage comes from human activity. Factories, mining, improper waste disposal—they all play a part. These toxic metals seep into rivers, lakes, and groundwater through a mix of careless accidents, slow leaks, and outright dumping. Once they're in the water, they don't just disappear. They linger, build up, and eventually make their way into ecosystems, crops, and even our bodies. A few key ways:

Industrial Activities: Industrial activities encompass the activities of mining and smelting, manufacturing and metal processing, electroplating and metal finishing, textiles, paints, and dyes. These activities contribute to the introduction of heavy metals like Copper (Cu), Arsenic (As), Lead (Pb) and Chromium (Cr) into water sources. The unique properties of water, as a universal solvent, facilitate the absorption, adsorption, and suspension of these contaminants, leading to significant water pollution and associated health risks[1], [2].

Agricultural Runoff: Fertilizers and pesticides contain cadmium, arsenic, lead, and other metals. The use of fertilizers and pesticides in agriculture leads to non-point-source pollution, introducing nutrients and chemicals into surface and groundwater systems[3].

Waste Disposal: When we dump stuff in landfills or waste sites - especially electronics and hazardous materials - metals like mercury, cadmium, and lead can seep out. They basically leak through the soil and end up contaminating groundwater and rivers. It's a big problem when waste isn't handled properly.

Urban Stormwater Runoff: Metals like zinc and copper are washed into waterways from roadways, infrastructure, and roofing materials. Stormwater can also carry pollutants from urban areas into nearby lakes and streams.

Atmospheric Deposition: Heavy metal released into the atmosphere through power plants burn coal and oil, industrial emission, fossil fuel combustion, and vehicle exhaust.

Natural Process: Nature itself contributes to heavy metal contamination too. When rocks weather and break down, or when rain washes over surfaces, metals that are naturally in the

earth's crust get carried into water and soil. Erosion does the same thing - it moves these metals around. Even volcanic eruptions can release metals into the environment. And there's leaching, where metals slowly seep through soil layers. So even without human interference, these natural processes are constantly moving metals from rock and soil into our water systems, which affects the overall health of ecosystems. [4].

Table 1.1 presents the characteristics of common heavy metals, including their physical and chemical properties, sources, and environmental impacts.

Table 1.1: Characteristics of common heavy metal [5].

Heavy metal	Health effects	Common sources	Maximum Contamination Level	
			USEPA	WHO
Arsenic(As)	Skin damage, Circulatory system issues	Naturally-occurring, Electronics production	0.010 mgL ⁻¹	0.010 mgL ⁻¹
Cadmium(Cd)	Kidney damage, Carcinogenic	Naturally-occurring, Various chemical industries	0.005 mgL ⁻¹	0.003 mgL ⁻¹
Chromium(Cr)	Allergic dermatitis, Diarrhea, nausea, and vomiting	Naturally-occurring, Steel manufacturing	0.1 mgL ⁻¹	0.05 mgL ⁻¹
Copper(Cu)	Gastrointestinal issues, Liver or kidney damage	Naturally-occurring, Household plumbing systems	1.3 mgL ⁻¹	2.0 mgL ⁻¹
Lead(Pb)	Kidney damage, Reduced neural development	Household plumbing systems, Lead-based products	0.0 mgL ⁻¹	0.01 mgL ⁻¹
Mercury(Hg)	Kidney damage, Nervous system damage	Fossil fuel combustion, Electronics industries	0.002 mgL ⁻¹	0.006 mgL ⁻¹

Divalent Copper in water can have significant adverse effects on human health and the environment. Here are several potential impacts:

Neurotoxicity: Excessive copper accumulation in the brain can act as a barrier to proper

neurodevelopment. When copper levels exceed the body's ability to regulate them, it can lead to severe neurological conditions. One such condition is Wilson's disease, a genetic disorder where the body cannot properly eliminate copper, leading to copper accumulation. This buildup can cause neurobehavioral abnormalities that resemble schizophrenia symptoms. Zinc presents a different challenge. While zinc deficiency is known to negatively impact neurodevelopment, the full consequences of excessive zinc exposure remain poorly understood. The effects of high zinc concentrations are still being studied[6]. Copper can amplify the neurotoxic effects induced by zinc, suggesting a harmful interaction between the two metals in the brain [7].

Hepatotoxicity: Copper buildup in the liver is one of the main signs of Wilson's disease. When copper levels get too high, it creates oxidative stress that damages liver tissue. So in Wilson's disease, the copper accumulation in the liver does double duty - it's both how doctors diagnose the condition and what's actually causing the liver damage in the first place. Elevated copper levels can also be seen in certain liver diseases, like cholestatic liver diseases, but in these cases, the increase happens because the liver can't properly excrete copper, rather than copper itself being the direct cause of the damage or infection. [8], [9], [10].

Respiratory Issues: Inhalation of copper-contaminated water vapor or mist can irritate the respiratory tract, leading to coughing, throat irritation, and, in severe cases, lung damage.

Gastrointestinal Distress: Drinking water with high levels of copper (Cu^{2+}) can lead to gastrointestinal distress, causing symptoms like nausea, stomach cramps, diarrhea, vomiting and shortly after ingestion.

Liver and Kidney Damage: Long-term exposure to high copper levels can cause various health issues. Over time, consistent contact with copper may irritate the nose, mouth, and eyes and cause symptoms like dizziness, stomachaches and headaches. Intentional or prolonged high intake of copper can result in serious health consequences, including liver and kidney damage, and in extreme cases, it can even lead to death [11].

Disruption of Ecosystems: Excess Cu^{2+} can disrupt the balance of aquatic ecosystems by inhibiting the growth of beneficial microorganisms and plants, which are vital for nutrient cycling and water quality maintenance.

Soil and Plant Contamination: Irrigation with copper-contaminated water can lead to soil contamination. High copper concentrations in soil can affect plant growth, reducing agricultural productivity and altering soil microbial communities, which are essential for healthy soil ecosystems.

Using fruit and agricultural waste peels as adsorbents for removing heavy metals comes with

several benefits. These materials are low-cost, as they are often discarded or readily available, making them an economical alternative to synthetic adsorbents. They are environmentally sustainable, being both biodegradable and renewable, thus posing minimal environmental risks. These materials have lots of surface area and functional groups, which means they're really good at grabbing onto different heavy metals. The nice thing about these waste-based adsorbents is that they don't need much chemical treatment or prep work. That makes them pretty straightforward to use and doesn't require a lot of energy. Additionally, they are available in large quantities, making them scalable for widespread use, especially in agricultural regions. Many can be regenerated for reuse, further enhancing their cost-effectiveness and sustainability, while their non-toxic nature ensures they do not introduce harmful by-products into the environment.

Coconut husk works really well for removing heavy metals from wastewater. Since it's basically agricultural waste, it's cheap and environmentally friendly compared to synthetic materials. The husk contains lots of lignocellulosic fibers - cellulose, hemicellulose, and lignin - which give it a large surface area. These fibers also have functional groups like carboxyl and hydroxyl that are great at binding to heavy metal ions such as cadmium, copper, and lead. Coconut husk is biodegradable, making it environmentally sustainable, and it requires minimal chemical processing. Additionally, it can be regenerated and reused in some cases, further reducing costs and enhancing sustainability. Its widespread availability in tropical regions also makes it highly scalable for use in water treatment systems, especially in developing countries where cost-effective solutions are needed.

1.1 TECHNOLOGIES AVAILABLE TO REMOVE HEAVY METAL FROM WASTE WATER

Removing heavy metal ions from water is an essential process, both for protecting the environment and for industrial purposes. There are several methods available for this, each with its own pros and cons. Here's an overview of the most common methods:

Adsorption: Adsorption is a process where molecules from a gas or liquid stick to the surface of a solid material called an adsorbent. It's both a physical and chemical process that happens when these molecules come into contact with the solid surface. This process is crucial in various industrial applications, particularly for separating and purifying substances. The interaction is primarily driven by van der Waals forces, resembling condensation, where the adsorbate accumulates on the adsorbent's surface [12], [13].

Common Adsorbents:

- Activated Carbon: Known for its high surface area and porosity, it is highly effective in removing heavy metals from water.
- Bio-adsorbents: Natural materials like chitosan, algae, peat, and agricultural wastes have been explored for eco-friendly applications.
- Synthetic Adsorbents: Zeolites, silica gel, and resins are examples of engineered adsorbents with tailored properties.

Chemical Precipitation: Chemical precipitation is a method used in water and wastewater treatment to remove unwanted dissolved metals and certain other substances. It works by converting these dissolved materials into solid particles.

Ion exchange: Ion exchange is a reversible process where ions get swapped between a solid material - usually an ion exchange resin - and a water-based solution. This method is widely utilized in water treatment to remove unwanted dissolved ionic constituents, such as heavy metals and nitrates, thereby improving water quality for various applications [14].

Membrane Filtration Techniques: Membrane filtration relies on size exclusion or electrostatic interactions to separate heavy metal ions from water. Various membrane processes are employed:

- Reverse Osmosis (RO): Pressure-driven process where water passes through a semi-permeable membrane, leaving contaminants behind.
- Nanofiltration (NF): Similar to RO but with larger pore sizes, suitable for divalent ions like heavy metals.
- Ultrafiltration (UF): Works for larger particles and can be combined with adsorbents or coagulants to remove heavy metals.
- Electrodialysis (ED): It uses an electric field to push metal ions through ion-exchange membranes.

Coagulation and Flocculation: In this method, coagulants are added to break down and destabilize tiny particles in the water that contain heavy metals. Then, flocculants are used to help these particles form larger aggregates, called flocs, which can be easily removed through settling or filtration.

Common Coagulants:

- Aluminum salts (e.g., alum) or iron salts (e.g., ferric chloride).
- Polymers: Used as flocculants to enhance the aggregation process.

Electrochemical Treatment: Electrochemical processes such as electrocoagulation and electroflootation use electrical currents to induce reactions that remove heavy metal ions from

water.

Bioremediation and Phytoremediation: Biological methods involve using living organisms to remove or neutralize heavy metal ions.

- Bioremediation: Microorganisms like bacteria, fungi, or algae metabolize or adsorb heavy metals, making them either less toxic or easier to remove.
- Phytoremediation: Plants, especially hyperaccumulator species, absorb and concentrate heavy metals from contaminated water or soil in their tissues.

Photocatalysis: This advanced oxidation process uses semiconductor materials like TiO₂ that work under UV or visible light. They produce reactive species such as hydroxyl radicals, which can break down organic compounds and convert metal ions into less toxic or insoluble forms.

Chemical Reduction: Reduction techniques use reducing agents to change metal ions into their elemental forms, which are less toxic or don't dissolve in water. Once they're converted, these metals can be removed through filtration or sedimentation. Common Reducing Agents are Sodium borohydride (NaBH₄), Zero-valent iron (ZVI).

1.2 BIOADSORPTION

A bio-sorbent refers to materials derived from natural sources like microbial biomass, seaweed, or plants that possess the ability to adsorb contaminants. Adsorption is a process where a solid material, usually called a bio-sorbent, interacts with water to trap dissolved substances like heavy metals. Both living and non-living materials can be used for this, though there are still questions about whether they're cost-effective. There are several methods physical, chemical, and biological for removing metal ions using waste from the food and agricultural industries. These biological materials are particularly effective at reducing metal concentrations in food, water, and wastewater [15].

1.2.1 Bioadsorption Mechanisms

Biosorption works through mechanisms related to how microbial cells function and where they remove metals. These mechanisms can be divided into two categories: those that depend on the cell's metabolism and those that don't. Metals get removed in various ways - they can accumulate or form solids outside the cell, bind to the cell surface, or get absorbed inside the cell. Although these processes might appear distinct, they often overlap and involve both metabolic and non-metabolic activities.

Non-metabolism-dependent methods are usually quicker. In contrast, metabolism-dependent mechanisms, such as intracellular uptake (or bioaccumulation), occur at slower rates and are

driven by cellular metabolism. Metal precipitation can either be facilitated by microbial metabolism, where microorganisms produce compounds that promote precipitation, or it can occur without metabolism, as a result of direct chemical interactions between metals and the cell surface [16].

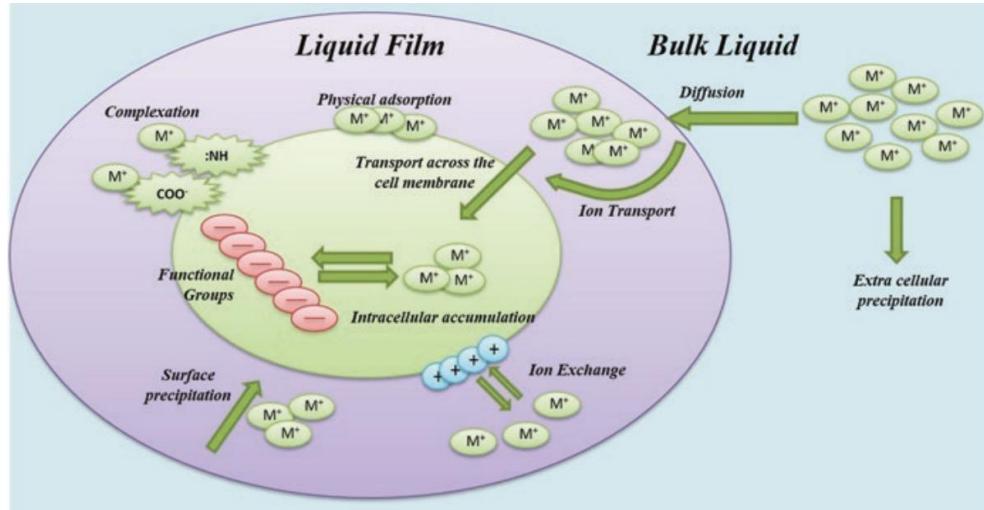


Fig 1.1 : Schematic of Main Biosorption Mechanisms: Metabolic vs. Non-Metabolic Processes [16].

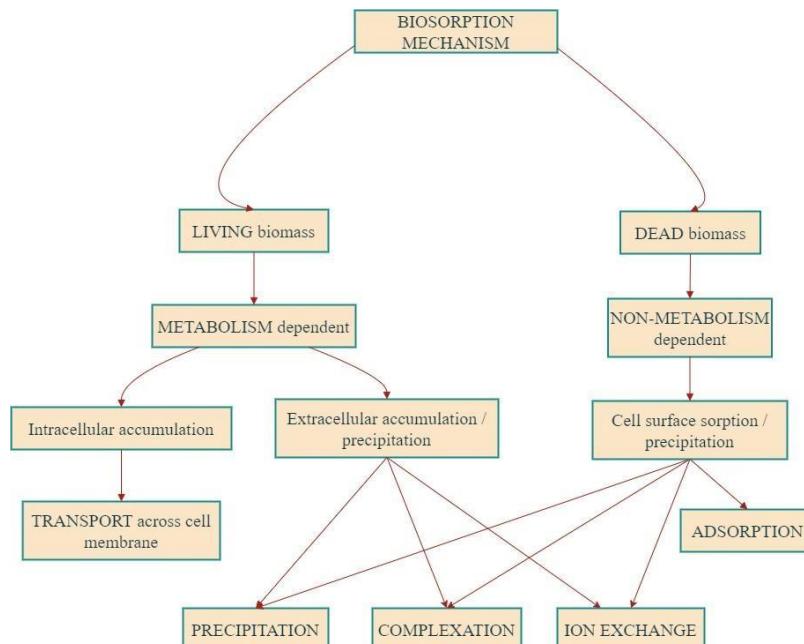


Fig 1.2 : Biosorption Mechanisms: Metabolism and Metal Removal Correlation [16].

The biosorption process involves various mechanisms, which can be broadly classified into metabolic and non-metabolic processes, as illustrated in Figure 1.1. Additionally, the correlation between metabolism and metal removal is depicted in Figure 1.2.

1.3 OBJECTIVES

The main objectives of this project are:

- To determine the optimal contact time for maximum divalent copper ion removal from aqueous solution using coconut husk.
- To evaluate the adsorption capacity of coconut husk to remove divalent copper ion from aqueous solution.

1.4 SCOPES AND LIMITATIONS

1.4.1 Scopes

Coconut husk is an abundant and renewable agricultural waste material, especially in tropical regions, which makes it a cost-effective and environmentally friendly biosorbent for removing Cu(II) ions from water. The high lignocellulosic content and functional groups in coconut husk give it a natural ability to bind heavy metals, offering a promising alternative to conventional water treatment methods.

1.4.2 Limitations

- **Biosorbent Preparation:** The coconut husk used in this study will be prepared under specific conditions (e.g., drying, grinding, or chemical modification). The effectiveness of the biosorbent may vary depending on preparation methods, and this study will not exhaustively explore all possible pretreatment techniques.
- **Synthetic Solutions:** The study will be conducted using synthetic aqueous solutions of Cu(II), which may not entirely replicate the complexity of real-world industrial wastewater. In real wastewater, other contaminants or competing ions could affect the biosorption process, but these are not addressed here.
- **Scale of Study:** The experiments are conducted on a laboratory scale, and the results may not directly translate to large-scale industrial applications. Scaling up the process may present additional challenges that are outside the scope of this research.
- **Environmental Variables:** While this study investigates the effect of temperature and pH, other environmental factors such as the presence of organic matter, competing ions, or fluctuating environmental conditions will not be thoroughly explored.
- **Biosorbent Reusability:** Although desorption and reusability are discussed, the study may not delve into long-term reusability of coconut husk or explore the degradation or potential loss of biosorption capacity over multiple cycles of use.
- **Limited Focus on Other Metals:** The study focuses solely on Cu(II) ions, and the

biosorption capabilities of coconut husk for other heavy metals or pollutants are not addressed, even though they may coexist in real wastewater scenarios.

- **Equilibrium and Kinetic Models:** The study assumes that biosorption kinetics and equilibrium can be adequately described by traditional models (Langmuir, Freundlich, etc.), but the exact fit of these models may be limited by assumptions, particularly in non-ideal systems.
- **pH Range:** The pH range for the experiments is limited to a controlled set of values, and extreme pH conditions or varying pH in real-world applications may yield different results.

1.5 OUTLINE OF THIS PROJECT

This thesis is organized into six chapters, each focusing on different aspects of the research. A brief overview of the contents of each chapter is provided below:

Chapter 1 introduces the background of heavy metal contamination, particularly copper (Cu(II)), and reviews conventional and emerging methods for their removal from aqueous environments. The objectives, scope, and limitations of the present study are also outlined in this chapter.

Chapter 2 presents a literature review summarizing previous research related to biosorption techniques. The focus is on various biosorbents, including agricultural waste materials, and the outcomes of those studies relevant to copper removal.

Chapter 3 explains the materials, methods, and experimental procedures used in this study. It includes the preparation of the biosorbent (coconut husk), metal solution, and the analytical techniques applied.

Chapter 4 provides details on data collection and calculation methods, including how initial and final metal concentrations were measured, and how removal efficiency and adsorption capacity were determined.

Chapter 5 presents the results and analysis, including the effects of various parameters on biosorption efficiency, isotherm model fitting, and characterization results obtained from SEM and EDX analyses.

Chapter 6 concludes the study by summarizing key findings and discussing the potential of coconut husk as a biosorbent for Cu(II) removal. Suggestions for future research and practical applications are also provided.

PROBLEM STATEMENT OF THIS PROJECT

This research established that optimal contact time which will provide the maximum removal of the trivalent chromium form an aqueous solution with a constant value of initial concentration, solution pH, agitation speed, and adsorbent dose. Atomic Absorption Spectroscopy was used to measure the concentration of the filtrated solution. The morphology of the peel elemental composition was observed before and after adsorption by using Scanning Electron Microscope (SEM) and Energy Dispersive X-ray (EDX) respectively.

Chapter 2

Project Methodology

2.1 INTRODUCTION:

There are a few different ways to tackle heavy metals in wastewater—some folks use ion exchange; others go for chemical precipitation. And then there's membrane filtration, which can be pretty effective too. It really depends on the situation, but each method has its pros and cons. These processes are often costly and generate secondary pollution. Agricultural waste materials have great potential due to their natural availability and adsorption capacities. Here aim is to find out the optimal value of contact time for the maximum Copper(II) elimination from aqueous solution by make use of Coconut husk. Coconut husk, an agricultural byproduct abundant in tropical regions, contains lignocellulosic materials and functional groups with a strong attraction for metal ions. The goal is to test how different factors—like the starting concentration of metal ions, pH levels, contact time, and temperature—affect the process. Basically, we're trying to figure out what works best under different conditions. The results of this study will provide to the development of sustainable water treatment solutions that use locally available resources.

2.2 MATERIALS AND INSTRUMENTS:

The following chemicals and instruments will be needed for this research:

- **Coconut Husk:** Collected from local sources and used as the biosorbent after proper preparation.
- **Distilled Water:** Used for cleaning the coconut husk and preparing the copper solution.
- **Chemicals:**
 - (a) Copper(II) Chloride Dihydrate [CuCl₂.2H₂O]
- **Beakers:** Used to contain the adsorption solutions and for conducting the experiments.
- **Electric Oven:** For drying the coconut husk after washing.
- **Grinding or Milling Equipment:** Used to grind the dried coconut husk into fine powder.
- **Analytical Balance:** For precise weighing of the coconut husk and chemicals.
- **pH Meter:** To measure the pH of the aqueous solutions during the experiments.
- **Magnetic Stirrer:** Used to stir the solutions to maintain uniform mixing during the adsorption process.

- **Filter Paper and Funnels:** For separating the coconut husk from the solution after adsorption.
- **Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES):** To compute the concentration of Cu(II) ions in the solution preceding and subsequent of biosorption.
- **Scanning Electron Microscope (SEM) and Energy Dispersive X-ray Spectroscopy (EDS):** To investigate the morphological structure and elemental composition of the coconut husk preceding and subsequent biosorption.

2.3 METHODS OF THE STUDY

The following steps will be followed for completing this research:

2.3.1 Material Selection:

- Selection of the heavy metal to be tested (Divalent Copper ion is selected for this study)
- Coconut husk is selected as an adsorbent.

2.3.2 Pre-treatment and Preparation of Coconut Husk Biosorbent

Fresh coconut husk was collected from local sources and employed as the biosorbent to eliminate Cu(II) ions from the aqueous solution. The preparation process involved the following steps:

1. **Cleaning:** The coconut husk was thoroughly washed with distilled water to eliminate dust, dirt, and additional impurities.
2. **Drying:** After cleaning, the coconut husk was dried in sunlight for 2 days. To ensure complete moisture removal, the husk was then placed in an electric oven.
3. **Grinding:** The coconut husk was dried and then finely ground using a mechanical grinder. The particle size of the powder was adjusted to ensure maximum surface area for biosorption.
4. **Sieving:** The ground coconut husk powder was sieved to remove larger particles and to obtain a uniform size range suitable for biosorption experiments.
5. **Storage:** The prepared coconut husk powder was stored in an airtight container to prevent moisture absorption and contamination before being used in the adsorption experiments.

This preparation ensured that the coconut husk was in an optimal condition for maximum adsorption of Cu(II) ions from the aqueous solutions.



Fig. 2.1: Preparation of coconut husk for biosorption (a) washed and Dried and (b) grinded coconut husk

The preparation process of the coconut husk involved washing, drying, grinding, and sieving to obtain a uniform biosorbent suitable for adsorption experiments. The visual representation of these preparation steps is shown in Figure 2.1.

2.3.3 Preparation of Cu(II) Stock Solution

A stock solution of Cu(II) ions was prepared using Copper(II) sulfate pentahydrate ($\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$) for the biosorption experiments. The preparation process involved the following steps:

- 1. Weighing the Copper Salt:** An accurately weighed amount of 0.035 g of $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ was measured using an analytical balance. This specific quantity was calculated to prepare a solution containing the desired initial concentration of Cu(II) ions for use in the biosorption experiments.
- 2. Dissolution in Distilled Water:** The measured copper chloride was dissolved in distilled water to create a stock solution containing 1000 mg/L of Cu(II). This stock solution was used as the base solution for further dilutions in the biosorption experiments.
- 3. Dilution:** To obtain the desired working concentrations of Cu(II) ions, the stock solution was diluted with distilled water. A volumetric flask was used to ensure precise dilutions. The target concentration was calculated using the formula: $C_1V_1 = C_2V_2$, where C_1 represents the stock solution concentration, V_1 is the volume of the stock solution used, C_2 is the target concentration, and V_2 is the final volume after dilution.
- 4. Storage:** The prepared Cu(II) solution was stored in clean, airtight containers to prevent contamination or evaporation before use in the biosorption experiments.

This method ensured that the Cu(II) solution was prepared with the necessary precision to

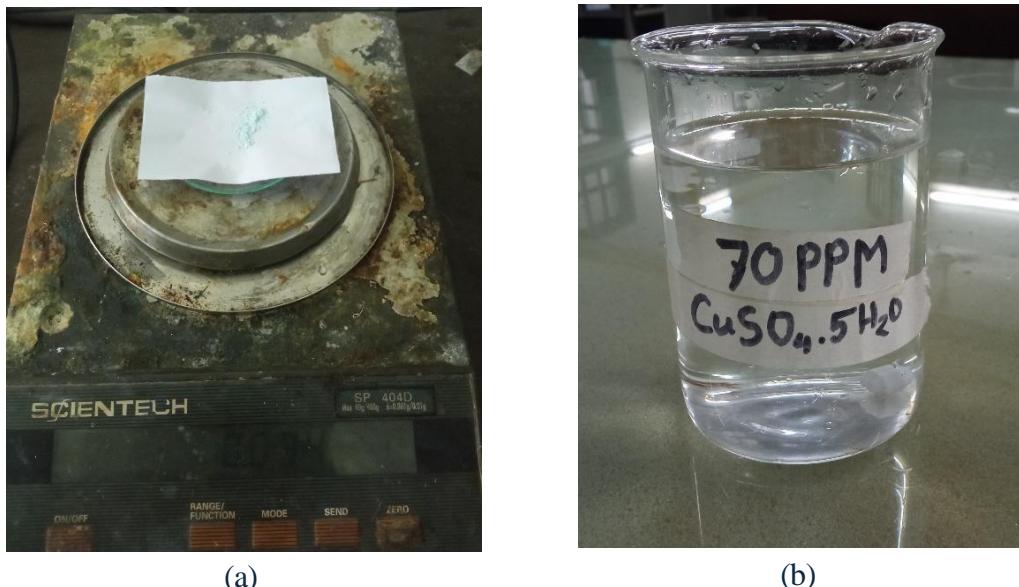


Fig. 2.2: Preparation of metal solution (a) Measuring 0.035 g CuSO₄·5H₂O (b) 70 ppm stock solution preparation using 500mL volumetric flask.

evaluate the adsorption capacity of the coconut husk. The metal solution was prepared by accurately weighing 0.035 g of $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ and dissolving it in distilled water to obtain a 70 ppm stock solution using a 500 mL volumetric flask. The steps involved in the preparation of the Cu(II) stock solution are illustrated in Figure 2.2.

2.3.4 Cu(II) Adsorption Procedure

Batch adsorption experiments were carried out to assess the efficiency of coconut husk as a biosorbent for removing Cu(II) ions from aqueous solutions. The following procedure was followed:

1. **Weighing the Coconut Husk:** A measured quantity 0.4 g of coconut husk powder was accurately weighed using an analytical balance for each experimental setup. The weighed adsorbent was then placed into individual beakers. The required amount of biosorbent was measured accurately using a digital balance to ensure precision in the adsorption experiments. This step is illustrated in Figure 2.3



Fig. 2.3: Weighing the banana peel powder by using digital balance

2. **Preparation of Cu(II) Solution:** A pre-determined volume of the $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ solution with a known concentration (e.g., 70 ppm) was added to the beakers containing the coconut husk powder.
3. **Mixing:** The mixture of Cu(II) solution and coconut husk powder was stirred using a magnetic stirrer at a constant speed (e.g., 200 rpm) to ensure uniform contact between the metal ions and the adsorbent. The $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ solution was prepared by mixing it

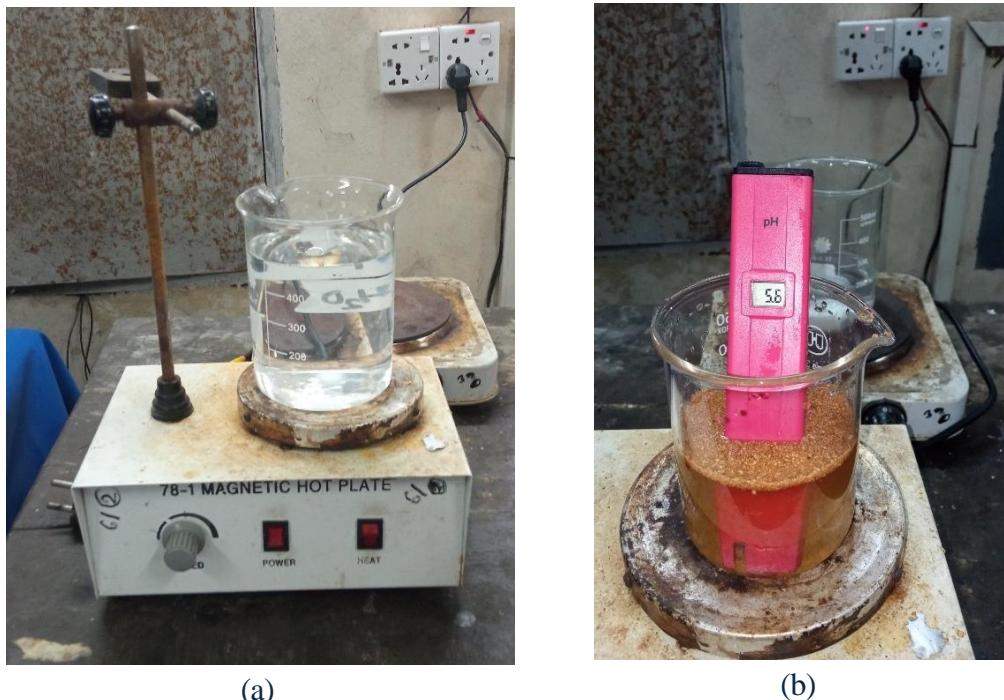


Fig. 2.4: (a) Preparation of $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ solution by mixing with distilled water using a magnetic stirrer. (b) Mixing of coconut husk powder with Cu(II) solution and pH check using a pH meter.

with distilled water using a magnetic stirrer to ensure complete dissolution.

Subsequently, coconut husk powder was added to the metal solution, and the pH was measured and adjusted as needed using a digital pH meter. These steps are demonstrated in Figure 2.4.

4. **Contact Time:** Adsorption experiments were performed at different contact times (15, 30, 45, and 60 minutes) to identify the optimal duration for maximum removal of Cu(II) ions.
5. **Filtration:** At the end of the specified contact time, the coconut husk powder was separated from the solution through filtration using filter paper, and the filtrate was collected for further analysis. After the biosorption process, the Cu(II) solution was filtered at predetermined contact times of 15, 30, 45, and 60 minutes to separate the coconut husk biosorbent from the solution. The filtration process at these intervals is illustrated in Figure 3.5.

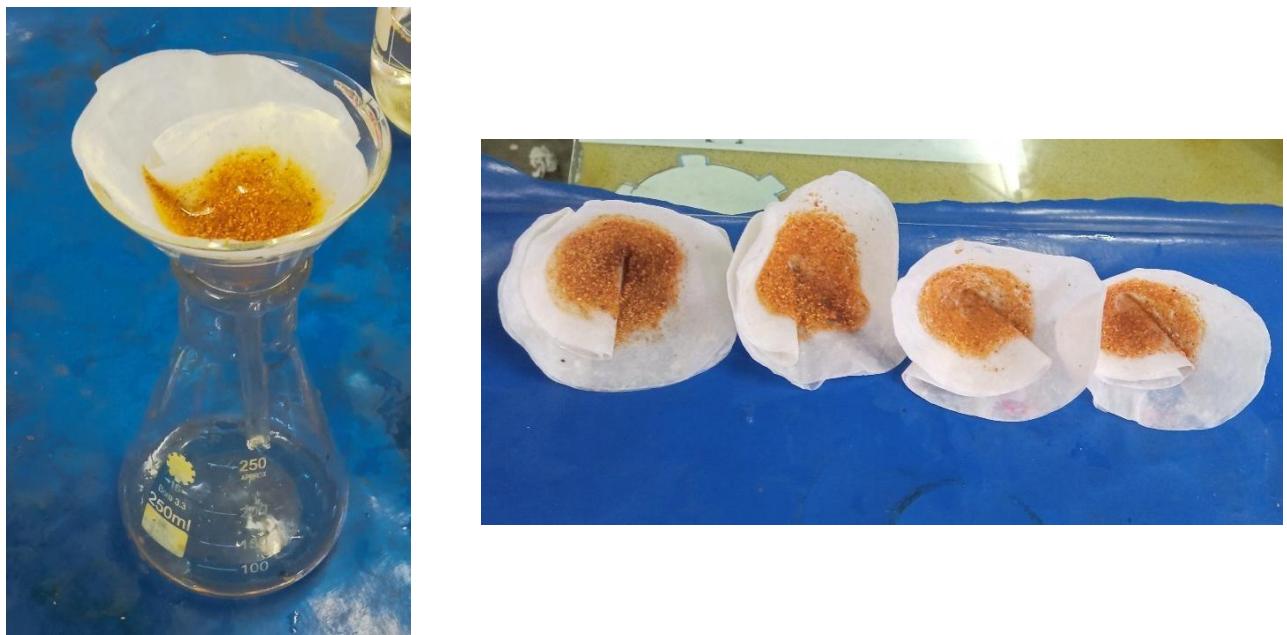


Fig. 2.5: Filtration of Cu(II) solution after biosorption at different contact times: 15, 30, 45, and 60 minutes.

6. **Analysis of Residual Cu(II) Concentration:** The remaining concentration of Cu(II) ions in the solution after biosorption was measured using Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES). This data was used to calculate both the percentage removal of Cu(II) and the adsorption capacity of the coconut husk.
7. **SEM and EDS Analysis:** The coconut husk powder was collected after adsorption for morphological and elemental analysis using Scanning Electron Microscopy (SEM) and Energy Dispersive X-ray (EDS) spectroscopy to observe the surface changes and Cu(II) adsorption.

This experimental setup was repeated for different initial concentrations of Cu(II) ions, pH levels, and temperatures to investigate the factors influencing biosorption performance. The



Fig. 2.6: (a) Residual $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ solution after filtration at different time intervals, showing variation in color intensity. (b) Coconut husk powder before and after Cu(II) biosorption, indicating visual changes due to metal ion adsorption.

residual Cu(II) solutions collected after filtration at various contact times showed noticeable changes in color intensity, indicating progressive removal of copper ions over time. Additionally, visual differences were observed in the coconut husk powder before and after biosorption, reflecting the adsorption of Cu(II) onto the biosorbent surface. These observations are presented in Figure 2.6.

2.3.5 Analytical Techniques

To evaluate the efficiency of coconut husk as a biosorbent for Cu(II) ions, a series of analytical techniques and calculations were employed during the study. These methods ensured the accurate determination of biosorption performance and supported the analysis of experimental results.

1. Measurement of Initial Concentration (C_i): The initial concentration of Cu(II) ions in the prepared stock solution was determined using Equation 2.1:

$$C_i = \frac{w}{V} \quad 2.1$$

Where:

- C_i = Initial concentration (mg/L or ppm)
- w = Mass of pure $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ (mg)
- V = Volume of solution (L)

2. Solution Dilution Using Ostwald's Dilution Law: To obtain the desired working concentrations of Cu(II) from the stock solution, dilutions were made using Ostwald's dilution law, given by Equation 2.2:

$$C_1V_1 = C_2V_2 \quad 2.2$$

Where:

- C_1, V_1 = Concentration and volume before dilution
- C_2, V_2 = Desired concentration and final volume after dilution

3. Measurement of Final Concentration (C_f): The final concentration of Cu(II) ions after biosorption was measured using Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES). This allowed accurate quantification of the remaining Cu(II) ions in the solution post-adsorption.

4. Determination of Removal Efficiency: The percentage of Cu(II) removed from the solution was calculated for each sample using Equation 2.3:

$$\text{Removal Efficiency (\%)} = \frac{C_i - C_f}{C_i} \times 100 \quad 2.3$$

Where:

- C_i = Initial Cu(II) concentration (mg/L)
- C_f = Final Cu(II) concentration after biosorption (mg/L)

5. Determination of Adsorption Capacity (q_t): The amount of Cu(II) adsorbed per unit mass of coconut husk was determined using Equation 3.4:

$$q_t = \frac{C_i - C_f}{M} \times V \quad 2.4$$

Where:

- q_t = Adsorption capacity at time t (mg/g)
- C_i = Initial Cu(II) concentration (mg/L)
- C_f = Final Cu(II) concentration at time t (mg/L)
- V = Volume of solution (L)
- M = Mass of biosorbent (g)
- **Surface and Elemental Analysis (Optional but Recommended):** To support the adsorption results, Scanning Electron Microscopy (SEM) and Energy-Dispersive X-ray Spectroscopy

(EDS) were used to analyze the surface morphology and confirm Cu(II) binding on the coconut husk.

- SEM helped visualize surface texture changes before and after adsorption.
- EDS confirmed the presence of Cu(II) on the biosorbent by detecting copper peaks in the spectrum.

2.3.6 Data Analysis

The data was statistically analyzed using the Langmuir and Freundlich isotherm models to explain the adsorption mechanism.

2.3.6.1 Langmuir isotherm

The Langmuir isotherm is a mathematical framework that explains how gas molecules adsorb onto a solid surface. This model is based on the premise that biosorption happens on a uniform surface with a limited number of identical adsorption sites. It also assumes that once a site is occupied, no additional adsorption can occur at that specific site, indicating a monolayer adsorption process. The Langmuir isotherm can be represented by the following equation:

$$\frac{C_e}{q_e} = \frac{1}{q_m k_L} + \frac{C_e}{q_m} \dots \dots \dots \dots \quad (2.5)$$

Where:

- C_e = Equilibrium concentration of Cu(II) ions in the solution (mg/L)
- q_e = Amount of Cu(II) adsorbed per unit mass of coconut husk at equilibrium (mg/g)
- q_m = Maximum monolayer adsorption capacity of the biosorbent (mg/g)
- k_L = Langmuir constant related to the affinity of binding sites (L/mg)

The Langmuir isotherm equation was linearized and plotted as $\frac{C_e}{q_e}$ versus C_e , and the slope and

intercept of the straight line were used to determine the values of q_m and k_L .

The correlation coefficient (R^2) was utilized to assess the suitability of the experimental data in relation to the Langmuir isotherm model. An R^2 value near 1 signifies a strong fit, indicating that the adsorption of Cu(II) ions onto coconut husk aligns with the Langmuir model and takes place as a monolayer on a uniform surface.

2.3.6.2 Freundlich isotherm

The Freundlich isotherm model was used to characterize the adsorption of Cu(II) ions onto coconut husk. In contrast to the Langmuir isotherm, the Freundlich model assumes that adsorption takes place on a heterogeneous surface, allowing for the formation of multiple adsorption layers, with binding sites exhibiting varying affinities. This model is expressed by the following equation:

$$\ln(q_e) = \ln(K_F) + \frac{1}{n} \ln(C_e) \dots \quad (2.8)$$

Where:

2.3.6.2.1 q_e = Amount of Cu(II) adsorbed per unit mass of coconut husk at equilibrium (mg/g)

2.3.6.2.2 C_e = Equilibrium concentration of Cu(II) ions in the solution (mg/L)

2.3.6.2.3 K_F = Freundlich constant related to adsorption capacity ((mg/g)(L/mg)^{1/n})

2.3.6.2.4 n = Freundlich constant related to adsorption intensity (dimensionless)

The Freundlich equation was linearized by plotting $\ln(q_e)$ versus $\ln(C_e)$, resulting in a straight line. The slope and intercept of this line were used to determine the values of K_F and n :

$$2.3.6.2.5 \dots \text{Slope } (m) = \frac{1}{n} \dots \quad (2.9)$$

$$2.3.6.2.6 \dots \text{Intercept } (c) = \ln(K_F) \quad (2.10)$$

The correlation coefficient (R^2) was determined to evaluate the alignment of the experimental data with the Freundlich isotherm model. A high R^2 value signifies a strong fit, indicating that the adsorption process takes place on a heterogeneous surface with varying adsorption intensities.

2.4 FLOW CHART OF THE WORKING PROCESS

The whole working process is shown in Fig.2.1 with a flow diagram.

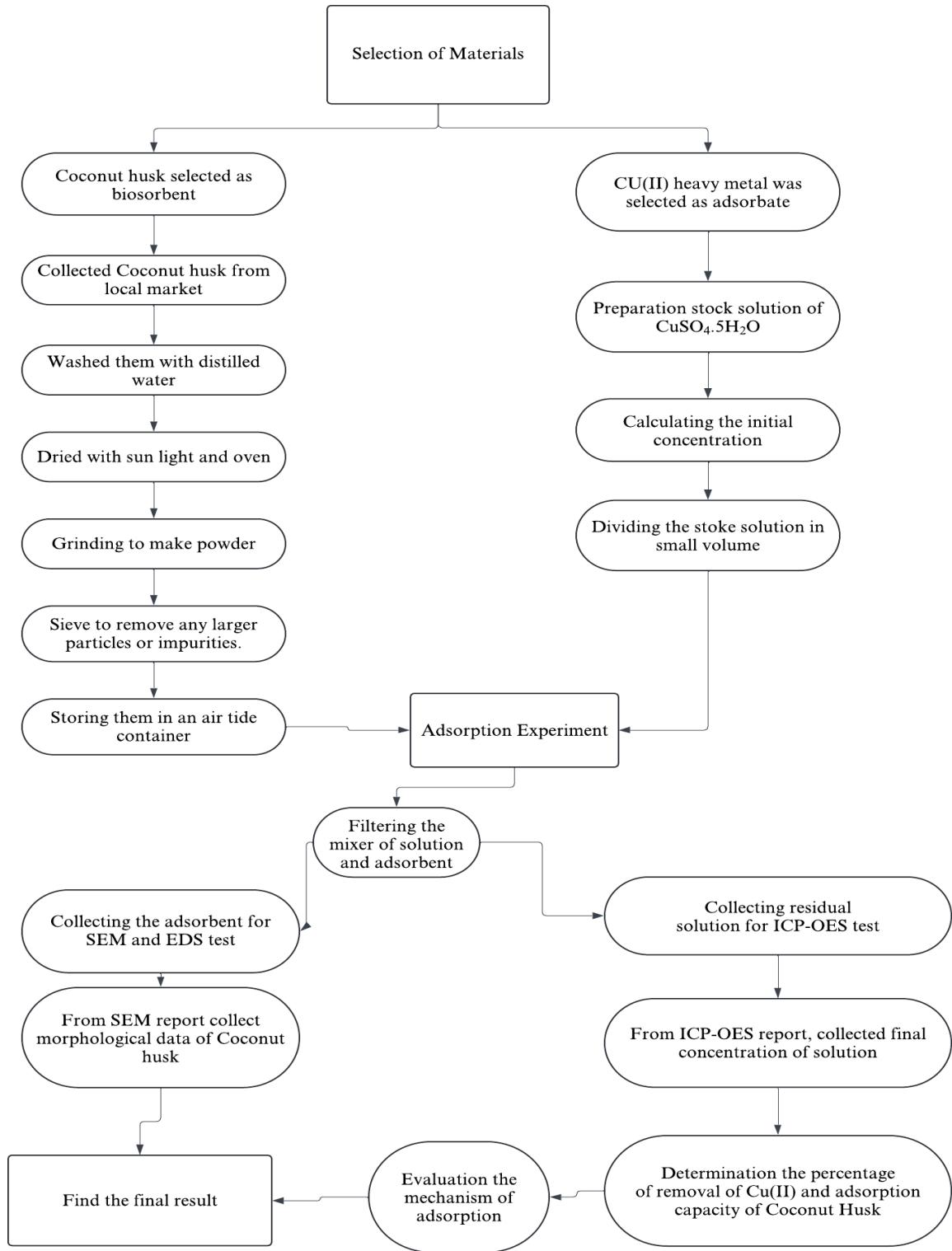


Fig 2.7 : Flow Chart of Working Process.

Chapter 3

Data Collection

The initial concentration of the solution was determined based on the mass of Copper(II) sulfate pentahydrate and the volume of the prepared solution. Experimental parameters such as pH, agitation speed, adsorbent dose, and temperature were recorded during the experimental setup and analyzed through graphical methods. The final concentration of copper ions in the solution was measured using Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES) at the Department of Chemistry, CUET. Additionally, Scanning Electron Microscopy (SEM) images and Energy Dispersive X-ray Spectroscopy (EDS) data were obtained from KUET for surface characterization. Data comparison and graphical representations were performed using Microsoft Excel.

3.1 METHOD OF DATA COLLECTION

- An accurate amount of Copper(II) sulfate pentahydrate ($\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$) and the required dose of coconut husk biosorbent were measured using a 3-digit analytical balance to ensure precise mass values.
- A 500 mL volumetric flask was used to prepare the stock solution of Cu(II) ions. The salt was dissolved in distilled water, and the solution was mixed thoroughly using a magnetic stirrer to ensure complete dissolution.
- The agitation speed during the biosorption experiments was recorded from the digital display of the magnetic stirrer, which maintained consistent mixing of the solution throughout the contact period.
- The pH of the Cu(II) solution was measured and adjusted using a digital pH meter before and during the adsorption process. The pH was maintained within an optimal range to maximize biosorption efficiency.
- The final concentration of Cu(II) ions in the solution after biosorption was determined using an Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES)



Fig. 3.1: Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES)

instrument. ICP-OES provides high sensitivity and accuracy for detecting trace levels of metal ions in aqueous solutions. The instrument setup is shown in Figure 3.1.

- To study the morphological characteristics of the biosorbent, **Scanning Electron Microscopy (SEM)** was used to capture images of the coconut husk surface at magnifications of **1 kX, 3 kX, and 5 kX** before and after biosorption.
- The elemental composition of the coconut husk was further examined using **Energy-Dispersive X-ray Spectroscopy (EDS)**. This technique confirmed the presence of Cu(II) ions on the biosorbent surface, validating the effectiveness of biosorption.



Fig. 4.2: Scanning Electron Microscope (SEM)

The SEM instrument used in this analysis is shown in Figure 3.2.

4.1 Data Collection and Calculation

The collected data and calculated results for the biosorption of Cu(II) using coconut husk are presented below.

3.1.1 Initial Concentration

To prepare the stock solution, an accurately weighed amount of 0.035 g of Copper(II) sulfate pentahydrate ($\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$) was used.

Volume of the aqueous solution prepared = 500 mL or 0.5 L

The concentration of the stock solution was calculated using Equation 3.1:

$$C_i = \frac{w}{V} = \frac{35 \text{ mg}}{0.5 \text{ L}} = 70 \text{ ppm}$$

Therefore, the initial concentration (C_i) of the Cu(II) solution was 70 ppm.

3.1.2 Final Concentration

The final concentrations (C_f) of Cu(II) remaining in the solution after the biosorption process were measured using Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES). These values were recorded for each contact time and biosorbent dose and are summarized in Table 3.1.

Table 3.1 Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES) report made by UCRL, Chemistry Department, CUET.

Sample No.	Final Concentration (ppm)
01	7.751
02	6.745
03	6.219
04	5.603

Chapter 4

Result and Analysis

4.1 Determination of Percentage of Removal and Adsorption Capacity

The percentage of Cu(II) removal from aqueous solution and the corresponding adsorption capacity of coconut husk were determined using Equations 3.3 and 3.4, respectively. These equations take into account the initial concentration (C_i), final concentration (C_f), solution volume, and the mass of biosorbent used. The calculated results are presented in Table 5.1.

Table 4.1 Determination of percentage of removal and adsorption capacity.

Contact Time (min)	Initial Concentration C_i (ppm)	Final Concentration C_f (ppm)	Percentage of Removal (%)	Adsorption Capacity q_t (mg/g)
15	70.00	7.751	88.92714	15.56225
30	70.00	6.745	90.36428	15.81375
45	70.00	6.219	91.11571	15.94525
60	70.00	5.603	91.99571	16.09925

4.1 RESULT ANALYSIS

4.1.1 Effect of Contact Time

Contact time is a critical factor influencing the efficiency of biosorption. As observed in the results, both percentage of Cu(II) removal and adsorption capacity increased with contact time, indicating enhanced interaction between the Cu(II) ions and the active sites of the coconut husk surface. This trend is presented numerically in Table 4.2.

Table 4.2 Effect of contact time.

Contact Time (min)	Percentage of Removal (%)	Adsorption Capacity (mg/g)
15	88.92714	15.56225
30	90.36428	15.81375
45	91.11571	15.94525
60	91.99571	16.09925

These findings are also graphically represented in Figure 5.1, which shows a gradual increase in removal efficiency and adsorption capacity with time, reaching a near-equilibrium state around 60 minutes. This indicates that 60 minutes may be considered the optimal contact time under the studied conditions.

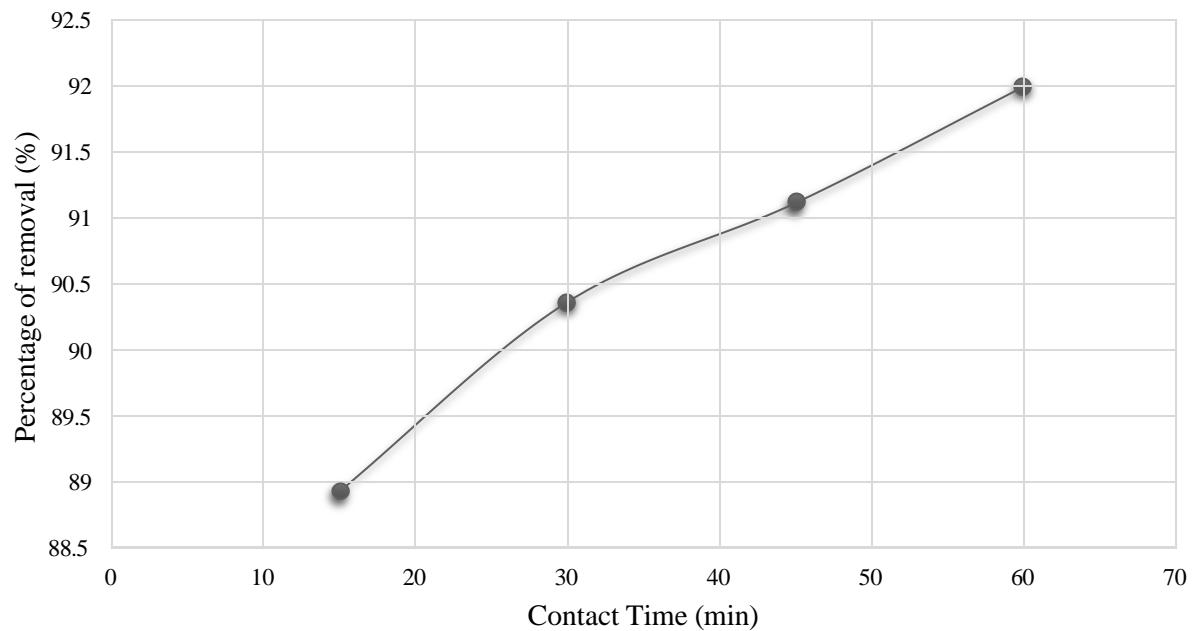


Fig. 4.1 Effect of contact time on percentage of removal of Copper.

The effect of contact time on the adsorption capacity of coconut husk is graphically represented in Figure 4.2.

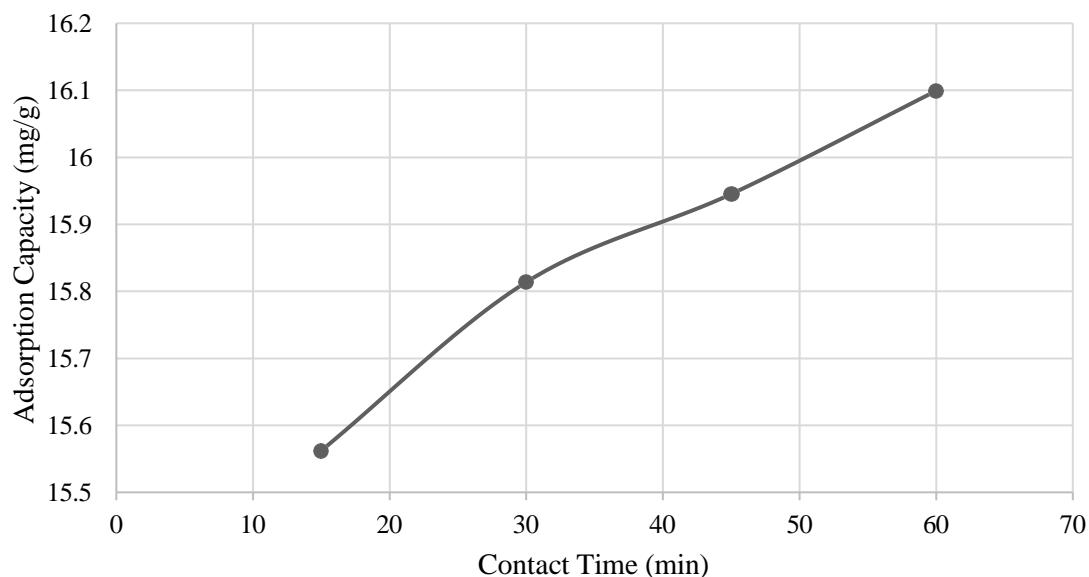


Fig. 4.2 Effect of contact time on adsorption capacity of Coconut husk.

4.1.1.1 Optimal Value of Contact Time

By analyzing the results presented in Table 4.2, as well as Figures 4.1 and 4.2, it is observed that the maximum percentage of Cu(II) removal was achieved at a contact time of 60 minutes, with a removal efficiency of 91.99%. At this same contact duration, the adsorption capacity of coconut husk reached its highest value of 16.10 mg/g, which means that 1 gram of coconut husk biosorbent can adsorb approximately 16.10 mg of Cu(II) ions from aqueous solution under optimal conditions.

This indicates that equilibrium between Cu(II) ions and the active binding sites on the coconut husk surface was effectively reached at 60 minutes. Beyond this time, no significant increase in removal was observed, suggesting saturation of available adsorption sites.

The experiment was conducted under controlled conditions:

- Temperature: 27°C
- pH: 5.6
- Adsorbent dose: 0.4 g
- Solution volume: 100 mL
- Initial Cu(II) concentration: 70 ppm

The observed trend confirms that contact time plays a critical role in biosorption performance. Initially, the adsorption rate is rapid due to the abundance of vacant active sites. However, as time progresses, the rate slows down as the sites become occupied, leading to equilibrium. The findings validate that 60 minutes is the optimal contact time for maximum Cu(II) removal using coconut husk under the given conditions.

This optimal contact time will be used as a standard parameter in subsequent experiments involving variation of other factors such as pH, adsorbent dose, and initial metal concentration.

4.1.2 SEM and EDX Report Analysis

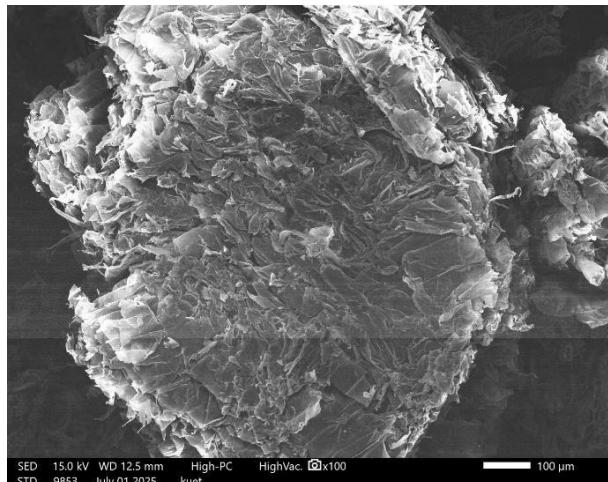
To gain deeper insight into the surface morphology and elemental composition of the biosorbent, Scanning Electron Microscopy (SEM) and Energy-Dispersive X-ray Spectroscopy (EDS) analyses were performed on coconut husk samples both before and after Cu(II) biosorption. These analyses provide crucial supporting evidence for the adsorption mechanism and confirm the successful binding of copper ions onto the biosorbent surface.

SEM offers high-resolution images that reveal changes in surface structure, porosity, and texture of the coconut husk as a result of metal ion interaction. In parallel, EDX analysis identifies and quantifies the elemental composition of the biosorbent, confirming the presence of copper and other associated elements. The comparative SEM images enable visual

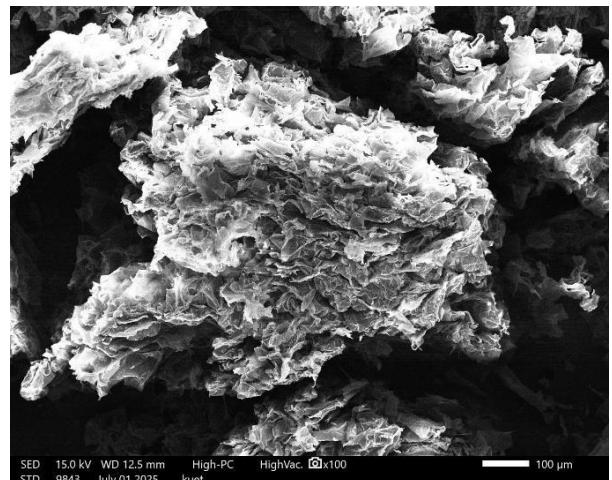
assessment of surface modifications, while EDS spectra validate the adsorption of Cu(II) ions by detecting copper peaks in the post-adsorption sample.

4.1.2.1 SEM Report Analysis

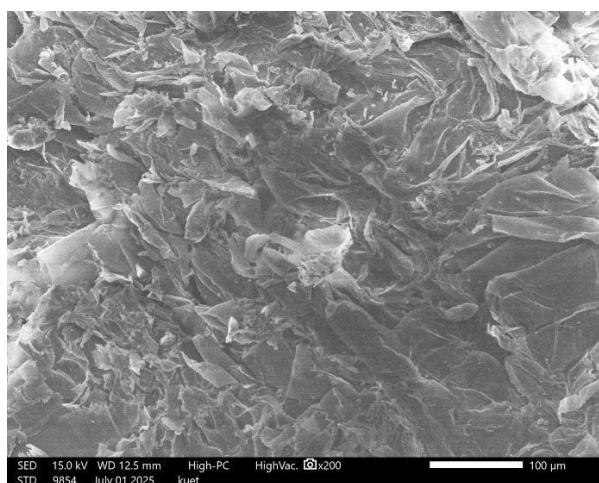
Here added some images of SEM test in Fig. 4.3.



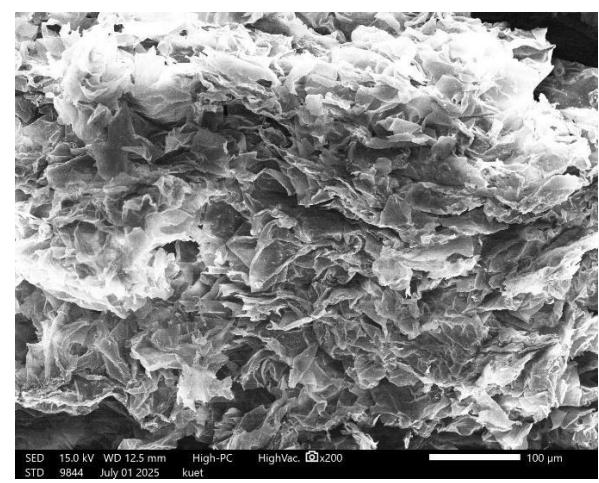
(a) Before adsorption (100 X)



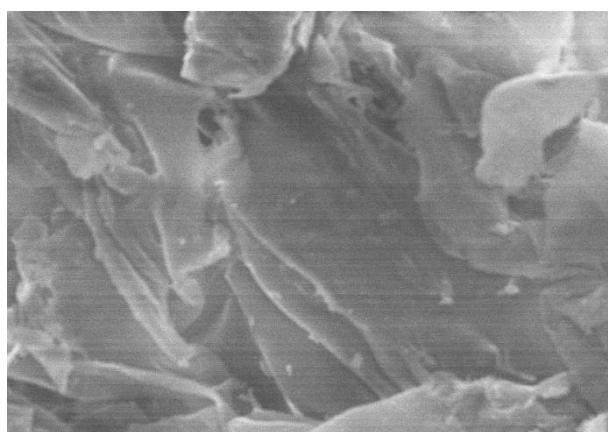
(b) After adsorption (100 X)



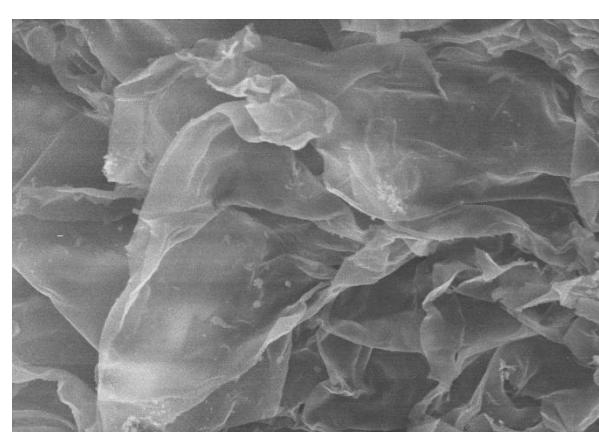
(c) Before adsorption (200 X)



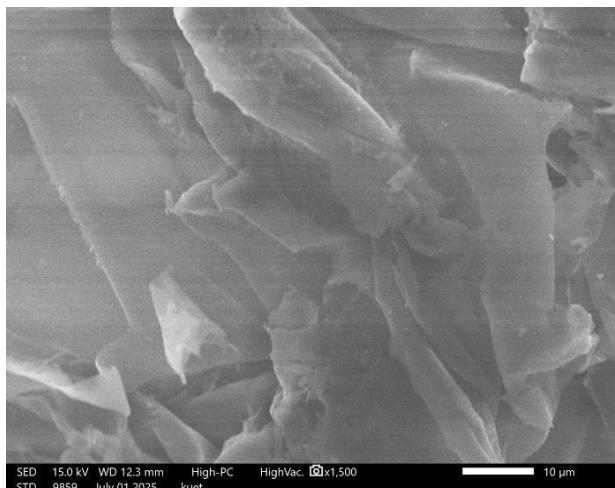
(d) After adsorption (200 X)



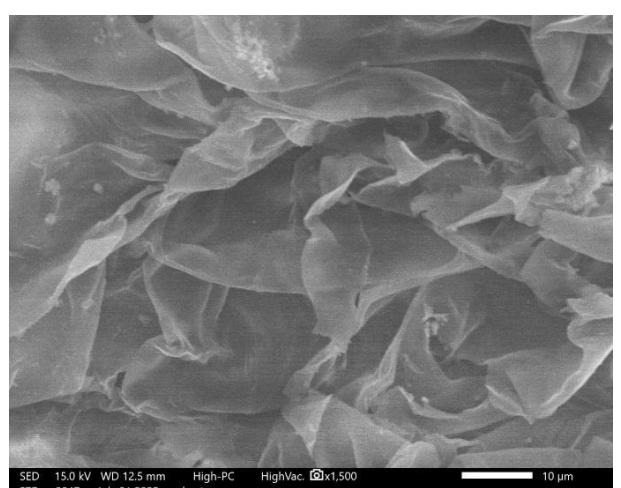
(e) Before adsorption (1.00 kX)



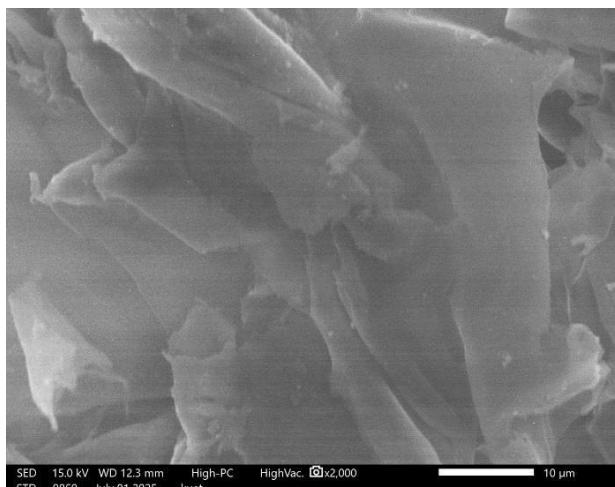
(f) After adsorption (1.00 k X)



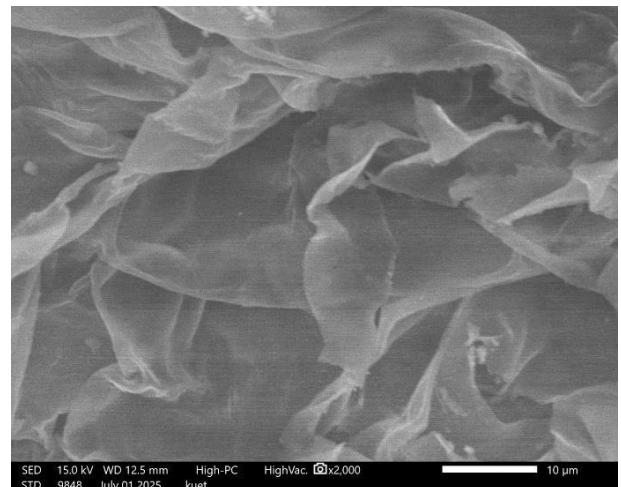
(g) Before adsorption (1.50 kX)



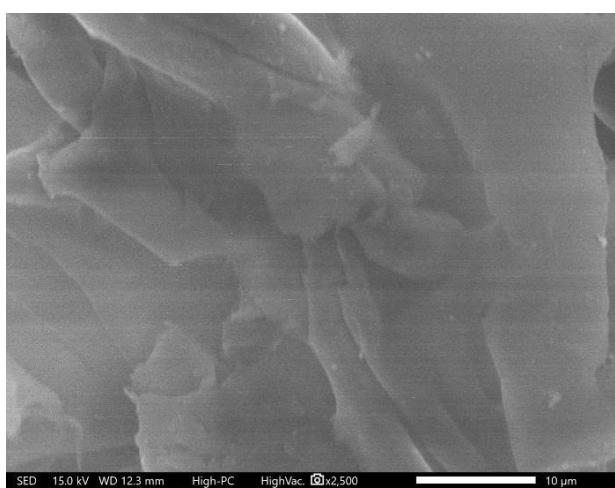
(h) After adsorption (1.50 kX)



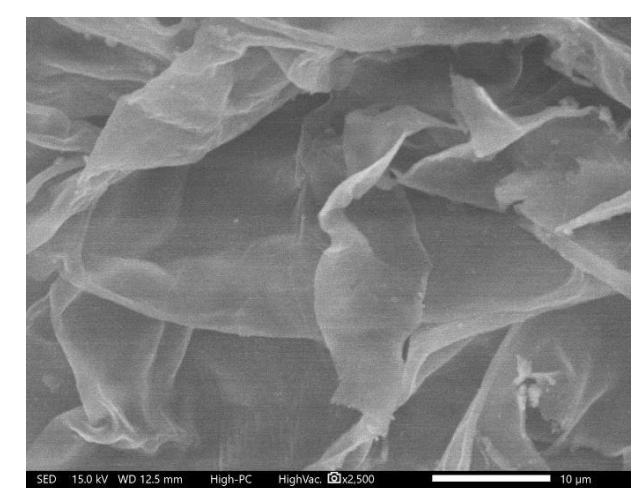
(i) Before adsorption (2.00 kX)



(j) After adsorption (2.00 kX)



(k) Before adsorption (2.50 kX)



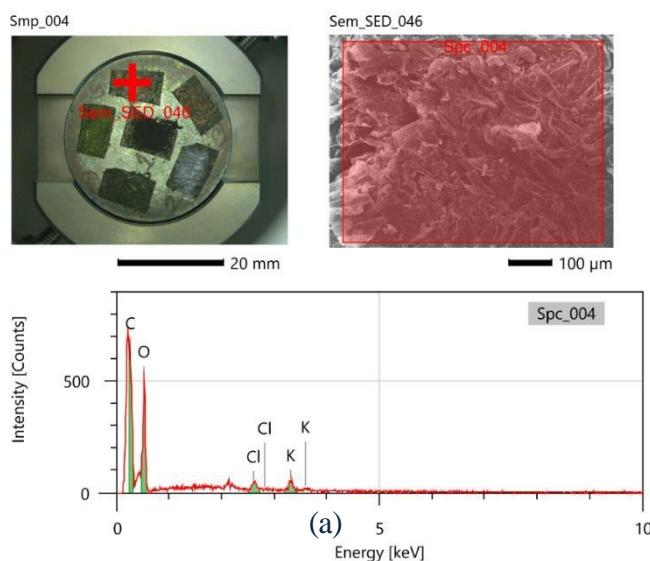
(l) After adsorption (2.50 kX)

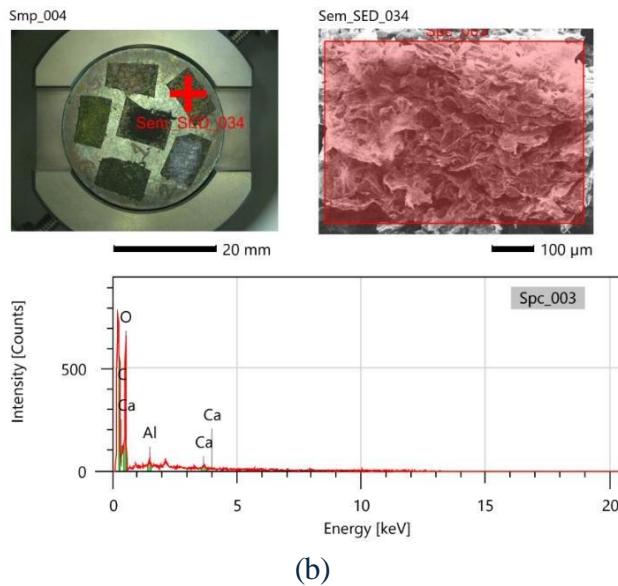
Fig. 4.3: SEM images of Coconut husk before and after adsorption

In Fig. 4.3, (a), (c), (e), (g), (i), (k) indicates that before adsorption the surface of coconut husk particle was rough and irregular shape, microporous with vast heterogeneity which could enhance the adsorption . (b), (d), (f), (h), (j), (l) denotes the coconut husk particle surface after bioadsorption . It reveals the surface has become regular, smooth, and filled up. It is evident that adsorption has taken place on the surface of coconut husk particle as the surface is with little or no spore.

4.1.2.2 EDS Report Analysis

Energy-Dispersive X-ray Spectroscopy (EDS) was conducted to determine the elemental composition of the coconut husk biosorbent before and after Cu(II) biosorption. This analysis provides qualitative and semi-quantitative information about the elements present on the surface of the biosorbent, thereby confirming the uptake of copper ions. In the EDS spectrum of the raw coconut husk (before adsorption), major peaks corresponding to elements such as carbon (C), oxygen (O), and potassium (K) were observed, which are consistent with the natural lignocellulosic structure of the biomass. These elements originate from cellulose, hemicellulose, and lignin components of the coconut husk. After Cu(II) biosorption, the EDS spectrum of the treated coconut husk displayed distinct copper (Cu) peaks, indicating successful adsorption of Cu(II) ions onto the biosorbent surface. A noticeable increase in copper content was detected, while minor shifts in other elemental intensities were also observed, suggesting ion exchange or surface complexation mechanisms. The appearance of Cu peaks in the post-adsorption spectrum provides direct evidence of metal ion accumulation on the biosorbent. This supports the assumption that coconut husk contains active functional groups capable of binding with heavy metal ions and confirms its potential as a cost-effective and environmentally friendly biosorbent. The EDX report is added below in Fig. 5.4.





(b)

Fig. 5.4: EDS report (a) Before adsorption (b)
After adsorption

4.1.2.2.1 Possible Reasons for the Absence or Low Detection of Copper in EDS Spectrum

Although copper biosorption was confirmed through other analytical methods (e.g., ICP-OES), the EDS spectrum of the coconut husk after biosorption did not show a clearly identifiable Cu peak in the selected scan region. This may be attributed to several experimental or physical factors, which are detailed below:

4.1.2.2.1.1 Surface Covered by Contaminants or Oxide Layers: The EDS report (Spc_003) showed high concentrations of oxygen (68.36%) and carbon (28.83%), indicating the presence of a thick organic or oxide-based surface layer. Such layers can form naturally from environmental exposure or as a result of biosorption byproducts. These surface coatings may absorb or attenuate the X-rays emitted by the underlying Cu atoms, thereby masking their signal. For instance, if Cu(II) ions are embedded beneath a layer of organic matter or bonded within calcium carbonate (CaCO_3) or aluminum oxide (Al_2O_3) complexes, the EDS detector may primarily register the outer matrix and not the embedded Cu.

4.1.2.2.1.2 Low or Localized Copper Distribution: If copper is present in very small quantities, as thin coatings, dispersed nanoparticles, or trapped beneath the surface, it may fall below the detection threshold of EDS—particularly if the local concentration is below ~0.5% by weight. Additionally, the detection is sensitive to the spot chosen for analysis. If the

EDS beam does not strike a Cu-rich region in a heterogeneous sample, the Cu signal may be absent.

4.1.2.2.1.3 Overlapping or Hidden Cu Peaks: The characteristic X-ray energy for copper (Cu-K α \approx 8.0 keV) lies within the 0–20 keV spectrum range used in the scan. However, the Cu peak may be:

4.1.2.2.1.3.1 Too small or weak, blending into the background noise

4.1.2.2.1.3.2 Overlapped by other element peaks

4.1.2.2.1.3.3 Suppressed due to matrix effects, where nearby heavier elements or high background count interfere with Cu detection

4.1.2.2.1.4 Instrumental and Operational Limitations: Though the beam energy of 15 kV is typically sufficient to excite Cu, the detector's sensitivity, resolution, and calibration play a crucial role in identifying trace elements. Additional issues may arise from:

4.1.2.2.1.4.1 Inadequate background subtraction

4.1.2.2.1.4.2 Sample charging, especially if the sample was not properly coated or grounded

4.1.2.2.1.4.3 Suboptimal detector efficiency at the energy range of Cu signals

4.1.2.2.1.5 Sample Preparation and Spot Selection Issues: The absence of Cu peaks might also result from sample preparation artifacts, such as:

4.1.2.2.1.5.1 Surface oxidation during drying or handling

4.1.2.2.1.5.2 Presence of debris, coatings, or biofilm blocking detection

4.1.2.2.1.5.3 The selected spot falling on a Cu-deficient region in a non-uniform sample

4.1.3 Adsorption Isotherm

The equilibrium adsorption isotherm study was conducted to understand the adsorption mechanism of Cu(II) ions onto coconut husk.

4.1.3.1 Langmuir Isotherm Analysis

Among the available models, the Langmuir isotherm is commonly used to describe monolayer adsorption on a surface with a finite number of identical homogeneous binding sites. It assumes that once a metal ion occupies a site, no further adsorption can occur at that site.

The linear form of the Langmuir isotherm equation is given as:

$$\frac{C_e}{q_e} = \frac{C_e}{q_m} + \frac{1}{q_m K_L} \quad 4.1$$

This equation can be compared with the linear equation format $y = mx + c$, where:

$$\text{Slope } m = \frac{1}{q_m} \quad 4.2$$

$$\text{Intercept } c = \frac{1}{q_m K_L} \quad 4.2$$

A graph of C_e/q_e vs. C_e was plotted and is shown in Figure 4.5. The trendline equation and its parameters were determined using the graph.

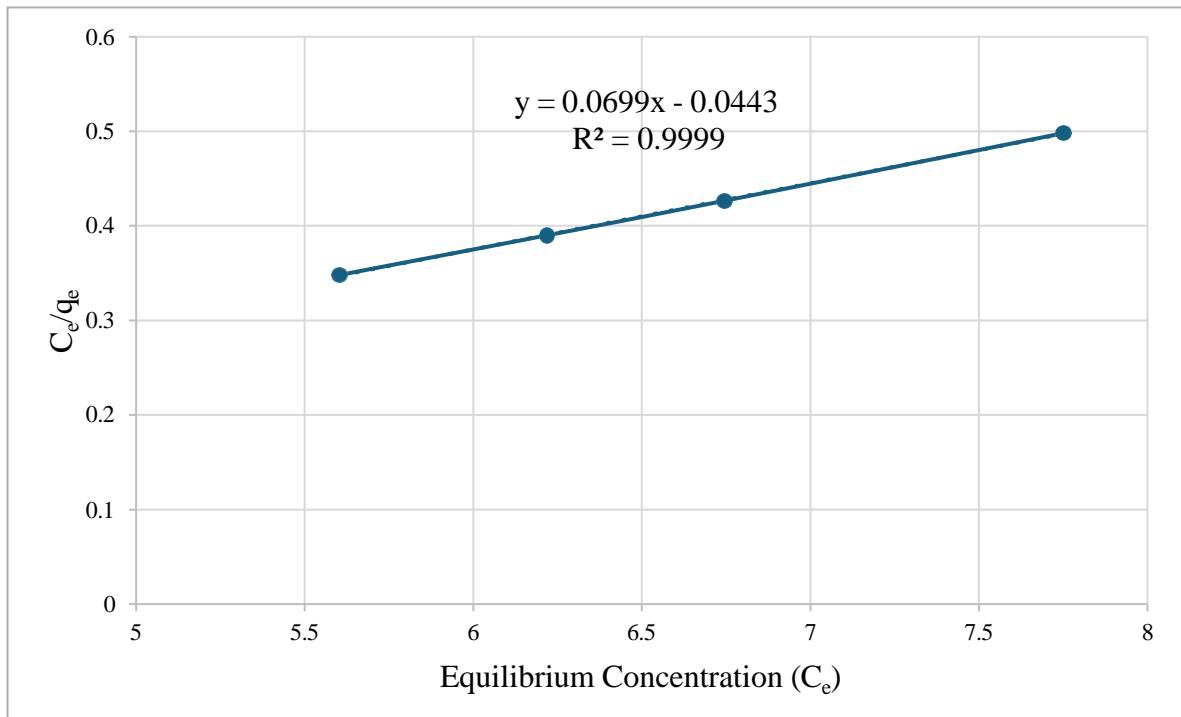


Fig. 4.5: Langmuir isotherm

Analysis of Langmuir isotherm graph using equations 4.1, 4.2 and 4.3 in Table 4.3.

Table 4.3 Analysis of Langmuir isotherm graph.

Equation of trendline configured from Langmuir isotherm graph: $y = 0.0699x - 0.0443$		
Slope = 0.0699		Intercept = - 0.0443
R^2	K_L (mg/L)	q_m (mg/g)
0.9999	1.5779	14.306

The correlation coefficient is 0.9999 is very near to 1 and it indicates that the Langmuir isotherm is well fitted with this experimental data. Maximum adsorption capacity is 14.306 mg/g.

4.2.3.2 Freundlich Isotherm Analysis

The Freundlich isotherm model was applied to further investigate the adsorption behavior of Cu(II) ions on the surface of coconut husk. Unlike the Langmuir model, which assumes monolayer adsorption on a homogeneous surface, the Freundlich isotherm is an empirical model that describes multilayer adsorption on heterogeneous surfaces with a non-uniform distribution of adsorption heat and affinities.

The linear form of the Freundlich isotherm equation (equation 3.5) is expressed as:

$$\ln q_e = \frac{1}{n} \ln C_e + \ln K_F$$

By comparing this with the general linear equation $y = mx + c$, the following interpretations can be made:

$$\text{Slope, } m = \frac{1}{n} \quad 4.4$$

$$\text{Intercept, } c = \ln K_F \quad 4.5$$

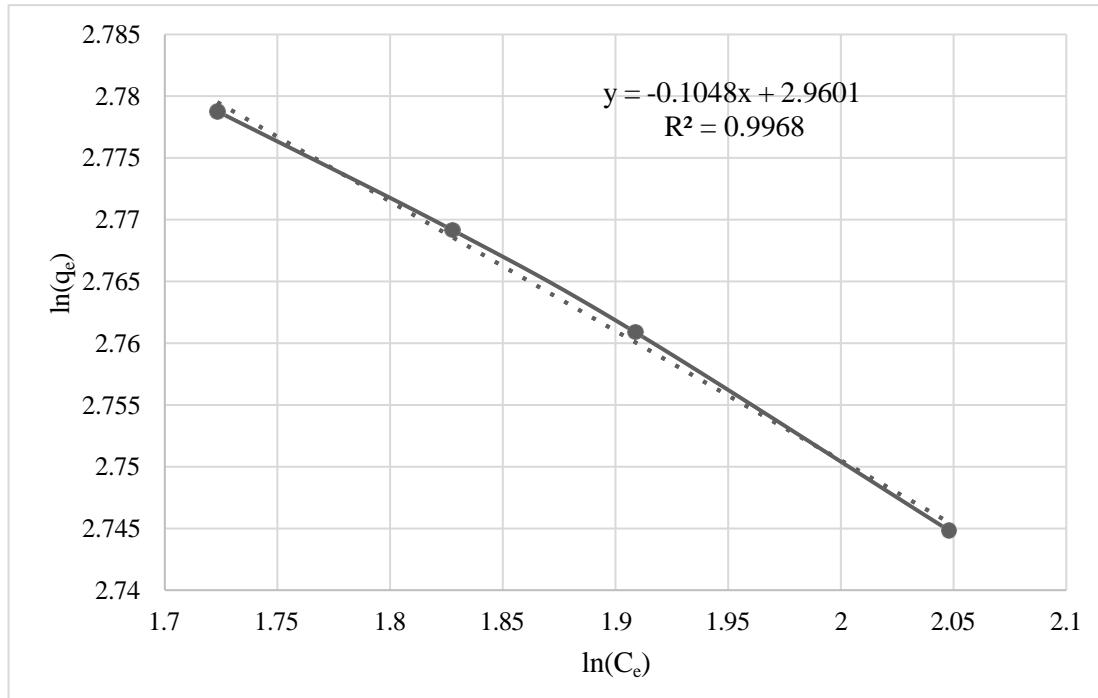


Fig. 4.6 Freundlich isotherm

The fitted graph representing the Freundlich isotherm is shown in Figure 4.6.

Analysis of Freundlich isotherm graph using equations 4.4 and 4.5 in Table 4.4.

Table 4.4 Analysis of Freundlich isotherm graph.

Equation of trendline configured from Freundlich isotherm graph: $y = -0.1048x + 2.9601$		
Slope = -0.1048		Intercept = 2.9601
R^2	K_F (mg/g)	n
0.9968	19.2999	9.54198

The correlation coefficient $R^2=0.9968$ demonstrates a strong linear relationship between $\ln(q_e)$ and $\ln(C_e)$, suggesting that the Freundlich model fits the experimental data reasonably well. However, when compared with the Langmuir model ($R^2=0.9999$), the Langmuir isotherm shows a slightly better fit, indicating that the biosorption of Cu(II) onto coconut husk primarily occurs via monolayer adsorption on a homogeneous surface.

Chapter 5

Conclusion

In this study, coconut husk has demonstrated notable potential as a low-cost, eco-friendly biosorbent for the effective removal of copper ions (Cu(II)) from aqueous solutions. The natural lignocellulosic structure of coconut husk—comprising cellulose, hemicellulose, lignin, and various functional groups—contributed significantly to its biosorption capacity. The biosorption efficiency was evaluated under various experimental parameters, including solution pH, contact time, initial concentration, biosorbent dose, and temperature. Among these, contact time was found to be a critical factor influencing both removal efficiency and adsorption capacity. From the experimental results, the maximum Cu(II) removal efficiency was found to be 91.99% at a contact time of 60 minutes, with a corresponding adsorption capacity of 16.10 mg/g. The optimal conditions under which these results were achieved included a pH of 5.6, temperature of 27°C, adsorbent dose of 0.4 g per 100 mL, and an initial Cu(II) concentration of 70 ppm. SEM and EDS analyses provided insight into the morphological and elemental changes in the biosorbent surface before and after biosorption. SEM images revealed structural alterations and surface roughness due to Cu(II) accumulation, while EDS spectra confirmed the presence of copper on the biosorbent surface post-adsorption. The adsorption data were further analyzed using Langmuir and Freundlich isotherm models. The Langmuir model showed a slightly better fit to the experimental data with a high correlation coefficient ($R^2 = 0.9999$), indicating that Cu(II) adsorption occurred via monolayer adsorption on a homogeneous surface. The Freundlich model also fit well ($R^2 = 0.9968$), supporting the potential heterogeneity in surface sites, although Langmuir was more dominant in describing the adsorption mechanism.

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