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PREPARATION AND CHARACTERIZATION OF TIMBER MILL SAWDUST DERIVED BIOCHAR FOR REMOVAL OF LEAD AND METHYLENE BLUE FROM DRINKING WATER

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DISSERTATION SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE BACHELOR OF SCIENCE HONORS DEGREE IN CHEMICAL TECHNOLOGY

JUNE 2026

APPROVAL FORM

The undersigned certify that they have supervised, read and recommended the Bindura University of Science Education for the acceptance of a research project entitled

PREPARATION AND CHARACTERIZATION OF TIMBER MILL SAWDUST DERIVED BIOCHAR FOR REMOVAL OF LEAD AND METHYLENE BLUE FROM DRINKING WATER

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In partial fulfilment of the requirements for the BACHELOR OF SCIENCE HONOURS DEGREE IN CHEMICAL TECHNOLOGY



19 June 2026

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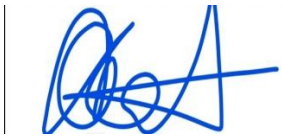

21 August 2026

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DECLARATION

I hereby declare that this project titled “Preparation and characterization of timber mill sawdust derived biochar for removal of lead and methylene blue from drinking water” is my original work and has not been submitted to any other institution for the award of any degree or qualification

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DEDICATION

This work is lovingly dedicated to my mother, who has been my greatest source of support since the beginning of my university journey. Her endless encouragement, prayers and unwavering belief in me gave me strength to persevere throughout this academic journey. I also dedicate this work to my brothers and sister for their constant support and for always standing by my side

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ABSTRACT

Water pollution causes by synthetic dyes and heavy metals has posed a major environmental challenge due to the toxic effects of these contaminants released from industrial effluents, agricultural activities and mining. This study investigates the production of biochar and its application in removal of methylene blue dye and lead metal in aqueous solutions.

Biochar was produced from sawdust using pyrolysis and activated using 50% NaOH. Surface morphology was characterized by FTIR. Batch adsorption experiments were conducted to evaluate the removal efficiency of Pb and MB under varying contact times. The concentration of MB was analysed using UV-Vis spectrometry, and the concentration of Pb was analysed using AAS spectrometry.

The results showed that the biochar had good adsorption properties and effectively reduced the concentration of Pb and MB from the solution. Dye removal efficiently increases with contact time. The study concluded that sawdust derived biochar is a low cost and environmentally friendly adsorbent for the removal of Pb and MB from drinking water.

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1.0 INTRODUCTION

This study investigates the formulation and characterization of Biochar produced from timber mill sawdust to remove toxic pollutants in drinking water these include heavy metal like Lead (Pb) and synthetic dyes from agrochemical process; these dyes include cationic dyes such as Methylene Blue Dye. This study focuses in areas where illegal mining activities and agricultural activities are done in Zimbabwe. This chapter outlines the background of the study, statement of the problem, significance of the study, aim, objectives, organizational of the study and summary to the chapter.

1.1 BACKGROUND OF THE STUDY

Water quality depends on its physicochemical and biological parameters. Changes in parameters such as pH, temperature, and essential and non-essential trace metals in water can render it unfit for human use.(Zhang *et al.*, 2023). Water pollution refers to the contamination of water bodies (such as rivers, dams, lakes, ground water and oceans) due to the introduction of harmful substances including chemicals, waste materials and pathogens, that degrade the quality of the water and make it unsafe for use and consumption(WHO *et al.*, 2022). These pollutants maybe physical, chemical or biological and often originate from industrial discharge, agricultural runoff, sewage and improper waste disposal(UN encironment programme, 2021).

This study investigates the removal of water pollutants specifically heavy metals and synthetic dyes from aquatic environments using biochar. Biochar is a carbon-rich solid material produced through the thermal conversion of waste biomass under anaerobic or low-oxygen conditions(Moharm *et al.*, 2022). A porous, black solid, biochar is made through the pyrolysis of biomass. Since it can be produced from any carbon-rich organic material, a large range of feedstocks are suitable for its preparation(Varkolu *et al.*, 2025).

The biochar produced is utilized to eliminate toxic pollutants, including heavy metals and synthetic dyes, from water. Heavy metals are naturally occurring elements with comparatively high densities that exist within the environment and are widely recognized as pollutants of environmental concern (Laoye *et al.*, 2025). Heavy metal are a collections of naturally occurring metals with high densities (from 3.5g/cm^3 to 7g/cm^3) and atomic weights greater than 23 and atomic numbers greater than 20(Jagaba *et al.*, 2024). Water contamination by heavy

metals occurs through both natural and human activities. Industrial processes such as mining, metal smelting, and manufacturing often discharge wastewater containing metals like lead, cadmium, mercury, and chromium into nearby water bodies. Agricultural practices also contribute, as fertilizers, pesticides, and irrigation with contaminated water introduce metals such as arsenic and cadmium into soils and groundwater.

Synthetic dyes are man-made colorants, usually derived from petrochemical sources, and are widely used to add colour to textiles, food, plastics, paper, and cosmetics. Unlike natural dyes, they are produced through chemical synthesis, providing more vibrant, uniform colours and greater stability. Dyes are chemicals, which on binding with a material will give colour to them.

Dye is a chemical substance capable of binding to other substances, and the intense colouring of different materials is related to their chemical composition (Ali, 2024). Synthetic dyes are chemically manufactured compounds used to impart colour to a wide range of materials, including plastics, textiles, and other products. They are extensively utilized by various service sectors such as hospitals, universities, and the food industry. Due to their chemical stability and resistance to degradation, synthetic dyes tend to persist in the environment for extended periods (Chan, Rubiyatno and Akhmetov, 2024). Commonly used methods for removing dyes from wastewater include chlorination, ozonation, coagulation, chemical precipitation, adsorption, electrochemical techniques, membrane filtration methods, and biological treatment processes (Bożęcka, Orlof-Naturalna and Kopeć, 2021).

Due to the high costs and operational limitations associated with conventional water purification methods such as chemical treatment, membrane filtration, ion exchange, and coagulation–flocculation, this study investigates the use of sawdust-derived biochar as a low-cost and sustainable alternative for water treatment. In Zimbabwe's rural areas, timber processing activities generate large quantities of sawdust, which is often treated as waste. This study therefore focuses on converting timber mill sawdust into biochar and evaluating its effectiveness in removing heavy metals, particularly lead, and synthetic dyes such as methylene blue from contaminated water. By utilizing sawdust as a feedstock, the study not only provides an affordable approach to water purification but also promotes waste valorisation and environmental sustainability

1.2 PROBLEM STATEMENT

Aquatic environments and human communities are increasingly threatened by pollution resulting from rapid industrial and agricultural expansion. Rising human activities such as uncontrolled industrial effluents and extensive use of agricultural chemicals have introduced a diverse range of harmful inorganic and organic pollutants into vital water bodies. This contamination has significantly degraded water quality, making it unfit for human use. Of particular concern are substances like heavy metals (including metal oxides), synthetic dyes, and various forms of dissolved organic matter. These pollutants are highly toxic, resistant to degradation, and remain in the environment for long periods, highlighting the urgent need for efficient, affordable, and sustainable treatment methods(Kolya and Kang, 2024).

1.3 SIGNIFICANCE OF THE STUDY

The primary aim of this study is to advance biochar characterization by examining how variations in feedstock types and production temperatures influence its chemical and physical properties, ultimately identifying potential applications(Dzihora, 2021). As environmental and agricultural challenges continue to grow, the demand for sustainable solutions is rising. This makes it crucial to understand how biochar is produced, characterized, and applied to help tackle global sustainability issues(Varkolu *et al.*, 2025). This study supports better environmental and waste management by converting timber mill sawdust residues into biochar. It also promotes public health through cost-effective, community-friendly water treatment approaches that offer meaningful scientific and technological benefits.

1.4 LIMITATIONS

Lead and Methylene blue were selected as the primary pollutants for this study due to their affordability and accessibility. Furthermore, the complexities and safety risks associated with handling more hazardous chemicals necessitated their exclusion from the experiment.

1.5 DELIMITATIONS

This study is limited to the preparation and characterization of biochar produced from timber mill sawdust for the removal of selected toxic pollutants, specifically heavy metals (lead) and cationic dyes (such as methylene blue) from drinking water. The research focuses on areas in Zimbabwe affected by illegal mining and related environmental contamination, with particular

emphasis on the Domboshava region. Other types of feed stocks, pollutants, and geographic locations are beyond the scope of this study.

1.6 AIM

To prepare and characterize biochar derived from timber mill sawdust for the removal of toxic pollutants, specifically heavy metals (lead) and synthetic dyes (methylene blue), from drinking water in areas affected by illegal mining activities in Domboshava, Zimbabwe.

1.7 OBJECTIVES

1. To collect and pre-treat selected timber mill sawdust waste.
2. To produce biochar through pyrolysis.
3. To activate the biochar by 50% NaOH.
4. To characterize the prepared biochar using FTIR spectrophotometer.
5. To evaluate the adsorption efficiency of the biochar for selected heavy metals and synthetic dyes

1.8 ORGANISATION OF THE STUDY

This study is structured into five chapters. Chapter One provides an introduction, identifying the research problem and outlining the aim and objectives. Chapter Two presents a review of relevant literature. Chapter Three describes the methodology employed in the study. Chapter Four presents the results along with statistical analyses. Finally, Chapter Five discusses the overall findings, and includes the summary and recommendations of the study. This chapter primarily covered the introduction, statement of the problem, justification of the study, aim and objectives, and the organization of the study. The next chapter will focus on the literature review.

CHAPTER 2: LITERATURE REVIEW

2.0 INTRODUCTION

This chapter reviews existing literature on water pollution and examines how heavy metals (lead) and synthetic dyes (such as Methylene blue) affect drinking-water quality and human health. It also outlines the major water-treatment methods currently in use, identifies their limitations, and highlights biochar as a low-cost alternative with promising potential for improving water purification.

2.1 WATER POLLUTION

Water pollution is a major environmental problem affecting many developing countries and has become a growing concern throughout Africa (Kapanga *et al.*, 2024). Water is regarded as polluted when specific substances or conditions are present at concentrations that render it unsuitable for its intended use. Worldwide, contaminated water is responsible for numerous illnesses and deaths, with approximately 14,000 people estimated to die daily from water pollution–related causes. The growing seriousness of water pollution, reflected in declining water quality, increased health hazards, and rising mortality rates, emphasizes the urgent need for effective management strategies and stronger environmental protection measures to safeguard ecosystems and human health (Lin, Yang and Xu, 2022).

2.1.1 SOURCES OF WATER POLLUTION

Metal oxide pollutants enter the environment through various pathways, resulting from both natural processes and human activities. Natural weathering of rocks and minerals releases metal ions, while industrial activities discharge metal oxides directly into water bodies. Agricultural runoff containing metal-based fertilizers also contaminates aquatic systems, and urban runoff from corroding infrastructure further increases pollution levels. Mining operations disturb the soil and allow metal oxides to be washed into nearby rivers. Natural disasters can also mobilize these metals, thereby affecting water quality. In addition, atmospheric deposition transports metals into ecosystems, and poor landfill management allows them to persist in the environment for long periods. Biological processes may lead to the accumulation of metals, while the intentional use of metal-containing materials, such as adsorbents and nanoparticles, also contributes to their presence in the environment (Kolya and Kang, 2024).

In conclusion, water pollution is a complex issue driven by both natural processes and human activities. Factors such as climate, geology, and water flow interact with human influences industrial, agricultural, and urban activities to degrade water quality. Pollution can originate from identifiable point sources, like industrial outlets and sewage systems, or diffuse non-point sources, including agricultural runoff and widespread chemical use. Human-induced pressures, particularly population growth, urban overcrowding, and untreated sewage discharge, exacerbate water contamination, leading to oxygen depletion and biodiversity loss in aquatic ecosystems. Moreover, metal oxide pollutants from natural erosion, industrial operations, mining, and other anthropogenic activities further threaten water quality. Overall, understanding these diverse sources is essential for implementing effective strategies to protect and manage freshwater resources.

2.1.2 PROBLEMS OF WATER POLLUTION

Trace metals significantly influence the phytochemical and biochemical functions of living organisms, though their roles vary by classification. While some elements such as iron (Fe^{2+}), manganese (Mn^{2+}), zinc (Zn^{2+}), and copper (Cu^{2+}) are considered essential for biological health, others, including lead (Pb^{2+}), cadmium (Cd^{2+}), and arsenic (As^{3+}) are non-essential and highly toxic even at negligible concentrations.

Humans typically interact with these pollutants through three primary pathways: inhalation, ingestion (via contaminated food and water), and dermal absorption. Once these heavy metal ions enter the biological system, they trigger a cascade of adverse physiological reactions. The resulting health complications for both humans and animals are severe, ranging from congenital disorders and immune system suppression to oncogenesis (cancer). Despite their presence in only trace amounts within various ecosystems, their persistence and toxicity pose a profound threat to both individual health and broader ecological stability (Zhang *et al.*, 2023)

Consumption of contaminated water is associated with waterborne diseases such as cholera, diarrhoea, and typhoid, as well as long-term health conditions including cancer, neurodegenerative disorders, and endocrine system disorders. For instance, iron (Fe) is a vital element of haemoglobin and myoglobin, the proteins responsible for carrying oxygen to body tissues and muscles. However, prolonged exposure to excessive iron can cause damage to organs such as the liver, pancreas, and heart. Furthermore, elevated levels of iron in water can encourage the growth of Ferro bacteria, which are associated with unpleasant odours and

aesthetic problems in water (Collivignarelli, W A M A N Illankoon, *et al.*, 2024). Metal oxides are known to pose significant risks to human health as well as to aquatic organisms. In humans, exposure to these compounds can result in a variety of health complications, including neurological disorders, respiratory illnesses, and an increased likelihood of developing cancer. Prolonged or repeated exposure may further aggravate these conditions, highlighting the serious health implications associated with metal oxide contamination. In aquatic environments, metal oxides can also harm fish, invertebrates, and aquatic plants, thereby disturbing ecosystem stability and biodiversity.

Synthetic dyes likewise present multiple health hazards to humans while also affecting aquatic life. Ionic dyes can cause skin irritation, allergic reactions, and respiratory problems in humans, while also proving harmful to fish and aquatic invertebrates. Non-ionic disperse dyes generally exhibit low acute toxicity; however, long-term exposure may still pose carcinogenic risks and affect aquatic vegetation. Non-ionic vat dyes are considered to have relatively low toxicity, but their persistent presence in water may still contribute to environmental and health concerns. Cationic dyes are associated with skin irritation, eye irritation, and respiratory complications in humans and may also negatively affect fish and aquatic plants. Similarly, anionic acid and direct dyes can cause skin and respiratory irritation and may be toxic to fish and other aquatic organisms. Anionic reactive dyes can also induce skin irritation and respiratory issues in humans while disrupting aquatic plant life. –Overall, synthetic dyes demonstrate a wide range of toxic effects that threaten both human health and aquatic ecosystems. A major concern is that many textile dyes are non-biodegradable and can persist in water bodies even at low concentrations. When humans are exposed to contaminated water, it may lead to health problems such as skin rashes, headaches, nausea, allergic reactions, and an increased risk of cancer. The toxicity of these dyes is commonly classified into acute effects, which appear shortly after exposure, and chronic or genotoxic effects, which develop over long periods and may cause serious and lasting damage to human health (Kolya and Kang, 2024).

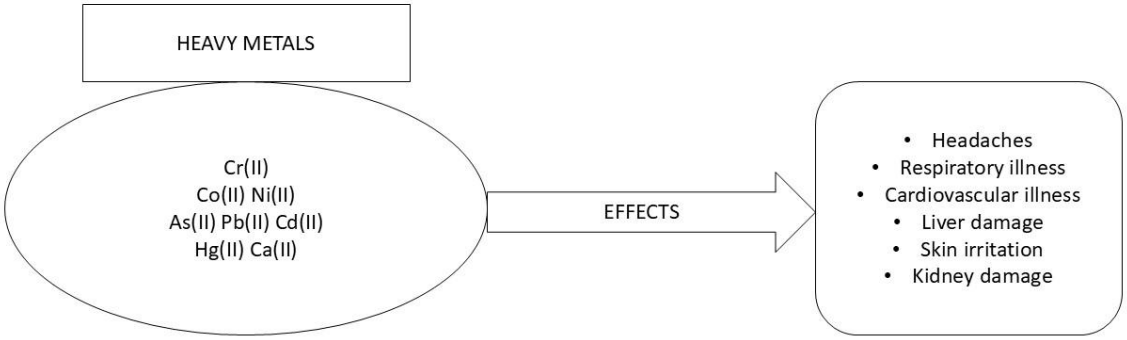

Figure 2.1. Water pollution and its harmful impacts on human health (Zhang et al., 2023).

2.1.3 METHODS OF WATER TREATMENT

Chemical precipitation is a widely used water treatment method for removing heavy metals, inorganic substances, oils, fats, and organic pollutants from wastewater. The process works by converting dissolved or suspended contaminants into solid precipitates that can be separated from the liquid. Coagulants such as polymers are often added to combine small particles into larger precipitates for easier removal. Different precipitation methods are applied depending on the type of contaminant present. Hydroxide precipitation involves adding hydroxides to convert soluble heavy metal ions into insoluble metal hydroxides by adjusting the pH of the water. This method is particularly effective for treating wastewater containing low concentrations of heavy metals in acidic or neutral conditions. The efficiency of the process mainly depends on metal concentration and water pH. Sulphide precipitation is considered more effective than hydroxide precipitation because metal sulphides have much lower solubility, resulting in greater heavy metal removal. This method is less affected by chelating agents and can remove metals such as cadmium, zinc, copper, arsenic, and selenium with very high efficiency. Additionally, sulphide precipitation produces denser and more stable sludge with improved dewatering properties compared to hydroxide precipitation (Bożęcka, Orlof-Naturalna and Kopeć, 2021).

Ion exchange is an effective and cost-efficient wastewater treatment method widely used for environmental protection. It is applied to remove various pollutants, including heavy metals such as cadmium (Cd^{2+}), lead (Pb^{2+}), mercury (Hg^{2+}), radionuclides, and toxic anions from industrial and nuclear wastewater. Compared to other treatment methods like precipitation and biological techniques, ion exchange offers advantages such as high removal efficiency and the possibility of regenerating and reusing the exchanger materials. Common ion exchange materials include organic polymers, zeolites, and clays. Their removal efficiency depends on the chemical selectivity of the functional groups present, such as sulfonate, amino, thiol, amide, and carboxylate groups, which are effective in removing metals like cadmium, nickel, copper, and lead. However, conventional materials may suffer from limitations such as low reusability, slow kinetics, and poor chemical or thermal stability. As a result, recent research has focused on developing advanced ion exchange materials with higher surface area, multiple functional groups, and improved stability, including metal-organic materials and nanoparticle-modified zeolites. Carbon-based adsorbents are commonly used for removing heavy metal ions due to their porous and heterogeneous surfaces, which enhance adsorption capacity. Surface properties can be modified through processes such as nanoparticle impregnation, carbonization, calcination, and chemical treatment to improve adsorption performance. Although some modifications may reduce surface area, they help introduce functional groups that increase the adsorbent's affinity for heavy metals. Recent studies emphasize that surface modification plays a crucial role in optimizing the physicochemical and adsorption properties of carbon materials for environmental remediation applications (Shakoor, Khan and Khan, 2025).

A range of technologies has been developed to remove metals from water, including coagulation–flocculation, membrane filtration, reverse osmosis, chemical precipitation, ion exchange, electrochemical treatment, and flotation. However, these methods have several limitations, such as high energy consumption and expensive operation and maintenance. In addition, some of these techniques are not effective when pollutants are present at low concentrations. In contrast, adsorption is widely considered a preferred method for removing various pollutants from water because of its high efficiency, low cost, and simple operation. Furthermore, it can utilize locally available bio sorbents, which helps to reduce operational expenses (Collivignarelli, W A M A N Illankoon, *et al.*, 2024)

Physicochemical methods, such as reverse osmosis, chemical precipitation, membrane filtration, etc., are frequently used for heavy metal removal. These methods are cost-effective and generate large amounts of secondary pollutants. Moreover, these methods are only effective relative to higher concentrations of heavy metal (above 2 mM) ions in the water. Considering the disadvantages of physical and chemical water treatment methodologies, there is an urgent need for suitable eco-friendly and cost-effective alternatives to these physicochemical methods for the removal of heavy metals from water. Biological methods, such as bio sorption, bioaccumulation, bio reduction, phytoremediation, and mycoremediation, are effective alternatives to physicochemical methods. These biological methods also work on low-cost and eco-friendly methodologies. These methods can be divided into two categories: metabolically independent and metabolically dependent methods. Biosorption is a metabolically independent method based on dead biomass and agriculture residue. A variety of biomass, such as rice husk, wheat husk, banana peels, and microbial biomass, are used as biosorbents. Metabolically dependent heavy metal remediation is based on living microorganisms, and several metabolic reactions are involved in this process. Living microbes, like bacteria and fungi, are considered effective remediating agents. The heavy metals present in the aqueous medium bind to the microbial surface and enter the cell through the cell surface receptor. Antioxidants, such as superoxide dismutase (SOD), catalase (CAT), and glutathione S-transferases (GST), are present in the bacterial cell and are neutralized relative to the heavy-metal-mediated oxidative stress in the cell. These antioxidants also help in heavy metal bioremediation by minimizing heavy metal stress in microbial cells(Zhang *et al.*, 2023).

2.2.0 HEAVY METALS

Heavy metals are a major concern in environmental pollution because they are associated with many health problems. When they accumulate in soil and water, they create serious risks for ecosystems as well as human populations. This project discusses the definition of heavy metals, their sources, the problems they cause, and the methods used for their removal.

Heavy metals are dense metals that are generally less reactive than lighter metals and occur in low amounts in the Earth’s crust. They are strong, difficult to cut, and have high tensile strength with varying melting points and low thermal expansion. Their hydroxides are usually insoluble, and their sulphides are highly insoluble. Heavy metal compounds often form colourful

complexes that dissolve in water. Some heavy metals are essential micronutrients needed in small amounts for functions such as enzyme production, hormone formation, maintaining acid–base balance, and building skeletal structures. However, in high amounts they become toxic. Because they are non-biodegradable, heavy metals persist in soil and wastewater for long periods. They can form soluble complexes, move through water systems, and accumulate in living organisms, especially aquatic life. This bioaccumulation can harm plants, animals, and humans, making heavy metal pollution a serious environmental concern (Jagaba *et al.*, 2024).

2.2.1 SOURCES OF HEAVY METALS

Heavy metals differ widely in their chemical properties, and are used extensively in electronics, machines and the artifacts of everyday life, as well as in high-tech applications. As a result, they are able to enter into the aquatic and food chains of humans and animals from a variety of anthropogenic sources as well as from the natural geochemical weathering of soil and rocks.

Heavy metal contamination in the environment arises from both natural processes and human activities. Naturally, metals are released through processes such as weathering of rocks, mineral breakdown, volcanic eruptions, forest fires, biological activity, sea-salt sprays, evaporation, and wind-blown dust, which can transport these elements into water bodies like rivers and lakes. However, human activities are the major contributors to elevated levels of heavy metals, often exceeding natural background concentrations. Industrial processes such as mining, metal smelting and refining, electroplating, coal combustion, and manufacturing release significant amounts of metals into the environment through wastewater and emissions. Agricultural practices also play a role through the excessive use of fertilizers, pesticides, and other chemicals, which contaminate soil and water. In addition, improper disposal of sewage, industrial waste, and electronic waste introduces hazardous substances into aquatic systems. Mining and mineral processing further accelerate contamination by releasing metals during extraction and ore processing, while nonferrous smelting contributes to pollution of soil, water, and vegetation. Urban sources such as vehicle emissions, wear of tires and brakes, and road dust also add to the burden, with lead being a common contaminant. Together, these natural and anthropogenic sources lead to the accumulation of heavy metals in water bodies, posing risks to ecosystems and human health (Jagaba *et al.*, 2024)

2.2.2 PROBLEMS OF HEAVY METALS

Heavy metals are highly toxic, persistent in the environment, and prone to bioaccumulation, significantly impacting water quality and safety. Metals such as arsenic, cadmium, lead, and copper are particularly concerning due to their long-lasting presence and irreversible toxic effects. Even low-level, chronic exposure can harm both the environment and human health, potentially causing carcinogenic effects. Contaminated water threatens ecosystems and human well-being alike, as these metals do not break down and can accumulate in living organisms, disrupting the food chain. Humans can absorb heavy metals through ingestion, skin contact, or inhalation, leading to health problems ranging from mild symptoms like fatigue, gastrointestinal issues, and anxiety to severe conditions such as lung disease, kidney damage, neurological disorders, and cancer. Acute toxicity and chronic low-level exposure both contribute to these health risks. In soils, heavy metal contamination impedes plant growth and survival, posing nutritional, ecological, and evolutionary challenges. Consumption of contaminated food can result in heavy metal accumulation in bones and fatty tissues, causing nutritional deficiencies and weakening the immune system (Hama Aziz *et al.*, 2023).

2.3.0 SYNTHETIC DYES

Synthetic dyes are widely used in industries because of their bright colours and low cost. They are chemically manufactured colorants commonly applied in textiles, paper, leather, food products, and laboratory applications. Synthetic dyes can be classified according to their chemical structure, such as azo and thiazine dyes, or by their electrical charge, including cationic and anionic dyes. Despite their industrial importance, synthetic dyes present serious concerns related to occupational hazards, environmental pollution, and increasing global usage. Many of these dyes are also associated with harmful effects on human health. A natural alternative is dyes derived from plants (Negi, 2025).

In ancient times, dyes were obtained from natural sources such as vegetables, insects, lichens, plants, and berries, and were used to colour natural fibres like wool, cotton, fur, leather, and silk. The invention of the first synthetic dye by Perkins in 1856 marked the beginning of a gradual decline in the use of natural dyes. Over time, extensive research has been conducted to develop new dyes suitable for a variety of materials and products to satisfy the increasing demands of consumers. Today, dyes find applications across numerous industries, including pulp and paper, plastics, paints, printing, textiles, leather, cosmetics, food, pharmaceuticals, and medical sciences (Kavitha, Govindhan and Premkumar, 2025).

2.3.1 GENERAL PROPERTIES

Synthetic dyes possess characteristics that make them ideal for various industrial applications. These include strong colour intensity and resistance to light, heat, and chemicals, depending on the dye type. They are synthesized from aromatic rings containing chromophores, which absorb light and provide colour. Functional groups in the dyes determine their solubility and affinity for different materials. Synthetic dyes are classified as anionic, cationic, or non-ionic. They are slow to degrade, making them stable, but they are also toxic. Additionally, they are less expensive to produce compared to natural dyes

Methylene Blue

It is a thiazine dye with the chemical formula $C_{16}H_{18}N_3CIS$, due to this structure it has chemical stability and water solubility making it useful in industries (Moharm *et al.*, 2022). MB is a solid, odorless, dark green powder at room temperature and yields a blue solution when dissolved in water MB is one of the most commonly used dyes in the industry. Its formula, $C_{16}H_{18}ClN_3S$ with a molecular weight of 319.85 g/mol. MB has a characteristic deep blue colour in the oxidized state and is colorless in the reduced form. The main components of MB dye molecule are: the chromophoric, which are responsible for producing the color, and the auxochrome, which can not only supplement the chromophoric but also render the molecule soluble in water and give enhanced affinity to attach toward the fibers. The colour of MB depends on its chromophoric and auxochrome groups. The chromophoric of MB is the N–S conjugated system on the central aromatic heterocyclic, while the auxochrome is N-containing groups with lone pair electrons on the benzene ring (Patra and Mishra, 2026)

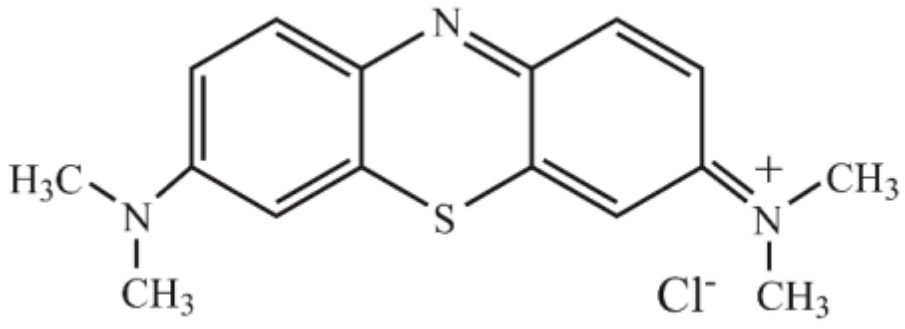

Figure 1.2 The structure of Methylene blue (MB) dye

2.3.2 PROBLEMS OF SYNTHETIC DYES

Despite undergoing treatment, dye effluents still carry significant amounts of pollutants, such as toxic metals, chlorinated compounds, and various organic substances. This ongoing contamination negatively impacts air, soil, vegetation, and water resources, leading to serious health problems for humans (Kolya and Kang, 2024).

The colored water reduces the entrance of sunlight into the water bodies affecting the aquatic life. In many cases, if the concentration of dye is present below 1 ppm, that produces an obvious water coloration. (Meghwal *et al.*, 2019).

2.4.0 BIOCHAR

Biochar is a type of charcoal made from different organic materials, including wood chips, agricultural residues, and other biomass sources. It is produced through pyrolysis, a process that transforms the material into a highly porous substance with a large surface area, giving it exceptional properties. Various feedstocks can be used to produce biochar, such as agricultural waste, forestry by-products, and other organic materials, providing a sustainable approach to waste management and resource utilization (Varkolu *et al.*, 2025).

Biochar is a carbon material produced by the thermal decomposition of biomass in an oxygen-free atmosphere. It is a highly aromatic compound, made up of layers of graphene and graphite structures and edge carbon atoms containing functional groups, such as carboxylic, hydroxyl, and carbonyl units. It is an environmentally friendly adsorbent that can be produced from agricultural, forest, and sewage wastes(Collivignarelli, W A M A N Illankoon, *et al.*, 2024).

Unlike traditional charcoal, which is primarily used as a fuel, biochar is a form of charcoal applied as a soil amendment to enhance plant growth and support agricultural productivity. It also serves as a tool for carbon capture and storage (Hua, 2024a).

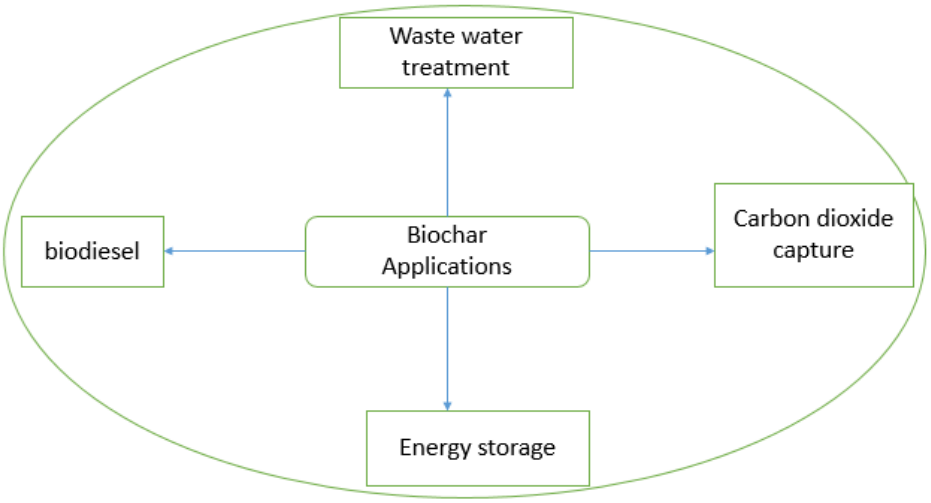

Figure 2.3 Applications of biochar (Varkolu et al., 2025)

2.4.1 BIOCHAR PRODUCTION

Generally, there are four different methods of biochar production: slow pyrolysis, fast pyrolysis, gasification and torrefaction. Only slow pyrolysis is utilized as an approach for primary biochar production, the fast pyrolysis and gasification aim for the production of bio-oil and syngas accordingly, the torrefaction's main focus is the production of solid fuel pellets alongside maximization of their energy content and solidification of charred products (Dzihora, 2021).

2.4.2 SLOW PYROLYSIS

Pyrolysis is the process of thermal decomposition of biomass at elevated temperatures (300-700 °C) in the inert atmosphere. The difference between slow and fast pyrolysis is in the heating rate and therefore residence time of the biomass. Slow pyrolysis occurs at the heating rate of 5-7 °C/min with common residence times of 30-120 min, meanwhile fast pyrolysis heating rate can reach 1000 °C/min and residence time of vapor being <2 s. this strongly affects the properties of the final biochar. Slow pyrolysis provides sufficient time for each fraction of biomass to decompose. Hemicellulose starts depolymerizing at 170–240 °C, cellulose at 240–310 °C, and lignin as the most stable fraction decomposes at 300–550 °C, thus each fraction requires its optimal temperature range and residence time to be optimally depolymerized and for exhaust gases and volatiles coming from each fraction to transfer out from reacting bulk mass. Steady heating also gives sufficient time for the solid carbon flushed with the gaseous

phase to deposit back on a solid fraction. The higher temperature of pyrolysis also promotes better removal of volatile organic carbon (VOC) from biochar and increase of carbon content, solid density alongside with higher specific surface area of biochar, however, reducing the overall yield (Dzihora, 2021).

2.4.1 GENERAL PROPERTIES

Biochar has many favorable properties that come from the sources of the biochar and to the final product making it useful for water purification. It is an environmentally friendly adsorbent that can be produced from agricultural, forest, and sewage wastes. Biochar is a relatively inexpensive material because the raw materials are abundant and do not have an economic value (Collivignarelli, W A M A N Illankoon, *et al.*, 2024).

Biochar is a carbon-rich material characterized by its porous structure and high stability. It has the ability to reduce the bioavailability of organic pollutants and heavy metals in the environment. Essentially, biochar is a fine-grained charcoal that is rich in organic carbon and resistant to decomposition, classifying it broadly as a form of black carbon. Its elemental composition primarily includes carbon, nitrogen, hydrogen, and oxygen, along with essential soil nutrients. These nutrients include major elements like phosphorus, calcium, magnesium, and potassium, as well as trace elements such as manganese, zinc, and copper. Typically, biochar contains 60% or more carbon. Structurally, it consists of a stable aromatic framework combined with numerous aliphatic and oxidized carbon compounds. Additionally, biochar has a highly porous structure, offering a large specific surface area (Hua, 2024a).

The surface functional groups of biochar, including amino, hydroxyl, and carboxyl groups, exhibit strong affinity for metal cations, playing a key role in the adsorption of heavy metals. For instance, the presence and enhancement of oxygen-containing groups (such as C–OH, HO–C=O, and C–O–C=O) on biochar can promote the immobilization of heavy metals during anaerobic digestion. Furthermore, nitrogen-doped biochar generates numerous amino functional groups on its surface. During the adsorption of copper ions (Cu^{2+}), these amino groups coordinate with the Cu^{2+} ions to form stable complexes with high stability constants, thereby improving the efficiency of copper adsorption. Biochar surfaces generally carry a negative charge, which facilitates cation exchange with metal ions in solution and strengthens electrostatic attraction toward heavy metals. When the solution is acidic, neutral, or slightly

alkaline (pH < pHpzc), the biochar surface becomes positively charged, leading to repulsion of metal cations. Conversely, in alkaline conditions (pH > pHpzc), the surface remains negatively charged, allowing it to bind cations such as Cd^{2+}, Pb^{2+}, and Ni^{2+}. In this state, heavy metals can also precipitate as low-solubility compounds, so the alkaline nature of biochar contributes to minimizing heavy metal leaching (Hua, 2024b).

2.4.2 LOCATION AND OCCURRENCE OF BIOCHAR

Biochar can be produced from readily available organic materials such as agricultural residues and tree biomass. Because these raw materials are abundant and accessible, producing biochar is a cost-effective process.

2.4.3 ADVANTAGES AND DISADVANTAGES OF BIOCHAR

Advantages

Biochar is widely recognized as an effective material for water treatment due to its numerous advantages. Its porous structure and large surface area enable it to efficiently adsorb contaminants such as heavy metals (including lead and cadmium), organic pollutants, and nutrients like phosphates and nitrates. Biochar is also cost-effective because it can be produced from agricultural and forestry waste materials such as rice husks, sawdust, and corn cobs, making it less expensive than commercial activated carbon. In addition, biochar is environmentally friendly, as its production promotes the recycling of biomass waste and contributes to carbon sequestration, thereby helping to reduce the carbon footprint and mitigate climate change. Another important benefit is its ability to buffer pH and retain nutrients, which is useful in agricultural water reuse and treatment systems. Biochar is highly versatile and capable of removing a broad range of pollutants, including heavy metals, dyes, pesticides, and certain pathogens, depending on the feedstock and production conditions. Furthermore, biochar can often be regenerated through washing or thermal treatment, allowing it to be reused in water treatment applications (Collivignarelli, W. A.M.A.N. Illankoon, *et al.*, 2024).

Disadvantages

Despite its advantages, biochar also has several limitations in water treatment applications. Its adsorption efficiency largely depends on the type of biomass used and the pyrolysis conditions during production, meaning that poor-quality biochar may exhibit low effectiveness. In some cases, biochar is less efficient at removing dissolved salts, certain anions such as fluoride, and

very small organic molecules unless it undergoes chemical modification. Additionally, improperly processed biochar may contain residual tars, polycyclic aromatic hydrocarbons (PAHs), or metals that can leach into water and cause secondary contamination. Another drawback is that the adsorption process for some pollutants can be relatively slow, requiring longer contact times compared to other treatment methods. Once biochar becomes saturated with contaminants, especially heavy metals, it may pose disposal challenges and require safe regeneration or disposal procedures. Furthermore, to improve the adsorption of specific pollutants such as heavy metals or dyes, biochar often needs chemical activation or surface modification, which increases both the complexity and cost of the treatment process (Hama Aziz *et al.*, 2023).

2.4.4 MECHANISM OF ACTION

Several studies have reported that biochar can serve as an excellent photocatalyst and mediator for AOPs. The numerous functional groups on the surface of biochar allow the production of Persistent Free Radicals (PFRs) and OH, which can decompose organic pollutants. Biochar is a widely accepted adsorbent due to its low cost, pore filling effect, Π-Π stacking interaction, and hydrogen bonding. Additionally, activated, and modified biochar has been used as a potent agent for removing various organic pollutants, including organic dyes and antibiotics. Biochar-based adsorption has been demonstrated to be an effective method of eco-remediation in reducing heavy metal pollution in water and soil, with multitude of advantages. Extensive research has been conducted on the utilization of adsorbents, specifically biomass-based activated carbon compounds and biochar derived from agricultural waste, owing to their exceptional capacity to remove heavy metal pollutants present in wastewater (Hama Aziz *et al.*, 2023).

Organic pollutants, insecticides, and heavy metals may all be adsorbed and retained by biochar because of their porous nature. By binding to these pollutants specifically, biochar can stop them from migrating across the soil profile through ion exchange (Varkolu *et al.*, 2025).

2.5 CHOICE OF METHOD

The choice of using biochar over other water purification methods is based on its simplicity, cheap and readily availability of raw materials in rural areas. Use of biochar from agricultural

waste will improve waste management and an alternative cheaper way for water in rural areas to be purified before being consumed.

This literature review shows that water pollution from heavy metals such as lead and from synthetic dyes like methylene blue poses serious risks to both human health and aquatic ecosystems. It also highlights that conventional water treatment methods, while effective, often have limitations including high cost, high energy requirements, and reduced performance at low contaminant concentrations. Biochar is presented as an affordable and environmentally friendly alternative that can adsorb and remove contaminants due to its porous structure and surface functional groups. In addition, activating biochar can further improve its adsorption efficiency, making it a promising option for low-cost water purification. Overall, biochar-based treatment offers a realistic approach for improving water quality, particularly in resource-limited communities.

CHAPTER 3: METHODOLOGY

3.0: INTRODUCTION

This chapter outlines the methodology for the preparation and characterization of biochar, and evaluates its effectiveness in water purification. It also outlines the chemicals and equipment used in the study

3.1 MATERIALS AND PREPARATION

3.1.1 EQUIPMENT AND INSTRUMENTATION

- 8 × 200 mL beakers
- 8 × 500 mL conical flasks
- Stirring rods
- Thermometer
- 3 × 50 mL graduated cylinders
- 1000 mL and 500 mL volumetric flasks
- Drying oven
- Muffle furnace
- Analytical balance
- Centrifuge
- Filter papers
- Funnels
- Distilled water
- pH meter
- UV–Vis spectrophotometer
- Atomic Absorption Spectroscopy
- Fourier Transform Infrared Spectroscopy (FTIR)

3.1.2 CHEMICALS AND MATERIALS

- Sodium hydroxide (NaOH)
- Hydrochloric acid (HCl)
- Nitric acid

- Lead (ii) Nitrate
- Methylene blue dye
- Timber mill sawdust

3.1.3 COLLECTIONS AND PREPARATION OF BIOCHAR RAW MATERIALS

Timber mill sawdust was collected from processing sites in Bindura market place and carefully sieved to obtain uniform particles of approximately 5 mm or less for use in the study. The sawdust was then washed three times with tap water and twice with distilled water to remove impurities and adhering contaminants. Thereafter, the cleaned sawdust was oven-dried at 105 °C for 5 hours until completely dry (Le *et al.*, 2021).

3.2 SYNTHESIS AND CHARACTERIZATION OF BIOCHAR

3.2.1 PRODUCTION OF BIOCHAR: PYROLYSIS

The dried sawdust was transferred into an alumina boat and pyrolyzed at 350 °C for 6 hours at a heating rate of 10 °C/min (Collivignarelli, W A M A N Illankoon, *et al.*, 2024).

3.2.2 ACTIVATION OF BIOCHAR

The pyrolyzed sawdust biochar was divided into six portions and chemically activated by soaking in 50% NaOH at room temperature for contact periods of 3 and 6 hours, with three samples assigned to each duration. A biochar to NaOH weight ratio of 2:1 was maintained. Following alkali activation, the samples were washed and further treated with 0.1 M HCl under constant agitation until a neutral pH was achieved. The biochar was then thoroughly rinsed with deionized water using a vacuum filtration system. Finally, the NaOH-activated biochar was oven-dried at 90 °C for 12 hours (Collivignarelli, W A M A N Illankoon, *et al.*, 2024).

The mass of feedstock before pyrolysis was compared with the mass of biochar obtained after activation and drying to determine the efficiency of the conversion process.

$$\%\ yield = \frac{mass\ of\ biochar}{mass\ of\ feedstock} \times 100$$

3.2.3 FOURIER TRANSFORM INFRARED SPECTROSCOPY (FTIR) CHARACTERIZATION

A spirit Qatr-s Fourier Transform Infrared Spectroscopy (FTIR) was used to identify the surface functional groups present on the sawdust-derived biochar before and after chemical activation. FTIR analysis provides information on the types of chemical bonds and functional groups on the biochar surface, which play a crucial role in the adsorption process.

3.3 EXPERIMENTAL PROCEDURE

3.3.1 Preparation of pollution stock samples (lead and methylene blue)

Preparing the lead stock solution

Lead (ii) Nitrate was used to make stock solutions, 1.598g of $Pb(NO_3)_2$ was dissolved in 1000mL of distilled water to make 1000ppm. 2 drops of concentrated Nitric Acid were added to prevent the lead from precipitating of sticking to the walls of the beakers.

Preparation of mb stock solution

MB is very strong therefore 1.00g of MB was dissolved in 1000mL of dissolved water to make 1000ppm. Thorough stirring was done because MB takes a long time to dissolve completely.

Mixed pollution stock solution (Lead and MB)

A stock solution of 500mg/L Lead and 500mg/L MB in a 2000mL volumetric flasks was prepared according the following way

a) The formula $c_1v_1 = c_2v_2$ was used to determine how much of Lead and MB solution was needed to make the required solution.
b) The 2000mL volumetric flask was filled solution of 1000mg of Pb and MB and mixed carefully
c) pH adjustment was done using 25% NaOH and dilute HCl to maintain pH of 5.5 to 6.0

The concentration of the stock solution can be determined by a Thermo Scientific Genesys 10s UV/Vis spectrophotometer at 664nm to measure the concentration of MB, and using a thermos Scientific iCE 3000 series AAS to measure the concentration of Lead the dilution ratio of 2 was used

3.3.2 ADSORPTION EXPERIMENTS

For the adsorption experiments, 2.00g of each NaOH activated sawdust biochar, prepared at different contact times, was weighed and added to separate flasks containing 500 mL of the pollutant stock solution. The mixtures were agitated at 200 rpm at room temperature for a total of 24 hours. Samples were withdrawn at 2-hour intervals, starting from the 4th hour, to monitor the pollutant concentration. At the end of the 24-hour period, the biochar was separated from the solution by filtration.

3.3.3 BIOCHAR ACTIVITY TEST

After filtration, the liquid samples are taken to the UV/Vis spectrophotometer to measure the final MB concentration at 664nm. And another of the samples was taken to the AAS for Lead concentration measurement. The biochar efficiency was calculated using the formula

$$R = \frac{C_o - C_e}{C_o} \times 100$$

Where:

- R is the removal efficiency (%)
- Co initial MB/Lead concentration (mg/L)
- Ce equilibrium MB/Lead concentration (mg/L)

3.4 ANALYTICAL METHODS AND CALIBRATION

3.4.1 pH meter calibration

1. About 30 mL of pH 10.01 buffer was poured into a 50 mL beaker and the beaker was covered with a watch glass or parafilm prior to calibration.
2. About 30 mL of pH 7.00 buffer was poured into a 50 mL beaker and the beaker was covered with a watch glass or parafilm prior to calibration.
3. About 30 mL of pH 4.01 buffer was poured into a 50 mL beaker and the beaker was covered with a watch glass or parafilm prior to calibration.
4. About 30 mL each of the pH 10.01, 7.00, and 4.01 buffers were poured into separate 50 mL beakers, and these beakers were used as rinse beakers during calibration.

5. All the buffers were allowed to reach the same temperature, since pH readings were temperature dependent (Thermo Fisher Scientific Inc., 2020).

3.4.2 UV-VIS SPECTROPHOTOMETER CALIBRATION

1. A stock solution of methylene blue was prepared in distilled water.
2. A series of standard solutions was prepared by diluting the stock solution (e.g., in the 1–10 mg/L range).
3. The UV–Vis spectrophotometer was switched on and allowed to warm up.
4. A wavelength of around 664 nm (λmax of methylene blue) was selected.
5. A cuvette was filled with distilled water and used as the blank.
6. The absorbance of each standard solution at 664 nm was measured and recorded.
7. A graph of absorbance versus concentration was plotted to obtain a calibration curve.
8. Linearity was verified using the Beer–Lambert law assumption for the selected range.
9. The calibration curve was used to determine the concentrations of unknown samples (IANZ, 2005).

3.4.3 AAS ANALYSIS OF LEAD CONCENTRATION

AAS was calibrated according to ISO standards (ISO, 2020)

1. FAAS was switched on and allowed to warm up for 20–30 minutes.
2. The Pb hollow cathode lamp was installed.
3. The wavelength was set to 283.3 nm.
4. The slit width was adjusted to 0.7–1.0 nm.
5. The flame was set to air–acetylene.
6. The burner alignment and gas flow were optimized.
7. A blank solution (0 mg/L Pb in 1–2% HNO_3) was prepared.
8. Pb standards (e.g., 10, 20, 50, 100, 200 mg/L) were prepared.
9. The blank was aspirated and the instrument was zeroed.
10. The standards were aspirated from low to high concentration.
11. Absorbance values were recorded.
12. A calibration curve (Absorbance vs. concentration) was plotted.
13. Linearity was checked ($R^2 \geq 0.995$).
14. A mid-level calibration check standard was run.

15. Samples were aspirated.
16. Absorbance was recorded and concentrations were determined from the calibration curve.
17. The blank was re-run periodically during analysis.
18. Duplicate and spike recovery checks were performed.

3.5 PRESENTATION OF RESULTS

The results from the experiments done where collected and tabulated where necessary

CHAPTER 4: RESULTS AND ANAYLSIS

4.0 INTRODUCTION

This chapter presents the results of the study. The presentation follows the sequence of the methodology. The chapter also provides statistical information of the descriptive data. Data was presented in form of pictures and tables; the conclusion was given there after

4.1 FEEDSTOCK COLLECTION

1kg of sawdust were collected from Bindura sawmills as feedstock for biochar. The sawdust was sun dried and later on dried in an oven to remove excess moisture



Figure 2.1 sawdust sun drying

4.2 PRODUCTION AND ACTIVATION OF BIOCHAR

The dried sawdust feedstock was pyrolyzed in a muffle furnace at $350^{o}C$ for 6hours. After pyrolysis, the biochar was activated using 50% NaOH for contact times of 3 hours and 6 hours and the biochar percentage yield was calculated



Figure 4.2 biochar from the furnace



Figure 4.3 activation process

The biochar from the muffle furnace was activated using 50% NaOH, the contact times was 3 hours and 6 hours.

Calculation of percentage yield

$$\%yield = \frac{mass\ of\ biochar/g}{mass\ of\ feedstocks/g} \times 100$$

$$\%yield = \frac{400g}{1000g} \times 100$$

$$\%yield = 40\%$$

1000g of sawmill sawdust was collected, after pyrolysis, 400g of biochar was obtained resulting in a 40% yield

4.3 FTIR RESULTS

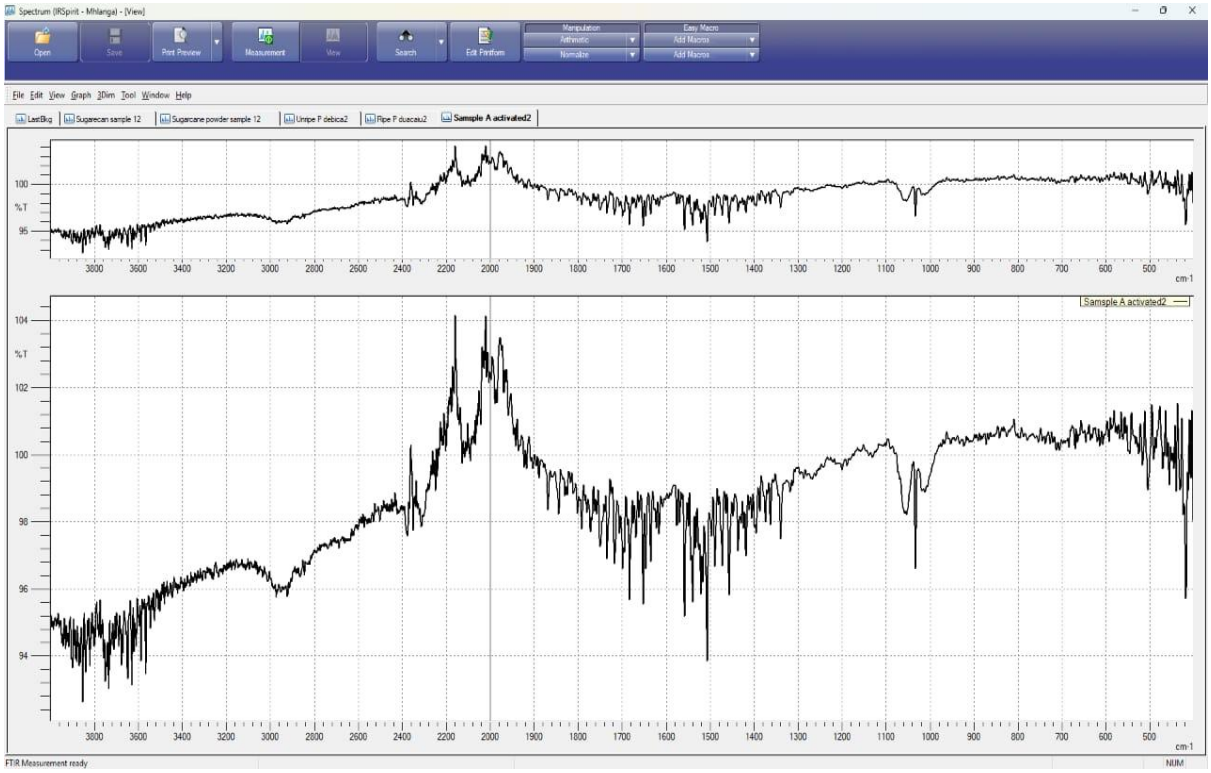

Figure 4.4 Sample A: 3 hours activation time

Sample A: 3 hours contact time

There was a broad peak around 3200-3500 cm^{-2}; this corresponds to O-H stretching vibrations. The presence of this broad peak indicates the oxygen containing functional groups on the surface of the biochar. Peaks around 1700-1600cm^{-2}; corresponds to C=O stretching from carbonyl groups or aromatic C=C vibrations, this confirms the formation of aromatic carbon structures and oxygenated groups. Weak peak near 2900cm^{-2} associated with C-H stretching, the intensity shows that most volatile organic compounds were removed during activation and carbonization. Strong peak around 1100-1000cm^{-2} shows C-O stretching from either ether or alcohol group, it suggests enhanced surface functionalization and development of active adsorption sites.

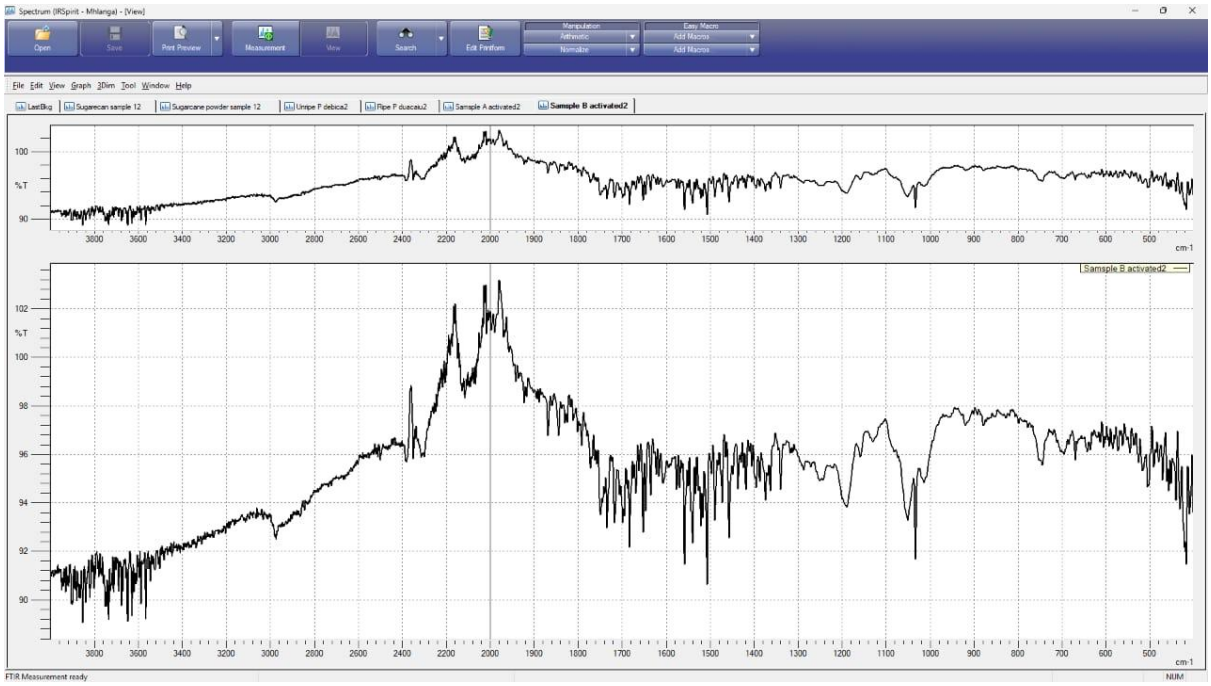

Figure 4.5 Sample B: 6 hours activation time

Sample B: 6 hours contact time

Broad and intense peak at 3200-3600cm^{-2} is assigned to O-H stretching, compared to sample A it shows more activation. Further removal of volatile organics is shown by a weaker peak near 2900cm^{-2}. Peak around 1700-1500cm^{-2} indicates better development of aromatic carbon structures, more oxygen containing functional groups that are important for adsorption. Strong peak around 1200-1000cm^{-2} indicates increased porosity and more adsorption sites. Changes in fingerprint region indicates the alteration of mineral and carbon framework after prolonged activation.

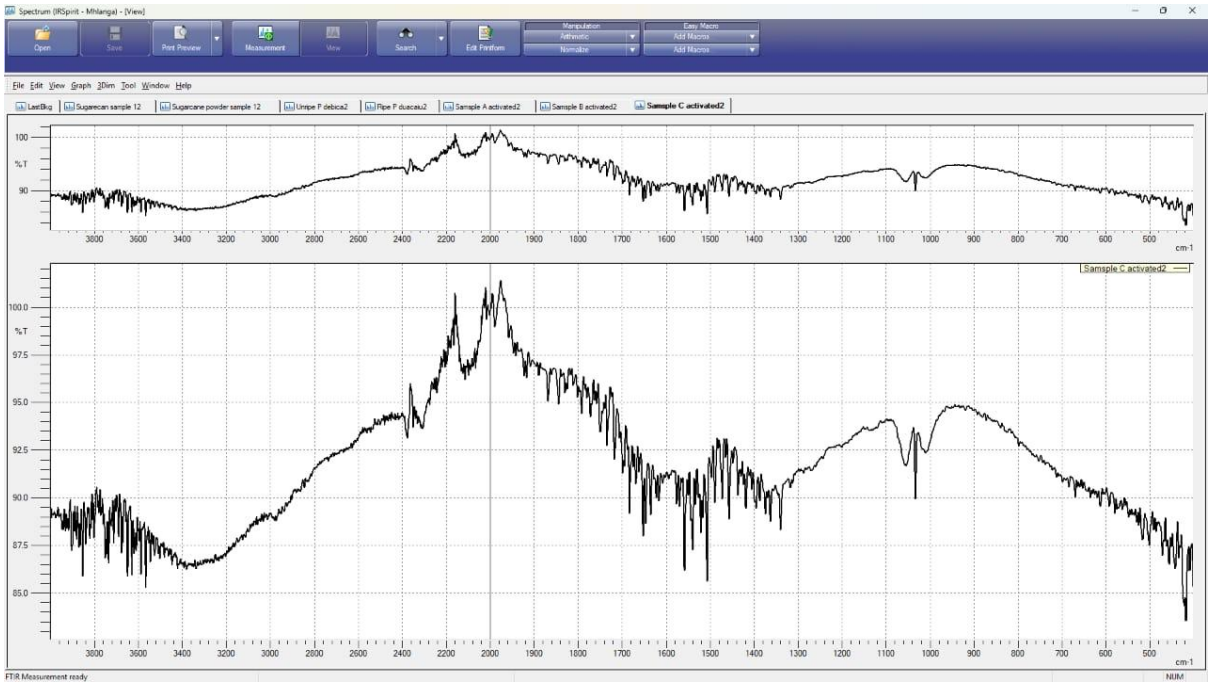

Figure 4.6 Sample C: un-activated

Sample C: un-activated

Broad band around 3200-3500cm^{-2} shows O-H stretching but less defined indicating fewer organized surface hydroxyl groups. Weak peaks around 1700-1500cm^{-2} indicates that lower aromaticity, fewer oxygen containing functional groups as compared to activated samples. There is a low intense peak around 1100-1000cm^{-2} showing that surface functionalism is lower.

Table 4.1 Comparative analysis table

Property	Sample A	Sample B	Sample C
Hydroxyl groups (O-H)	Moderate	High	Low
Oxygen containing groups	Moderate	High	Low
Aromatic structure development	Moderate	Strong	Weak
Surface modification	Good	Excellent	Low
Expected porosity	Moderate	High	Low
Adsorption potential	Improved	Highest	Lowest

Table 4.2 STOCK SOLUTIONS

1.598g of $Pb(NO_3)_2$	1000ml distilled water	389.3ppm of Pb(II)
1.000g of MB	1000ml distilled water	118.33ppm of MB

4.5 ADSORPTION EXPERIMENTS

Table 4.3 AAS Pb results

Pb sample ID	sample name	concentration(mg/L)	dilution ration	actual concentration(mg/L)
1	stock solution	0.778±0.002	500	389.300±1.000
2	C3	2.154±0.002	200	430.740±0.400
6	B2	0.828±0.002	200	165.600±0.400
8	A3	0.190±0.002	200	37.980±0.400
4	C1	2.023±0.002	200	404.520±0.400
5	B3	0.177±0.002	200	35.400±0.400
9	A2	0.021±0.002	200	4.260±0.400
3	C2	1.080±0.002	200	216.040±0.400
7	B1	0.113±0.002	200	22.680±0.400
10	A1	0.020±0.002	200	4.080±0.400

The samples were filtered and taken to the AAS for Lead analysis. The AAS results showed that as the contact time of the biochar and Lead solution, the concentration of Lead decreased. The biochar that was activated for 6 hours in 50% NaOH showed the best performance after 24 hours and un-activated showed the least performance, this was predicted earlier.

Table 4.4 Uv-vis MB results

MB sample ID	1st scan	2nd scan	3rd scan	average concentration	dilution ratio	actual concentration

stock sol	0.25	0.24	0.22	0.236	500	118.33
A2	0.71	0.71	0.72	0.713	200	142.67
B2	0.58	0.58	0.57	0.576	200	115.33
C3	0.40	0.41	0.40	0.403	200	80.67
A1	0.29	0.80	0.72	0.290	200	58.00
B1	0.12	0.12	0.12	0.120	200	24.00
C1	0.22	0.21	0.19	0.206	200	41.33
C2	0.17	0.17	0.17	0.170	200	34.00
A3	0.00	0.01	0.02	0.010	200	2.00
B3	0.04	0.05	0.03	0.040	200	8.00

For the analysis of MB, solution was filtered and an UV-Vis spectrophotometer was used to analyse the concentration. The results showed that the concentration of MB was reduced due to biochar adsorption. The biochar that has the best performance was the biochar that was activated for 6 hours followed by that was activated for 3 hours. The colour change of the solution was able to be detected by naked eyes showing the positive results of the work

4.6 BIOCHAR ACTIVITY

$$R = \frac{c_o - c_e}{c_o} \times 100$$

MB removal efficiency after 24 hours

3 hours activation contact time (B3) efficiency

$$R = \frac{118.33 - 8}{118.33} \times 100$$

$$R = 93\%$$

6 hours activation contact time (A3) efficiency

$$R = \frac{118.33 - 2}{118.33} \times 100$$

$$R = 98.31\%$$

Un-activated biochar (C2) efficiency

$$R = \frac{118.33 - 34}{118.33} \times 100$$

$$R = 71.27\%$$

After the analysis, the efficiency of Biochar in the removal of MB was calculated. Biochar activated for 6 hours showed the greatest efficiency of 98% after 24 hours. Un activated has the least performance at 71% but this showed that even un-activated biochar can be used to clean drinking water

Pb removal efficiency after 24 hours

Un-activated biochar (C2)

$$R = \frac{389.3 - 216.68}{389.3} \times 100$$

$$R = 44.34\%$$

3 hours activation contact time (B1)

$$R = \frac{389.3 - 22.68}{389.3} \times 100$$

$$R = 94.17\%$$

6 hours activation contact time (A1)

$$R = \frac{389.30 - 4.08}{389.30} \times 100$$

$$R = 98.95\%$$

Biochar efficiency for the removal of Lead was calculated, biochar with the best efficiency was the biochar activated for 6 hours and it has 98% efficiency. The biochar activated for 3 hours has 94% and un-activated has 44% after 24 hours contact time. This proved that for the removal of Lead in the solution, the biochar should be activated for best performance.

CHAPTER 5: DISCUSSION

5.0 INTRODUCTION

Biochar is widely recognized as an environmentally friendly, inexpensive, and high-performance adsorbent in applications such as water pollution treatment, soil remediation, and greenhouse gas abatement. Biochar has received more and more attention in the treatment of heavy metal-contaminated water and soil over the past decade. In the existing studies, biochar has been used to reduce the concentration of heavy metals or their toxicity through different mechanisms to achieve remediation effects. However, in the treatment of heavy metals, there are still many problems that need to be solved, and there is still a very broad space for research. (Hua, 2024a). The characteristics and applications of biochar are heavily influenced by production methods and the type of organic material used as feedstock (Varkolu *et al.*, 2025). Biochars derived from agricultural by-products including sawdust were successfully produced, homogenized following the calcination process, and then activated by *50% NaOH* (Le *et al.*, 2021). This work provides an insight into the use of modified biochar for the removal of metals from real wastewater (Collivignarelli, W. A.M.A.N. Illankoon, *et al.*, 2024). This chapter reveals a summary of the research findings. Conclusions are to be drawn and recommendations are to be made from the research findings.

5.1 EXPERIMENTAL DESIGN

Production and activation of biochar

The method of production and activation of the biochar was adopted from (Collivignarelli, W. A.M.A.N. Illankoon, *et al.*, 2024). The sawdust were collected from sawmill in Bindura, washed, dried and weighed. After drying, 1kg of the sawdust was pyrolyzed in a muffle furnace at $350^{o}C$ for 6 hours. A solution of 50% NaOH was prepared to activate the biochar at 3 hours and 6 hours contact time. The conversion rate of the feedstock to biochar was 40%. The process of production and activation was successful and samples were taken to be characterized by FTIR.

Adsorption experiments

The study evaluated the effectiveness of biochar in removing lead (Pb) and methylene blue (MB) from water. The removal efficiency was determined after 24 hours of contact between the biochar and the contaminated water. For the experiments, biochar samples were tested in three forms: un-activated biochar, activated biochar with a 3-hour activation/contact time, and activated biochar with a 6-hour activation/contact time. For each condition, three replicates were prepared by placing 2 g of biochar in separate Erlenmeyer flasks. Then, 200 mL of polluted water was added to each flask, and the mixtures were agitated on a laboratory shaker. During the run, 50 mL aliquots were collected and filtered after 3, 15, and 24 hours. The filtered samples were analysed using UV–Vis spectroscopy for MB concentration and atomic absorption spectroscopy (AAS) for Pb concentration.

MB removal (UV–Vis)

Five MB standard solutions were prepared, and the UV–Vis instrument was calibrated using a blank and these standards. The MB concentration in the unknown samples was then measured. The results indicated that biochar significantly reduced MB concentration: the activated biochar achieved above 90% removal, while the un-activated biochar removed approximately 70%. The MB removal was also confirmed visually, as the solution colour changed from dark purple to light purple after 24 hours, indicating a decrease in MB concentration over time.

Pb removal (AAS)

For Pb analysis, three Pb standard solutions were prepared and used to calibrate the AAS instrument along with a blank. The Pb concentration in the unknown samples was then measured. The results showed a strong reduction in Pb levels. Specifically, biochar activated for 3 hours and 6 hours resulted in approximately 94% and 98% Pb removal, respectively. In contrast, un-activated biochar showed a lower removal efficiency of about 44%.

In conclusion, the findings demonstrate that biochar effectively removes methylene blue (MB) from water. Even without activation, the biochar was able to reduce MB concentrations by about 70%. However, activating the biochar increases its adsorption capacity and leads to higher removal efficiency, although this comes with added cost. Therefore, if cost is a key consideration, non-activated biochar can be used for MB removal; if maximum performance is required, activation is recommended.

Regarding lead (Pb) removal, activation of the biochar is necessary to achieve more effective and reliable results. Un-activated biochar removed only about 40% of the Pb, whereas activated biochar performed significantly better.

5.2 RECOMEMNDATIONS

To gain a better understanding of sawdust biochar and improve the available information, further studies should test a wider range of dyes and metals and evaluate how the biochar interacts with each contaminant. In addition, future research should incorporate more advanced characterization methods such as SEM, XRD, and TEM. These were not used in the present study due to financial limitations and limited access to the required equipment. For optimization, activation should also be carried out using different concentrations of activating agents and varying contact (activation) times. This would help identify the most effective conditions that are also economically practical. Finally, more investigation is needed to determine the safest and most appropriate method for disposing of the used biochar, and to confirm that its use and disposal do not create additional environmental or health risks.

5.3 CONCLUSSION

Activated sawdust biochar was found to effectively remove methylene blue (MB) and lead (Pb) from contaminated water. The FTIR confirmed that NaOH activation altered the surface chemistry of the biochar by introducing new functional groups such as hydroxyl groups and carbonyl groups. Increasing activation times increased the intensity of these functional groups and also improved the adsorption efficiency of the biochar. Overall, this study demonstrates that water treatment can be achieved using low-cost methods that can be applied widely, since biochar can be produced from many carbon-rich materials such as timber sawdust and agricultural waste. Moreover, increasing the contact time between the biochar and the polluted water is expected to further improve removal efficiency. Although complete (100%) removal was not achieved, using repeated contact cycles between the biochar and contaminated water is likely to lead to better and more favorable overall results.

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APPENDIX



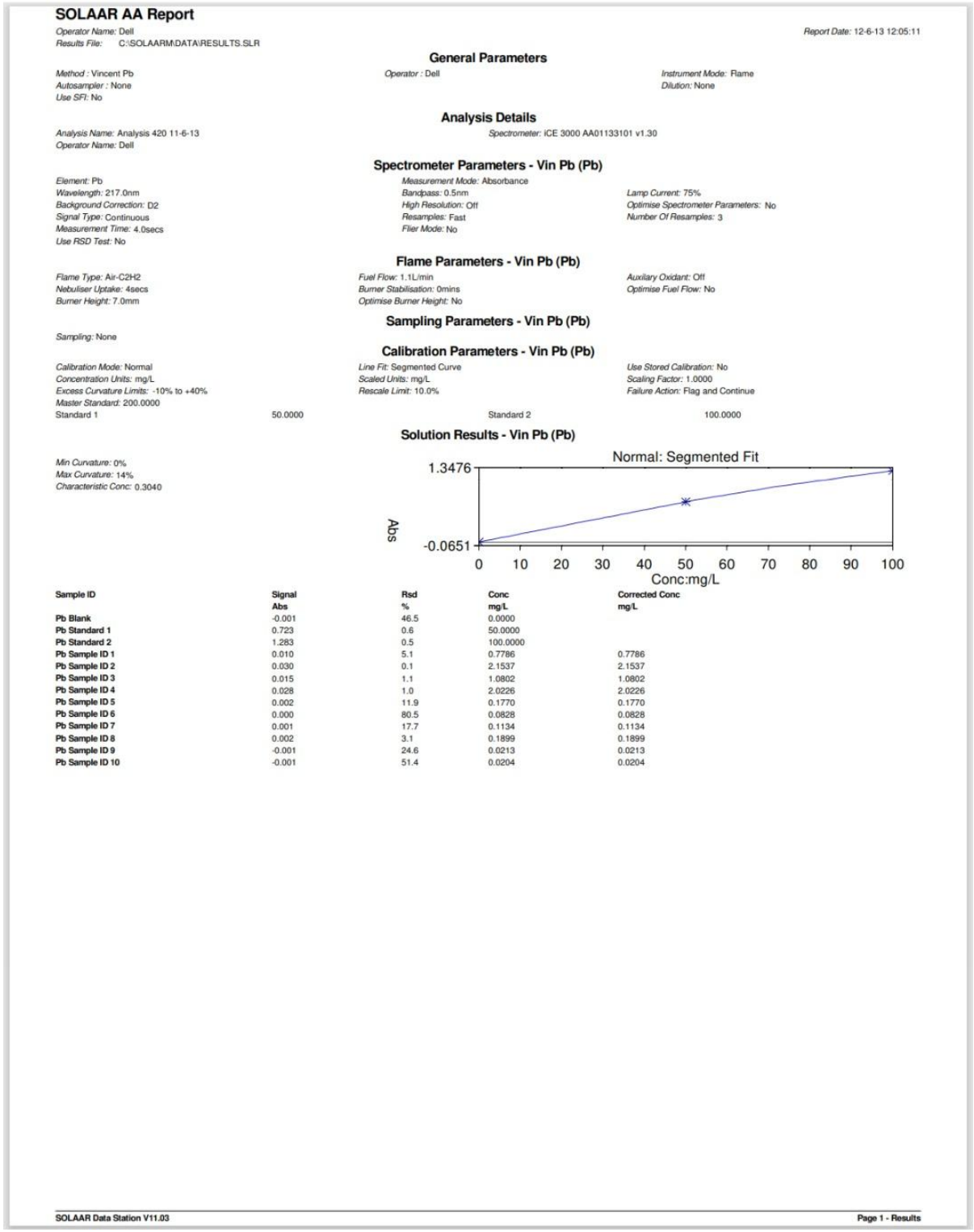
Figure 3 sawdust feedstocks in the muffle furnace



Figure 4 Adsorption experiments, the samples and biochar on a shaker

Table 1 samples for UV-Vis and AAS analysis

		
Figure 5 Samples for UV-Vis and AAS analysis after 15 hours	*Figure 6 Samples for UV-Vis and AAS analysis after 3 hours*	*Figure 7 Samples for UV-Vis and AAS analysis after 24 hours*



SOLAAR AA Report

Operator Name: Dell
Results File: C:\SOLAARM\DATA\RESULTS.SLR

Report Date: 12-6-13 12:05:11

General Parameters

Method : Vincent Pb
Autosampler : None
Use SFI: No

Operator : Dell

Instrument Mode: Flame
Dilution: None

Analysis Details

Analysis Name: Analysis 420 11-6-13
Operator Name: Dell

Spectrometer: ICE 3000 AA01133101 v1.30

Spectrometer Parameters - Vin Pb (Pb)

Element: Pb
Wavelength: 217.0nm
Background Correction: D2
Signal Type: Continuous
Measurement Time: 4.0secs
Use RSD Test: No

Measurement Mode: Absorbance
Bandpass: 0.5nm
High Resolution: Off
Resamples: Fast
Flier Mode: No

Lamp Current: 75%
Optimise Spectrometer Parameters: No
Number Of Resamples: 3

Flame Parameters - Vin Pb (Pb)

Flame Type: Air-C2H2
Nebuliser Uptake: 4secs
Burner Height: 7.0mm

Fuel Flow: 1.1L/min
Burner Stabilisation: 0mins
Optimise Burner Height: No

Auxilary Oxidant: Off
Optimise Fuel Flow: No

Sampling Parameters - Vin Pb (Pb)

Sampling: None

Calibration Parameters - Vin Pb (Pb)

Calibration Mode: Normal
Concentration Units: mg/L
Excess Curvature Limits: -10% to +40%
Master Standard: 200.0000
Standard 1 50.0000

Line Fit: Segmented Curve
Scaled Units: mg/L
Rescale Limit: 10.0%

Use Stored Calibration: No
Scaling Factor: 1.0000
Failure Action: Flag and Continue

Standard 2 100.0000

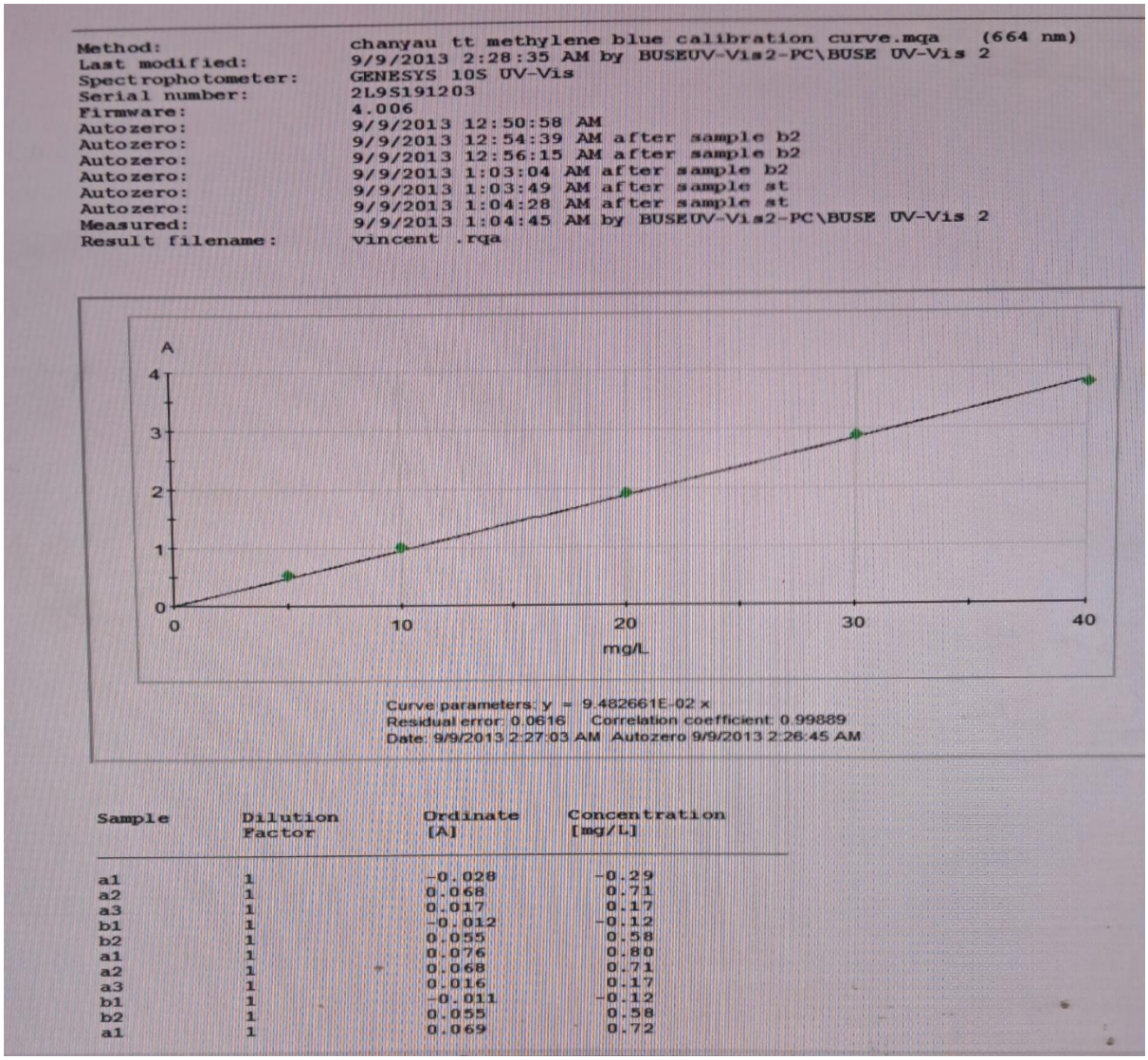
Solution Results - Vin Pb (Pb)

Min Curvature: 0%
Max Curvature: 14%
Characteristic Conc: 0.3040

Sample ID	Signal Abs	Rsd %	Conc mg/L	Corrected Conc mg/L
Pb Blank	-0.001	46.5	0.0000	
Pb Standard 1	0.723	0.6	50.0000	
Pb Standard 2	1.283	0.5	100.0000	
Pb Sample ID 1	0.010	5.1	0.7786	0.7786
Pb Sample ID 2	0.030	0.1	2.1537	2.1537
Pb Sample ID 3	0.015	1.1	1.0802	1.0802
Pb Sample ID 4	0.028	1.0	2.0226	2.0226
Pb Sample ID 5	0.002	11.9	0.1770	0.1770
Pb Sample ID 6	0.000	80.5	0.0828	0.0828
Pb Sample ID 7	0.001	17.7	0.1134	0.1134
Pb Sample ID 8	0.002	3.1	0.1899	0.1899
Pb Sample ID 9	-0.001	24.6	0.0213	0.0213
Pb Sample ID 10	-0.001	51.4	0.0204	0.0204

SOLAAR Data Station V11.03 Page 1 - Results

Figure 8 AAS results

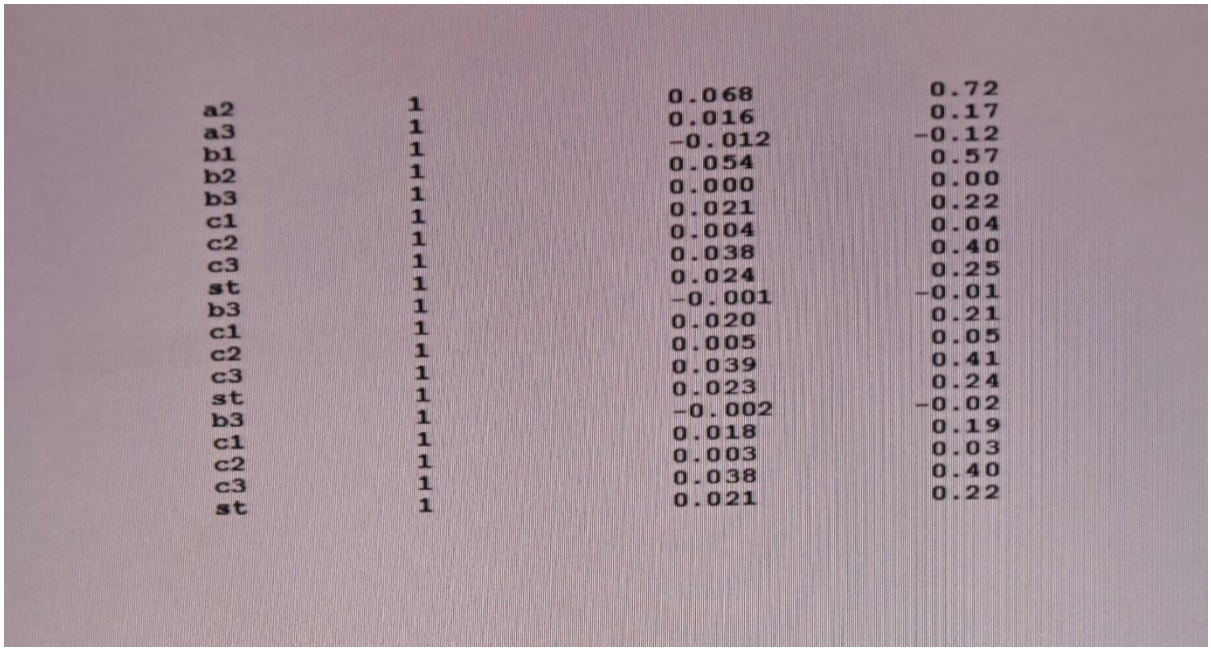


Method:	chanyau tt methylene blue calibration curve.mqa (664 nm)
Last modified:	9/9/2013 2:28:35 AM by BUSEUV-Vis2-PC\BUSE UV-Vis 2
Spectrophotometer:	GENESYS 10S UV-Vis
Serial number:	2L9S191203
Firmware:	4.006
Autozero:	9/9/2013 12:50:58 AM
Autozero:	9/9/2013 12:54:39 AM after sample b2
Autozero:	9/9/2013 12:56:15 AM after sample b2
Autozero:	9/9/2013 1:03:04 AM after sample b2
Autozero:	9/9/2013 1:03:49 AM after sample st
Autozero:	9/9/2013 1:04:28 AM after sample st
Measured:	9/9/2013 1:04:45 AM by BUSEUV-Vis2-PC\BUSE UV-Vis 2
Result filename:	vincent .rqa

Curve parameters: y = 9.482661E-02 x
Residual error: 0.0616 Correlation coefficient: 0.99889
Date: 9/9/2013 2:27:03 AM Autozero 9/9/2013 2:26:45 AM

Sample	Dilution Factor	Ordinate [A]	Concentration [mg/L]
a1	1	-0.028	-0.29
a2	1	0.068	0.71
a3	1	0.017	0.17
b1	1	-0.012	-0.12
b2	1	0.055	0.58
a1	1	0.076	0.80
a2	1	0.068	0.71
a3	1	0.016	0.17
b1	1	-0.011	-0.12
b2	1	0.055	0.58
a1	1	0.069	0.72

Figure 9 UV-Vis results page 1



a2	1	0.068	0.72
a3	1	0.016	0.17
b1	1	-0.012	-0.12
b2	1	0.054	0.57
b3	1	0.000	0.00
c1	1	0.021	0.22
c2	1	0.004	0.04
c3	1	0.038	0.40
st	1	0.024	0.25
b3	1	-0.001	-0.01
c1	1	0.020	0.21
c2	1	0.005	0.05
c3	1	0.039	0.41
st	1	0.023	0.24
b3	1	-0.002	-0.02
c1	1	0.018	0.19
c2	1	0.003	0.03
c3	1	0.038	0.40
st	1	0.021	0.22

Figure 10 UV-Vis results page 2