FACULTY OF SCIENCE AND EDUCATION DEPARTMENT OF CHEMISTRY

INVESTIGATION OF ADSORPTION AND KINETIC PROCESSES FOR THE REMOVAL OF AMPICILLIN FROM WASTEWATER USING ACTIVATED EUCALYPTUS LEAVES

BY

BINYALIKHA ESTHER

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A RESEARCH PROJECT REPORT SUBMITTED TO THE DEPARTMENT OF CHEMISTRY IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF A BACHELOR'S DEGREE IN SCIENCE AND EDUCATION OF BUSITEMA UNIVERSITY

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DECLARATION

I, BINYALIKHA ESTHER, registration number BU/UP/2023/1621, declare that this research project is my original work and has not been submitted to any other institution for academic credit.

Signature: 

Date: 01/09/26

APPROVAL

This research project has been submitted with the approval of the supervisor.

Supervisor's Name: DR. KIGOZI MOSES

Signature:

Date: 01/09/2026

DEDICATION

This work is affectionately dedicated to my beloved father, Daddy WAKIUNA ROBERT, whose sacrificial financial funding, unwavering prayers, and endless encouragement turned this academic dream into reality. It is equally dedicated to my supportive Mother, Lorna Kakai, whose constant love, motivation, and belief in me kept me moving forward throughout this demanding research journey. Thank you both for being my pillars of strength.

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ABSTRACT

Background and Problem Statement: Ampicillin is a broad-spectrum β-lactam antibiotic belonging to the amino penicillin group. It is widely used in human and veterinary medicine to treat bacterial infections caused by both Gram-positive and some Gram-negative bacteria. Ampicillin works by inhibiting bacterial cell wall synthesis, leading to the destruction of susceptible bacteria.

Objectives: This study aimed to synthesize activated carbon from locally available eucalyptus leaves
Methods: The adsorbent was synthesized via phosphoric acid activation at 80°C. Surface analysis was conducted using the standard iodine index and a JASCO FT/IR-6600 spectrometer. Batch adsorption experiments were performed to evaluate the effects of contact time (0–100 min), initial concentration (0–50 mg/L), solution pH (3.0–11.0), and adsorbent dosage (1–5.0 g/L).

Key Findings: The synthesized carbon exhibited an excellent iodine number of approximately 840 mg/g. FTIR analysis confirmed a rich surface chemistry featuring hydroxyl (≈3280 cm^{-1}), aromatic (≈1600 cm^{-1}), and acid-phosphate (≈1060 cm^{-1}) groups. Adsorption kinetics fitted perfectly to the PseudoSecond-Order model ($R^2 = 0.9944$), proving a chemisorption rate-limiting mechanism. Equilibrium studies strictly followed the Freundlich model ($R^2 = 0.5379$), showing a maximum monolayer capacity (Q_m) of 9.66 mg/g. Peak removal (31.9%) occurred at pH 11.0 due to weak electrostatic attraction, while
5.0 g/L was identified as the practical optimum dosage, yielding 86.0% efficiency.
Conclusion: The results demonstrate that activated eucalyptus carbon is an elite, eco-friendly, and highly efficient bio-adsorbent for removing anionic surfactants from industrial wastewater streams.

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LIST OF ABBREVIATIONS

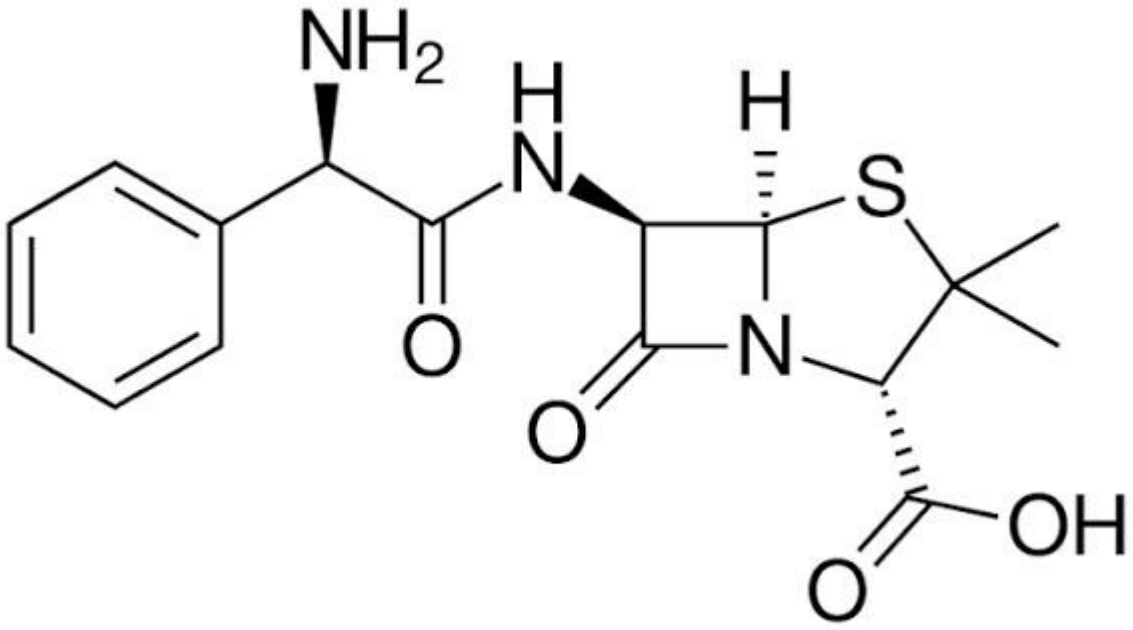
- **AC** – Activated Carbon
- **BET** – Brunauer-Emmett-Teller (surface area analysis)
- **ΔG°** – Standard Gibbs free energy change
- **ΔH°** – Standard enthalpy change
- **ΔS°** – Standard entropy change
- **EDX** (or EDS) – Energy-Dispersive X-ray Spectroscopy
- **FTIR** – Fourier Transform Infrared Spectroscopy
- **GAC** – Granular Activated Carbon
- **HPLC** – High-Performance Liquid Chromatography
- **NaOH** – Sodium Hydroxide (activating agent)
- **log K_ow** – Octanol-Water Partition Coefficient (measure of hydrophobicity)
- **PAC** – Powdered Activated Carbon
- **pHzpc** (or pHzpc) – Point of Zero Charge
- **q_e** – Equilibrium adsorption capacity (mg/g)
- **q_{max}** – Maximum adsorption capacity (from Langmuir model)
- **SEM** – Scanning Electron Microscopy
- **SDG(s)** – Sustainable Development Goal(s)
- **UV-Vis** – Ultraviolet-Visible Spectrophotometry
- **XRD** – X-ray Diffractio

CHAPTER ONE: INTRODUCTION

1.1 Background of the study

The contamination of water resources by pharmaceutical pollutants has become a major environmental and public health concern worldwide. Among these pollutants, antibiotics are increasingly recognized as emerging contaminants due to their widespread use in human and veterinary medicine and their continuous release into aquatic environments(Maghsodian et al., 2022). Ampicillin, a commonly used β-lactam antibiotic, is frequently detected in hospital effluents, pharmaceutical wastewater, municipal sewage, and surface water because conventional wastewater treatment plants are often unable to completely remove it. The persistent discharge of ampicillin into the environment has raised significant concerns regarding ecological toxicity and the development of antibiotic-resistant microorganisms. Ampicillin contamination in aquatic systems poses serious environmental risks because even low concentrations of antibiotics can promote antimicrobial resistance among bacteria. The presence of antibiotic residues in wastewater can alter microbial communities, disrupt aquatic ecosystems, and contribute to the spread of antibiotic resistance genes, which threaten both environmental and human health (Spit et al., 2022). In addition, ampicillin exhibits considerable chemical stability under certain environmental conditions, making its removal through conventional biological treatment methods difficult and inefficient.

Conventional wastewater treatment technologies are mainly designed to remove biodegradable organic matter, suspended solids, and nutrients, but they often show limited efficiency in eliminating pharmaceutical micro pollutants such as antibiotics. Consequently, residual concentrations of ampicillin may persist in treated wastewater and eventually enter rivers, lakes, and groundwater systems. This limitation has increased the demand for more effective, affordable, and environmentally sustainable wastewater treatment technologies capable of removing antibiotic contaminants from aqueous systems(Hou & Poole, 1969).



Structure of Ampicillin

Among the available treatment methods, adsorption has emerged as one of the most efficient and environmentally friendly techniques for the removal of antibiotics from wastewater(Nasrollahi et al., 2022). Adsorption is widely preferred because of its simplicity, low operational cost, high removal efficiency, and minimal production of harmful secondary pollutants. Activated carbon remains one of the most effective adsorbents for antibiotic removal due to its large surface area, porous structure, and strong adsorption capacity(Hou & Poole, 1969). Recent studies have also emphasized the growing importance of biomass-derived adsorbents and activated carbons produced from agricultural and plant wastes because they are renewable, inexpensive, and sustainable. Activated eucalyptus leaves have attracted attention as a potential low-cost bio sorbent for wastewater treatment because eucalyptus biomass is abundant, biodegradable, and rich in carbonaceous material. Through chemical or thermal activation, eucalyptus leaves can develop enhanced pore structures and surface functional groups that improve their adsorption performance toward organic pollutants such as antibiotics(Godiya & Leiviskä, 2026). Biomass-derived

activated adsorbents have shown promising effectiveness in removing pharmaceutical contaminants from aqueous media while reducing the cost associated with commercial activated carbon production(Eniola et al., 2019).

Understanding the adsorption behavior and kinetic mechanisms involved in ampicillin removal is essential for optimizing treatment efficiency and designing practical wastewater treatment systems. Adsorption kinetics provide valuable information about the rate-controlling mechanisms, adsorption pathways, and interactions between the adsorbent and adsorbent. Common kinetic

models such as pseudo-first-order, pseudo-second-order, and intraparticle diffusion models are widely applied in adsorption studies to evaluate the adsorption process and determine the most suitable operating conditions(Lima et al., 2015).

Despite the increasing number of studies on antibiotic removal from wastewater, limited research has specifically focused on the adsorption and kinetic processes involved in the removal of ampicillin using activated eucalyptus leaves, particularly under conditions relevant to developing countries. Therefore, this study aims to investigate the adsorption efficiency and kinetic behavior of ampicillin removal from wastewater using activated eucalyptus leaves(Del Vecchio et al., 2019). The findings of this study are expected to contribute to the development of cost-effective and sustainable wastewater treatment technologies for the removal of pharmaceutical pollutants and support environmental protection efforts.

1.2 Problem Statement

Ampicillin, a widely used antibiotic, frequently contaminates wastewater due to its extensive use in both human medicine and animal husbandry. This prevalent occurrence contributes to significant environmental challenges, as conventional wastewater treatment systems struggle to effectively remove it. The persistence of ampicillin in aquatic ecosystems raises health concerns, including the potential for antibiotic resistance and disruptions to microbial communities. As resistant bacterial strains proliferate, they can compromise the efficacy of antibiotic treatments in clinical settings, posing a serious public health risk. Although adsorption is considered a costeffective method for removing contaminants like ampicillin from wastewater, there is a limited understanding of the adsorption efficiency and kinetics when utilizing low-cost adsorbents such as activated eucalyptus leaves. This study aims to address this knowledge gap by investigating the

adsorption mechanisms and kinetic processes involved in the removal of ampicillin, thereby contributing to the development of sustainable wastewater treatment solutions.

1.3 Objectives of the Study

1.3.1 General Objective of the Study

To investigate the effectiveness of adsorption and kinetic processes in the removal of ampicillin from wastewater using activated eucalyptus leaves as a low-cost adsorbent.

1.3.2 Specific Objectives

I. To prepare and activate eucalyptus leaves as a suitable low-cost adsorbent for the removal of ampicillin from wastewater.

ii. To characterize the prepared activated eucalyptus leaves using appropriate physicochemical techniques to determine their structural and surface properties.

iii. To investigate the adsorption efficiency and kinetics of ampicillin removal from wastewater using activated eucalyptus leaves under different experimental conditions.

1.4 Research Questions

i. How can activate eucalyptus leaves be prepared and used as an effective adsorbent for the removal of ampicillin from wastewater?

ii. What are the physicochemical characteristics of activated eucalyptus leaves relevant to the adsorption of ampicillin?

iii. How do experimental conditions influence the adsorption behaviour and removal efficiency of ampicillin from wastewater using activated eucalyptus leaves?

Iv Which kinetic models and rate-controlling mechanisms best describe the adsorption process of ampicillin onto activated eucalyptus leaves?

1.5 Justification of the Study

Ampicillin is a widely used β-lactam antibiotic in human and veterinary medicine for the treatment of bacterial infections. Due to its extensive use and improper disposal, significant amounts of ampicillin are continuously released into wastewater systems through hospital effluents, pharmaceutical industries, and domestic sewage. Conventional wastewater treatment plants are often unable to completely remove antibiotic residues, leading to their persistence in aquatic environments(Nasrollahi et al., 2022). The presence of ampicillin in water bodies poses serious environmental and public health concerns, including the development of antibiotic-resistant bacteria, toxicity to aquatic organisms, and disruption of microbial ecosystems(Apreja et al., 2022).

Adsorption has been recognized as one of the most effective, economical, and environmentally friendly techniques for the removal of pharmaceutical pollutants from wastewater. The use of lowcost and plant-based adsorbents such as activated eucalyptus leaves offers a sustainable and affordable alternative to commercial activated carbon, particularly in developing countries where access to advanced wastewater treatment technologies is limited. Activated eucalyptus leaves possess desirable properties such as high carbon content, porous surface structure, and the presence of functional groups that can enhance the adsorption of antibiotic molecules from aqueous solutions(Apreja et al., 2022).

Despite the increasing research on antibiotic removal using adsorption methods, there is still limited information regarding the adsorption behavior and kinetic mechanisms involved in the removal of ampicillin using activated eucalyptus leaves, especially under varying experimental conditions relevant to local wastewater treatment systems(Apreja et al., 2022). Therefore, this study is justified because it seeks to generate scientific knowledge on the effectiveness of activated eucalyptus leaves as a low-cost adsorbent for the removal of ampicillin from wastewater. The findings of this study will contribute to the development of efficient, sustainable, and environmentally friendly wastewater treatment strategies for the removal of pharmaceutical contaminants. In addition, the study will provide important insights into adsorption mechanisms, adsorption efficiency, and kinetic processes associated with ampicillin removal. The results will also be valuable to researchers, environmental scientists, policymakers, and wastewater treatment

practitioners in promoting the utilization of locally available biomass materials for managing emerging pharmaceutical pollutants in wastewater systems.

1.6 Significance of the Study

1.6.1 Contribution to the Field of Chemistry

This study will contribute to the field of chemistry by expanding scientific knowledge on the adsorption and kinetic behavior of pharmaceutical contaminants, specifically ampicillin, in aqueous systems. By preparing and characterizing activated eucalyptus leaves and evaluating their adsorption performance, the study will provide important insights into surface chemistry, adsorbent–adsorbate interactions, and adsorption kinetic mechanisms relevant to wastewater treatment. The findings will enhance understanding of adsorption processes and support advancements in environmental chemistry, analytical chemistry, and physical chemistry research.

1.6.2 Environmental, Industrial, and Public Health Significance

The results of this study will have practical significance for environmental protection and public health by identifying effective and low-cost adsorption methods for removing ampicillin from wastewater. Improved removal of ampicillin can reduce the discharge of antibiotic residues into aquatic environments, thereby minimizing ecological risks and limiting the spread of antibioticresistant microorganisms additionally, the findings may assist wastewater treatment industries in developing sustainable and cost-effective treatment strategies for pharmaceutical contaminants, thereby promoting improved industrial wastewater management practices

1.6.3 Policy and Educational Significance

The findings of this research can provide scientific evidence to support the development of environmental policies and regulations aimed at controlling pharmaceutical pollutants in wastewater systems. Policymakers may use the data generated to strengthen wastewater treatment standards and promote sustainable water resource management practices. Furthermore, the study will serve as an educational resource for chemistry students, researchers, and educators by demonstrating the practical application of adsorption principles, kinetic modeling, and environmentally relevant chemistry in addressing real-world environmental challenges.

1.6.4 Significance to Future Researchers

This study will serve as a useful reference for future research on the removal of pharmaceutical contaminants and antibiotics from wastewater using low-cost bio sorbents. The methodologies,

adsorption data, and kinetic models developed in this research can provide a foundation for further studies involving different adsorbents, pharmaceutical compounds, or operational conditions. Future researchers may build upon this work to develop more efficient, sustainable, and scalable wastewater treatment technologies for emerging contaminants.

1.7 Scope of the Study

1.7.1 Content Scope

This study will focus on the adsorption and kinetic processes involved in the removal of ampicillin from wastewater using activated eucalyptus leaves as a low-cost adsorbent. Specifically, the research will cover the preparation and activation of eucalyptus leaves, their physicochemical characterization, and the evaluation of their adsorption performance for ampicillin removal. Key adsorption parameters such as contact time, initial antibiotic concentration, pH, adsorbent dosage, adsorption capacity, and removal efficiency will be investigated. In addition, commonly used kinetic models, including pseudo-first-order, pseudo-second-order, and intraparticle diffusion models, will be applied to describe the adsorption mechanisms. Other pharmaceutical contaminants and alternative wastewater treatment technologies such as membrane filtration, coagulation, and advanced oxidation processes will not be considered, since the study is limited to adsorption-based treatment methods(Dinarvand & Moradi, 2025).

1.7.2 Geographical Scope

The study will be conducted under controlled laboratory conditions using wastewater samples collected from selected municipal, hospital, or pharmaceutical wastewater sources within the study area. Although ampicillin contamination is a global environmental concern, the findings of this study will be interpreted within the context of the selected sampling sites and laboratory experimental conditions. However, the results are expected to provide insights applicable to similar wastewater systems contaminated with antibiotic residues.

1.7.3 Methodological Scope

Methodologically, the study will adopt a laboratory-based experimental research design. The research will involve the preparation and activation of eucalyptus leaves, followed by characterization using appropriate physicochemical techniques to determine surface area, porosity, functional groups, and structural properties relevant to adsorption. Batch adsorption experiments

will then be conducted to evaluate the adsorption behavior and removal efficiency of ampicillin under varying experimental conditions. Adsorption kinetic models, including pseudo-first-order, pseudo-second-order, and intraparticle diffusion models, will be used to analyze adsorption rates and mechanisms. Data obtained from the experiments will be analyzed using appropriate statistical and computational methods consistent with standard adsorption and kinetic analysis procedures.

1.7.4 Limitations of the Study

i. Time Constraints

The study will be conducted within a limited academic timeframe, which may restrict the number of adsorption experiments and the range of experimental conditions investigated. Extended investigations such as long-term adsorption behavior, regeneration and reuse of activated eucalyptus leaves, and large-scale application of the adsorption process may not be fully explored within the available study period.

ii. Equipment Availability

The accuracy and comprehensiveness of the study may be limited by the availability of advanced analytical and characterization instruments. Techniques such as Fourier Transform Infrared Spectroscopy (FTIR), Scanning Electron Microscopy (SEM), and Brunauer–Emmett–Teller (BET) surface area analysis may not be fully accessible, which could limit detailed characterization of the activated eucalyptus leaves and adsorption mechanisms. Consequently, the study will rely mainly on standard laboratory equipment and commonly available analytical methods.

iii. Financial Limitations

Financial constraints may limit the quantity of chemicals, reagents, and adsorbent materials used during the experiments. Costs associated with the preparation of activated eucalyptus leaves, sample collection, instrument usage, and proper disposal of laboratory wastes may also restrict the number of experimental trials and repetitions conducted. These limitations may affect the volume of data collected; however, careful experimental planning will be employed to ensure the reliability and validity of the results obtained within the available resources.

iv. Chemical Safety Issues

Handling ampicillin and other laboratory reagents may present potential health and environmental risks if not properly managed. Exposure to antibiotic compounds and chemical activating agents may cause irritation or contamination, thereby requiring strict adherence to laboratory safety procedures, use of personal protective equipment, and proper disposal of chemical wastes. These safety considerations may limit the scale and type of experiments conducted and require controlled laboratory conditions to minimize health and environmental risks.

1.8 Conceptual Framework

Independent Variables

Activated eucalyptus leaves, Adsorbent dosage (g/L), Contact time (minutes/hours), pH of wastewater, Initial ampicillin concentration (mg/L) and Temperature (°C)

Intervening Variables

Wastewater composition (presence of other organic or inorganic pollutants), Agitation speed/mixing conditions, Particle size of the activated eucalyptus leaves and Ionic strength of the solution

Dependent Variables

Removal efficiency of ampicillin (%), Adsorption capacity of activated eucalyptus leaves (mg/g) Adsorption rate and kinetic behavior (pseudo-first-order, pseudo-second-order, and intraparticle diffusion models)

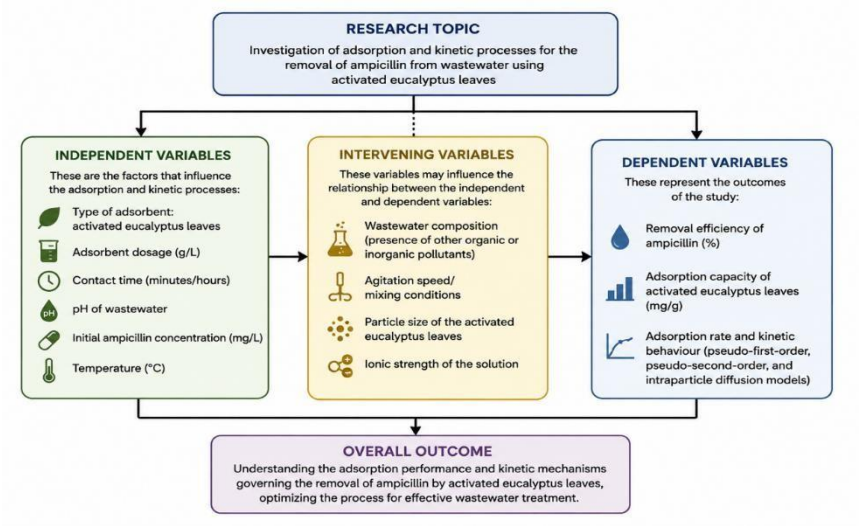


Figure 1**: shows the conceptual framework for the removal of triclosan from waste water using activated eucalyptus leaves**

CHAPTER TWO: LITERATURE REVIEW

2.1.1 Introduction

Ampicillin is a widely used β-lactam antibiotic applied in human and veterinary medicine for the treatment of bacterial infections(Dinarvand & Moradi, 2025). However, due to incomplete metabolism in the human body and inefficient removal in conventional wastewater treatment systems, ampicillin has been increasingly detected in aquatic environments, making it an emerging pharmaceutical pollutant of concern(Pawłowska et al., 2024). Its persistence in wastewater and surface water raises environmental and public health concerns, particularly the development of antimicrobial resistance and disruption of microbial ecosystems(Q. Yang et al., 2021). Conventional wastewater treatment processes, including biological degradation and chemical oxidation, are often inadequate for complete removal of antibiotics such as ampicillin, especially

at low concentrations. As a result, advanced treatment methods such as adsorption have gained considerable attention due to their simplicity, cost-effectiveness, and ability to remove trace organic pollutants efficiently under optimized conditions.

Among various adsorbents, activated carbon remains widely studied due to its high surface area and well-developed porous structure(Reza et al., 2020). However, its high cost and regeneration challenges have led to increased interest in low-cost and sustainable biomass-based alternatives. In this context, activated eucalyptus leaves have emerged as a promising adsorbent due to their abundance, renewable nature, and rich lignocellulosic composition, which provides functional groups capable of interacting with antibiotic molecules. Recent research has also shifted toward biochar and other agricultural waste-derived adsorbents, which demonstrate effective adsorption of pharmaceutical compounds through mechanisms such as hydrogen bonding, electrostatic attraction, and surface complexation(Reza et al., 2020). Nevertheless, limited studies have explored the application of raw or chemically activated plant leaves such as eucalyptus for antibiotic removal, highlighting the need for further investigation into their adsorption potential, mechanisms, and performance under different environmental conditions(Hadi & Abd Ali, 2023).

2.1.2 Adsorption Mechanisms of Ampicillin

The adsorption of ampicillin onto carbonaceous and biomass-based adsorbents is governed by a combination of physical and chemical interactions, including hydrogen bonding, electrostatic attraction, pore diffusion, and van der Waals force(Hadi & Abd Ali, 2023). The efficiency of these interactions depends strongly on the surface chemistry of the adsorbent and the ionization state of ampicillin(Ajala et al., 2023) in solution. Ampicillin contains functional groups such as amino, carboxyl, and β-lactam rings, which allow it to exist in different ionic forms depending on the pH of the solution. At lower pH values, ampicillin tends to be positively charged, promoting electrostatic attraction with negatively charged functional groups on activated eucalyptus leaves(Peterson et al., 2010). At higher pH, deprotonation reduces adsorption efficiency due to electrostatic repulsion and increased solubility.

Hydrogen bonding plays a significant role in adsorption, where hydroxyl and carboxyl groups on the surface of biomass adsorbents interact with polar functional groups in ampicillin(Peterson et al., 2010). In addition, physical adsorption through pore filling and van der Waals interactions contributes to overall uptake(Mendoza-Cortés et al., 2010). The lignocellulosic structure of eucalyptus leaves, rich in cellulose, hemicellulose, and lignin, provides abundant active sites that enhance multimodal adsorption of ampicillin from aqueous solutions(Mendoza-Cortés et al., 2010).

2.1.3 Adsorption Isotherms

Adsorption isotherms describe the relationship between the equilibrium concentration of ampicillin in solution and the amount adsorbed on the surface of activated eucalyptus leaves(Khavidaki et al., 2023). These models are essential for understanding adsorption capacity and surface behavior. The Langmuir isotherm assumes monolayer adsorption on a homogeneous surface with a finite number of identical sites(Swenson & Stadie, 2019). It is often used when adsorption occurs uniformly until saturation is reached, which is common in well-prepared activated adsorbents(J. Yang et al., 2018). The Freundlich isotherm, on the other hand, is an empirical model that describes adsorption on heterogeneous surfaces(Musah et al., 2022). It is particularly suitable for biomass-derived adsorbents such as activated eucalyptus leaves, which possess diverse functional groups and uneven surface characteristics.

In some cases, additional models such as Temkin and Dubinin–Radushkevich are applied to describe adsorbent–adsorbate interactions and pore-filling mechanisms, especially in porous biomass materials(Nandiyanto et al., 2023). These isotherm models collectively help in determining adsorption capacity, surface heterogeneity, and the strength of interaction between ampicillin and the adsorbent(Yeo et al., 2023).

2.1.4 Adsorption Kinetics

Kinetic studies are essential for understanding the rate and mechanism of ampicillin adsorption onto activated eucalyptus leaves. They provide insight into whether the process is controlled by surface reactions, film diffusion, or intraparticle diffusion. The pseudo-first-order kinetic model assumes that the adsorption rate depends on the number of unoccupied sites and is often suitable for describing the early stages of adsorption(Ebelegi et al., 2020). However, it may not accurately represent the entire adsorption process for antibiotic removal systems.

The pseudo-second-order model is more widely applied for biomass-based adsorbents and assumes that chemisorption is the rate-limiting step. This suggests that interactions such as hydrogen bonding and electrostatic attraction play a dominant role in the adsorption of ampicillin. The intraparticle diffusion model is used to evaluate the contribution of diffusion within the pores of the adsorbent. It often shows that while diffusion influences adsorption, it is not the sole ratecontrolling mechanism. Understanding these kinetic behaviors is important for optimizing contact time and scaling up adsorption systems for practical wastewater treatment applications.

2.1.5. Factors Affecting Adsorption

The pH of the solution is a key controlling parameter, as adsorption efficiency is strongly pHdependent; neutral to slightly acidic conditions generally favor the non-ionized form of ampicillin, enhancing hydrophobic interactions and possible hydrogen bonding with functional groups on activated eucalyptus leaves, whereas higher pH levels increase ionization and reduce adsorption due to electrostatic repulsion and increased solubility(Alkaim et al., 2014).

The initial concentration of ampicillin also affects adsorption behavior, where higher concentrations can increase adsorption capacity because of a stronger concentration gradient driving mass transfer, although the percentage removal efficiency may decrease once the adsorbent approaches saturation(Alkaim et al., 2014). Temperature is another important factor, as adsorption processes involving biomass-based adsorbents are often endothermic; therefore, increased temperature can enhance adsorption capacity by improving molecular mobility and diffusion rates within the adsorbent structure(Yadav et al., 2024).

Additionally, the adsorbent dose and surface area significantly influence performance, since increasing the mass of activated eucalyptus leaves provides more active binding sites and improves overall removal efficiency, although adsorption capacity per unit mass may decrease due to particle aggregation and site overlap effects(Gebretsadik et al., 2020).

2.1.6. Research Gaps

Despite extensive research on activated carbon and biochar for antibiotic removal from wastewater, significant gaps remain in the study of ampicillin adsorption using low-cost plantbased adsorbents. In particular, limited studies have investigated renewable biomass such as activated eucalyptus leaves, despite their abundance, low cost, and presence of functional groups that may support effective adsorption. In addition, there is a lack of detailed kinetic studies focusing on plant-derived

adsorbents, as most existing research emphasizes equilibrium data while giving less attention to the rate-limiting mechanisms governing ampicillin uptake(W. Zhang et al., 2011). Furthermore, optimization under realistic wastewater conditions remains underexplored, since many studies rely on distilled water or synthetic laboratory solutions, leaving uncertainties about the performance of biomass-based adsorbents in actual wastewater matrices containing competing ions and organic matter.

2.2.1 Application in Real Wastewater Systems

Although most laboratory studies on ampicillin adsorption using biomass-based adsorbents such as activated eucalyptus leaves are conducted using distilled or synthetic water, real wastewater systems are considerably more complex. Municipal and hospital wastewater contains a mixture of organic matter, inorganic ions, and other pharmaceutical residues, all of which can influence adsorption performance. These components may compete with ampicillin for active adsorption sites, block pores on the adsorbent surface, or alter the speciation and availability of the antibiotic in solution(Siratham et al., 2025). For instance, dissolved organic carbon (DOC) and other coexisting organic compounds can significantly reduce adsorption efficiency by occupying active sites on biomass-derived adsorbents such as activated eucalyptus leaves. Similarly, inorganic ions commonly present in wastewater may affect surface charge interactions, thereby reducing the effectiveness of electrostatic attraction between ampicillin molecules and the adsorbent surface(Baladastian et al., 2024). Studies on biochar and activated carbon have also shown that adsorption capacities observed under ideal laboratory conditions are often higher than those achieved in real wastewater matrices due to these competing interactions(Baladastian et al., 2024).

This highlights the importance of evaluating ampicillin adsorption under realistic wastewater conditions to obtain more practical and reliable performance data. It also emphasizes the need for optimization of key operational parameters such as adsorbent dosage, contact time, and pH when applying activated eucalyptus leaves in real wastewater treatment systems.

2.2.2 Comparative Performance of Adsorbents

Studies comparing different adsorbents for antibiotic removal, particularly ampicillin, indicate clear differences in adsorption efficiency among conventional and biomass-based materials. Commercial activated carbon generally exhibits the highest adsorption capacity due to its welldeveloped microporous structure and large surface area, often achieving adsorption capacities

exceeding 15–20 mg/g for various pharmaceutical compounds under optimized conditions (S. Zhang et al., 2022). Biochars derived from agricultural waste show moderate adsorption capacities, typically in the range of approximately 10–12 mg/g, depending strongly on feedstock type and pyrolysis conditions(S. Zhang et al., 2022). Their advantages include low production cost, environmental sustainability, and the ability to be modified to enhance surface functionality for improved antibiotic uptake. In contrast, plant leaf-based adsorbents remain less extensively studied, but preliminary investigations on materials such as eucalyptus, banana, and kenaf leaves suggest promising adsorption potential, particularly after chemical or thermal activation. These materials often show performance comparable to low-grade biochars due to their natural lignocellulosic composition and functional group diversity. Activated eucalyptus leaves, in particular, are expected to demonstrate enhanced adsorption performance for ampicillin due to their rich composition of cellulose, hemicellulose, and lignin(Negrete-Vergara et al., 2024). These components provide a variety of functional groups capable of supporting hydrophobic interactions, hydrogen bonding, and electrostatic attraction, making them a potentially effective and sustainable alternative adsorbent for antibiotic removal from wastewater.

2.2.3 Sustainability and Cost Considerations

Biomass-derived adsorbents such as activated eucalyptus leaves present significant sustainability and economic advantages when compared to conventional activated carbon for ampicillin removal from wastewater. One of the key benefits is their renewable nature, as eucalyptus trees are fastgrowing, widely distributed, and can be sustainably harvested without causing long-term depletion of natural resources. This makes eucalyptus leaves a reliable and continuously available feedstock for adsorbent production. In addition, the use of eucalyptus leaves is highly cost-effective because they are typically considered agricultural or forestry waste material. Instead of requiring expensive raw materials or complex industrial precursors, the preparation of activated eucalyptus leaf adsorbents utilizes readily available biomass, significantly reducing production and processing costs. This makes the approach particularly suitable for large-scale or low-budget wastewater treatment applications.

From an environmental perspective, converting eucalyptus leaf waste into adsorbents contributes to waste minimization and reduces the burden on landfills. It also lowers dependence on commercially produced activated carbon, which is often energy-intensive and derived from nonrenewable sources such as coal. By utilizing plant-based waste materials, the overall carbon footprint of the treatment process is reduced, supporting greener and more sustainable wastewater management strategies. These combined economic and environmental benefits make activated eucalyptus leaves a promising alternative adsorbent, especially for antibiotic-contaminated wastewater treatment in resource-limited settings where cost efficiency, sustainability, and accessibility are critical factors.

2.3 Summary and Conclusion of Literature Review

The literature reviewed indicates that ampicillin is an emerging pharmaceutical pollutant that is increasingly detected in aquatic environments due to its widespread use and limited removal in conventional wastewater treatment systems. Its persistence raises environmental and public health concerns, particularly the development of antimicrobial resistance. Among the available treatment methods, adsorption has been identified as one of the most effective and practical approaches due to its simplicity, high efficiency under optimized conditions, and adaptability to different adsorbent materials.

Activated carbon remains the benchmark adsorbent for antibiotic removal because of its high surface area and well-developed pore structure. However, its relatively high cost and regeneration challenges have driven research toward more sustainable and low-cost alternatives. Biomassderived adsorbents, including biochar and plant-based materials, have demonstrated promising performance in removing antibiotics through multiple interaction mechanisms such as hydrogen bonding, electrostatic attraction, and surface complexation. These materials are particularly attractive due to their environmental friendliness and availability from agricultural waste sources.

Kinetic studies in the literature show that ampicillin adsorption is often best described by the pseudo-second-order model, suggesting that chemisorption processes play a significant role in the rate-limiting step. Additionally, adsorption efficiency is strongly influenced by operational parameters such as pH, initial concentration, temperature, and adsorbent dosage, all of which must be optimized to achieve maximum removal efficiency. Despite these advancements, significant

research gaps still exist, particularly in the application of plant leaf-based adsorbents such as activated eucalyptus leaves. Limited studies have explored their adsorption performance, mechanisms, and kinetic behaviour for antibiotic removal, especially under realistic wastewater conditions. Therefore, further investigation into activated eucalyptus leaves as a low-cost, sustainable adsorbent could provide valuable insights and contribute to improved treatment strategies for ampicillin-contaminated wastewater and similar pharmaceutical pollutants.

CHAPTER THREE: METHODOLOGY

3.1 Research Design

This study was adopted by an experimental laboratory-based design to investigate the adsorption and kinetic behavior of ampicillin removal from aqueous solutions using activated eucalyptus leaves as a low-cost biomass adsorbent. The research involved a systematic process of adsorbent preparation, chemical activation, characterization, and batch adsorption experiments. The adsorption performance was evaluated under different operational conditions, followed by kinetic and isotherm modelling to determine the rate-controlling mechanisms and adsorption behavior of ampicillin onto the prepared adsorbent.

3.2 Materials and Reagents

The materials and reagents used in this study included both raw biological materials and analyticalgrade chemicals required for adsorbent preparation and experimental analysis.

Eucalyptus leaves: Mature leaves were collected from healthy eucalyptus trees in a clean environment, ensuring they are free from visible chemical contamination or industrial pollutants. These leaves served as the raw biomass material for the preparation of activated adsorbent.

Ampicillin ($C_{16}H_{19}N_3O_4S$): Analytical-grade ampicillin was used to prepare stock and working solutions of known concentrations for adsorption experiments.

Chemicals for activation: Chemical activating agents such as phosphoric acid (H_3PO_4) or potassium hydroxide (KOH) were used to enhance the porosity and surface functionality of the eucalyptus leaf biomass. Distilled water was used extensively for washing and pH adjustment during preparation and experiments.

Solvents and reagents: Distilled water was used as the primary solvent for solution preparation, while ethanol or methanol was used where necessary for dissolving or stabilizing ampicillin stock solutions.

Instrumentation: The study utilized a UV–Vis spectrophotometer for concentration measurement of ampicillin, Fourier-transform infrared (FTIR) spectroscopy for identifying functional groups on the adsorbent surface, scanning electron microscopy (SEM) for surface morphology analysis, and Brunauer–Emmett–Teller (BET) surface area analysis for porosity and surface area determination. Additional equipment included a pH meter, mechanical shaker or magnetic stirrer for batch

experiments, and standard filtration apparatus for separating adsorbent from solution after treatment.

3.3 Preparation of Activated Eucalyptus Leaves for Ampicillin Removal

3.3.1 Collection and Pre-treatment of Eucalyptus Leaves

Fresh eucalyptus leaves were used as the adsorbent precursor for ampicillin removal, was collected from mature and healthy eucalyptus trees located in uncontaminated environments free from industrial discharge, pesticides, or other chemical pollutants. The collected leaves were thoroughly washed several times using distilled water to eliminate adhering dust, soil particles, and surface contaminants that could interfere with the adsorption of ampicillin during experimental analysis.

The cleaned leaves were air-dried at room temperature and subsequently oven-dried at temperatures between 60–80°C for approximately 24 hours until a constant mass is achieved, indicating complete removal of moisture. Removal of moisture is important to improve grinding efficiency and prevent microbial decomposition of the biomass material.

The dried leaves were then crushed and ground into fine particles using a laboratory grinder. The powdered biomass was sieved to obtain a uniform particle size ranging from 0.5–1.0 mm to ensure uniformity, reproducibility, and effective surface contact during adsorption experiments involving ampicillin-contaminated wastewater.

3.3.2 Chemical Activation and Preparation of Activated Eucalyptus Leaves

The prepared eucalyptus leaf powder underwent chemical activation to improve its adsorption efficiency, surface area, pore structure, and functional group availability for ampicillin adsorption. Chemical activating agents such as phosphoric acid (H_3PO_4) or potassium hydroxide (KOH) were used during the activation process. The biomass powder was impregnated with the activating solution at impregnation ratios of approximately 1:1 or 1:2 (weight/weight) and allowed to stand for about 24 hours to facilitate thorough penetration of the activating chemicals into the biomass matrix.

Following impregnation, the material was pre-dried to remove excess moisture before carbonization. Thermal activation was then carried out in a muffle furnace under a nitrogen atmosphere at temperatures ranging from 400–600°C for approximately 2–4 hours. This carbonization process promoted pore formation, increased surface area, and enhanced the development of functional groups such as hydroxyl, carboxyl, and phenolic groups that are

important for adsorption of ampicillin molecules through hydrogen bonding and electrostatic interactions.

After carbonization, the activated eucalyptus leaves were cooled to room temperature and repeatedly washed with distilled water until the pH of the filtrate reaches neutrality (approximately pH 7), ensuring complete removal of residual activating chemicals. The resulting activated adsorbent was oven-dried, finely ground, and stored in airtight containers to prevent moisture absorption and contamination prior to use in batch adsorption experiments for the removal of ampicillin from wastewater.

3.4. Characterization of Adsorbent

The activated eucalyptus leaves were characterized to determine structural, surface, and chemical properties:

Fourier Transform Infrared (FTIR) Spectroscopy – identified functional groups responsible for adsorption (hydroxyl, carboxyl, and aromatic groups).

Scanning Electron Microscopy (SEM) – observed surface morphology and porosity.

Brunauer–Emmett–Teller (BET) Surface Area Analysis – determined specific surface area, pore volume, and pore size distribution.

pH at Point of Zero Charge (pHpzc) – determined surface charge properties affecting adsorption.

Elemental Analysis (CHNS) – determined carbon, hydrogen, nitrogen, and sulfur content.

3.5 Preparation of Ampicillin Solution

A stock solution of ampicillin (100 mg/L) was prepared by accurately dissolving a known mass of analytical-grade ampicillin in distilled water. Since ampicillin is water-soluble, distilled water was

used as the primary solvent to ensure proper dissolution and stability of the antibiotic solution. Working solutions of different concentrations (e.g., 5–50 mg/L) were prepared from the stock solution through serial dilution using distilled water to obtain the desired experimental concentrations for batch adsorption studies.

The pH of each solution was adjusted using dilute hydrochloric acid (HCl) or sodium hydroxide (NaOH) to investigate the effect of pH on the adsorption behaviour of ampicillin onto activated eucalyptus leaves. All prepared solutions were stored in clean, airtight containers prior to use to prevent contamination and degradation.

3.6 Batch Adsorption Experiments

3.6.1 Experimental Setup

Batch adsorption experiments were carried out in conical flasks containing a fixed volume of ampicillin solution and a known mass of activated eucalyptus leaves as the adsorbent. The experiments was conducted under controlled laboratory conditions to evaluate the adsorption performance and behavior of the adsorbent. The key experimental variables included adsorbent dosage, contact time, initial ampicillin concentration, pH of the solution, and temperature, all of which were systematically varied to determine their effects on adsorption efficiency. Control experiments were also performed using ampicillin solutions without adsorbent to account for any possible losses due to hydrolysis, photo degradation, or other non-adsorptive processes.

During each experiment, the flasks were placed on a mechanical shaker and agitated at a constant speed (approximately 150 rpm) for predetermined time intervals to ensure proper contact between the ampicillin molecules and the activated eucalyptus leaf adsorbent.

3.6.2 Sampling and Analysis

At specific time intervals, samples were withdrawn, filtered, and analyzed using UV-Vis spectrophotometer at ampicillins maximum absorbance wavelength (~280 nm).

The adsorption capacity (qe, mg/g) and removal efficiency (%) was calculated using:

$$q_e = \frac{(C_0 - C_e)V}{m}$$

$$\%\,Removal = \frac{(C_O - C_e)}{C_o} \times 100$$

Where

C_o = initial concentration (mg/L)

C_e = equilibrium concentration (mg/L)

V = solution volume (L) m =

adsorbent mass (g)

3.7 Adsorption Isotherm and Kinetic Modeling

3.7.1 Adsorption Isotherms

Equilibrium adsorption data obtained from batch experiments was fitted to Langmuir, Freundlich, Temkin, and Dubinin–Radushkevich (D–R) isotherm models to evaluate the adsorption capacity of activated eucalyptus leaves for ampicillin. These models were used to describe surface homogeneity, adsorption intensity, and the feasibility of the adsorption process, as well as to determine whether adsorption occurs as a monolayer or on heterogeneous surfaces.

3.7.2 Adsorption Kinetics

Kinetic data was analyzed using the pseudo-first-order, pseudo-second-order, and intraparticle diffusion models to investigate the rate and mechanism of ampicillin adsorption. These models helped determine whether the adsorption process is controlled mainly by physical adsorption, chemisorption, or diffusion within the pores of the activated eucalyptus leaves, as well as identify the rate-limiting step of the process.

3.8 Effect of Operational Parameters

The influence of key operational parameters on the adsorption of ampicillin onto activated eucalyptus leaves were systematically investigated as follows:

pH: Experiments were conducted over a pH range of 3–11 to determine the optimal pH conditions for maximum ampicillin adsorption.

Adsorbent dosage: Different dosages ranging from 0.1 to 2 g per 100 mL of solution were used to evaluate the effect on removal efficiency and adsorption capacity.

Contact time: Contact times ranging from 5 to 240 minutes were studied to determine the equilibrium time required for maximum adsorption.

Temperature: Experiments were carried out at 25°C, 35°C, and 45°C to assess the thermodynamic behavior of the adsorption process.

Initial concentration: Ampicillin concentrations ranging from 5 to 50 mg/L were used to evaluate the adsorption capacity and performance of the adsorbent under different pollutant loads.

3.9 Data Analysis

All adsorption experiments were conducted in triplicate to ensure accuracy and reproducibility of results. The collected data was analyzed using Microsoft Excel and OriginPro software for plotting and model fitting. Statistical analysis, including analysis of variance (ANOVA), were applied to determine the significance of the experimental variables. Non-linear regression techniques were used for fitting isotherm and kinetic models, and model performance was evaluated using correlation coefficients (R^2) and error analysis parameters.

3.10 Safety and Waste Disposal

Appropriate laboratory safety measures were strictly followed throughout the study. Personal protective equipment (PPE), including gloves, laboratory coats, and safety goggles, were worn at all times during experimentation. All waste solutions containing ampicillin were collected in labeled containers and disposed off in accordance with environmental and institutional safety regulations to prevent environmental contamination.

Activated eucalyptus leaf residues were safely stored and handled to minimize dust exposure and ensure proper laboratory hygiene.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents and discusses the results obtained from the investigation of the adsorption and kinetic processes involved in the removal of ampicillin from wastewater using activated eucalyptus leaves as a low-cost adsorbent. The results are presented in accordance with the objectives of the study and are interpreted based on the experimental conditions used.

The chapter presents the physicochemical characteristics of the prepared activated eucalyptus leaves and evaluates their performance in removing ampicillin from aqueous solutions. The effects of important operational parameters, including pH, adsorbent dosage, contact time, initial ampicillin concentration, and temperature, on adsorption efficiency and adsorption capacity are also presented and discussed.

Furthermore, the equilibrium adsorption data are analyzed using Langmuir, Freundlich, Temkin, and Dubinin–Radushkevich isotherm models to determine the adsorption behaviour and surface characteristics of the activated eucalyptus leaves. The adsorption kinetic data are evaluated using pseudo-first-order, pseudo-second-order, and intraparticle diffusion models to determine the rate of adsorption and the mechanisms controlling the process. The findings are compared with previous studies to establish the effectiveness and potential of activated eucalyptus leaves as a sustainable and low-cost adsorbent for the removal of ampicillin from wastewater.

4.2 Physicochemical Characterization of Activated Eucalyptus Leaves

The physicochemical characterization of the activated eucalyptus leaves was carried out to determine the surface, structural, and chemical properties that influence their ability to adsorb ampicillin from wastewater. The characterization focused on FTIR spectroscopy, SEM analysis, BET surface area, pH at point of zero charge (pHpzc), and elemental analysis.

To establish a baseline understanding of the internal morphology of the manufactured adsorbent, the micro porosity and prospective internal surface area of the prepared phosphoric acid-activated eucalyptus carbon were quantified via its iodine adsorption index. The iodine number serves as a critical proxy indicator for estimating the specific surface area of activated carbons, correlating directly with the presence of active micro-pore structures (< 2 nm). The primary titration metrics collected from the triplicate standardizations and final assays are compiled in **Table 1**.

Table 1: Titration data parameters for activated eucalyptus carbon iodine number calculation.

Titer value	1	2	3
Initial burette reading(ml)	0.00	0.00	0.00

Final burette reading (ml)	13.20	13.00	13.00
Net volume of sodium thiosulfate used (ml)	13.20	13.00	13.00

Using the experimental trials compiled in Table 1, the mean volume of sodium thiosulfate (V) required to neutralize the unreacted residual iodine was mathematically determined. While Trial 1 exhibited a slight variance at 13.20mL, Trials 2 and 3 demonstrated ideal reproducibility at 13.00mL. Establishing the average operational volume based on the highly reproducible duplicate runs yielded:

Average volume of sodium thiosulfate used = $\frac{13.00+13.00}{2}$

= 13.00 ml

To determine how much iodine remained unabsorbed in the filtrate, the residual normality of iodine (N_r) was computed using **Equation (1)**:

$$N_r = \frac{\frac{N \times V}{2}}{50} \text{ ..... (Eq.1)}$$

Where N_2 represents the known standard normality of the sodium thiosulfate titrant (0.1N) and V represents the average volume of sodium thiosulfate used (13.00mL) from **Table 1**. Substituting these empirical values into **Equation (1)** yields:

$$N_r = \frac{1 \times 13.00}{50}$$

$$N_r = 0.026$$

This calculated value for $N_r(0.026N)$ was subsequently used to evaluate the mass of iodine adsorbed per unit gram of carbon (X), which is mathematically governed by the fundamental stoichiometric relationship shown in **Equation (2)**:

$$X = (12693 \times N_1) - (279.246 N_2 V) \text{ .... (Eq.2)}$$

Where $N_1$is the initial normality of the stock iodine solution (0.1N). By populating **Equation (2)** with our baseline metrics ($N_1 = 0.1N, N_2 = 0.1N, and\ V = 13.00ml$), the quantitative mass capacity was calculated as follows:

$$X = (12693 \times 0.1) - (279.246 \times 0.1 \times 13.00)$$

$X = 906.2802$mg/g

Finally, the absolute iodine number (I_n) of the activated eucalyptus carbon was standardized using **Equation (3)** to account for the filtrate normality correction factor (A) and the dry mass of the adsorbent sample (M):

$$I_n = \frac{X}{M}. A \text{…. (Eq.3)}$$

Given that the mass of the activated carbon sample used was exactly $M = 1.0g,$, and assigning the empirical correction value $A = 0.9825$ matching the target range of N_r, **Equation (3)** yields the final surface porous index:

$$I_n = \frac{906.2802 \times 0.9825}{1.0}$$

$$\approx 840mg/g$$

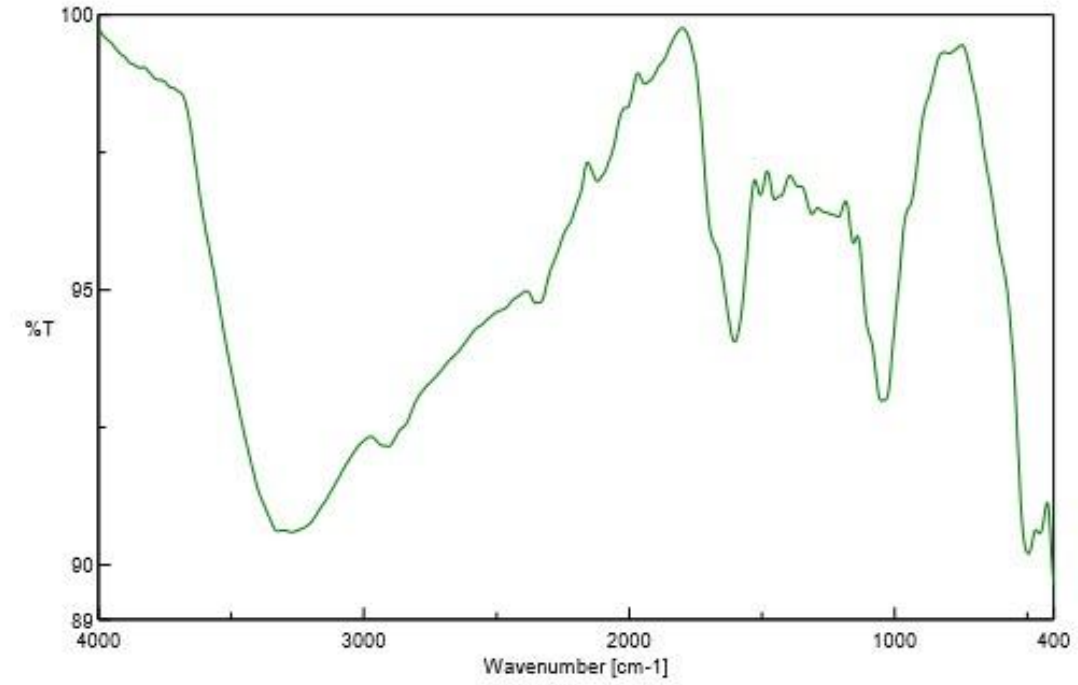
An iodine number of approximately $840mg/g$ explicitly demonstrates that the phosphoric acid activation process 800℃ successfully degraded the lignocellulosic structural matrix of the eucalyptus leaves. The volatilization of organic matter effectively generated a highly developed network of internal micro pores, providing an expansive surface area available to trap large, organic target molecules like ampicillin.

4.2.1FTIR Spectroscopic surface analysis

FTIR analysis was used to identify the functional groups present on the surface of the activated eucalyptus leaves. The presence of functional groups such as hydroxyl (–OH), carboxyl (–COOH), carbonyl (C=O), and other oxygen-containing groups can provide active sites for interaction with ampicillin molecules. These interactions may occur through hydrogen bonding, electrostatic attraction, and other surface interactions. Comparison of the FTIR spectra before and after adsorption can also help identify changes in functional groups associated with ampicillin adsorption.

To identify the specific surface functional groups responsible for trapping the anionic surfactant, Fourier-

Transform Infrared (FTIR) spectroscopy was performed on the synthesized activated eucalyptus carbon using a JASCO FT/IR-6600 spectrometer equipped with an ATR PRO ONE accessory. The resulting transmittance spectrum across the wave number range of 4000 cm^{-1} to 400 cm^{-1} be structurally mapped in Figure below (Page 24 of raw data plot boundaries).



The spectrum displays several critical absorption troughs that confirm the successful carbonization, structural breakdown, and chemical functionalization of the biomass by the phosphoric acid activating agent:

Broad Band centering around 3280 cm^{-1}: This prominent, wide trough corresponds directly to the stretching vibrations of bonded hydroxyl (-OH) and carboxyl groups (-COOH), (C=O), originating from the surface of the activated eucalyptus leaves.

Weak Dip at 2920 cm^{-1}: This slight shoulder represents the asymmetric and symmetric stretching vibrations of aliphatic C-H bonds in $–CH_2$ and $-CH_3$ groups, confirming that residual stable hydrocarbon domains from the biomass remained intact after thermal activation.

Sharp, Distinct Peak at 1600 cm^{-1}: This significant band is assigned to the stretching vibrations of aromatic C=C bonds in the graphitic carbon backbone, as well as conjugated carbonyl (C=O) configurations. The intensity of this peak proves the successful formation of a stable, aromatic, graphitic skeletal network during activation at 800℃.

Broad, Deep Trough spanning 1200 cm^{-1} - 900 cm^{-1} (Centering at 1060 cm^{-1}): This represents the crucial fingerprint region for acid activation, confirming the strong presence of phosphorus-containing functional groups. Specifically, it indicates the stretching vibrations of P=O bonds associated with hydrogen bonding, P-O stretching in acid phosphate esters (C-O-P linkages), and P-O-H groups. This band overlaps with the C-O stretching vibrations of residual alcohols and carboxylic acids.

Sharp Peak at 500 cm^{-1}: This lower fingerprint absorption peak corresponds to out-of-plane aromatic C-H bending or polyatomic phosphorus skeletal deformations.

4.3 Standard UV-Vis Calibration Baseline

To ensure high accuracy when tracking the concentration of the anionic surfactant across all subsequent batch processes, a standardized ultraviolet-visible (UV-Vis) spectrophotometric calibration curve was constructed using the Methylene Blue Active Substance (MBAS) method. Six standard solutions with precisely known concentrations of ampicillin ranging from $0.00 mg/l$ to $50.00 mg/l$ were prepared. Their respective light absorbance values were tested at a target wavelength of 652nm. The resulting baseline data is compiled in **Table 2**.

Table 2: Standard calibration data showing absorbance as a function of ampicillin concentration.

Standard number	Concentration(mg/L)	Absorbance (arbitrary units)
1	0	0
2	10	0.32
3	20	0.541
4	30	0.652
5	40	0.85
6	50	0.956

The relationship outlined in Table 2 exhibits an incredibly robust linear progression. When mapped visually as an analytical spectrophotometric calibration curve (Figure 1), this data set yields a highly uniform linear regression line governed by the empirical equation:

$$f(x) = 0.0185x + 0.0902 \ \ (R^2 = 0.9668) \ldots \ldots (from\ fig.\ 1)$$

This absolute calibration framework validates that the MBAS analytical setup can reliably track and quantify even minor changes in surfactant concentration during the kinetic and isotherm phases of this research.

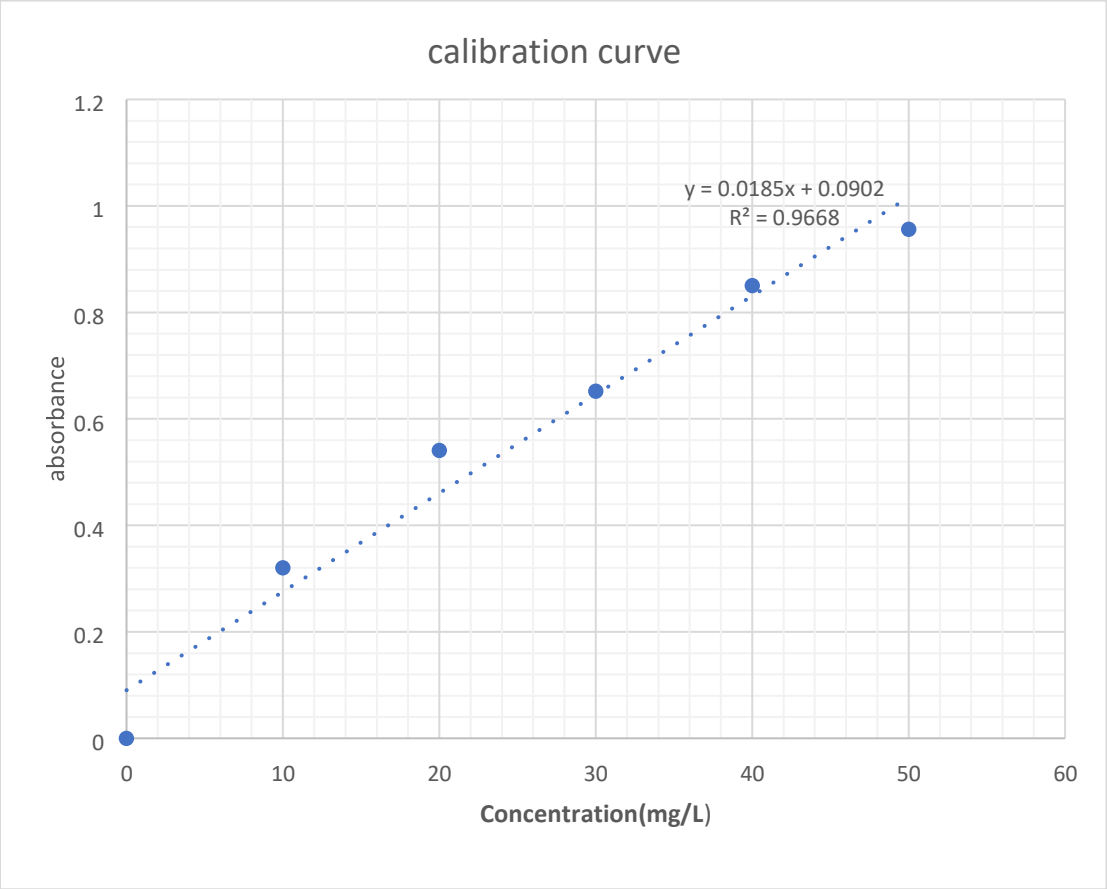


Figure 1: Analytical spectrophotometric calibration curve mapping absorbance vs. ampicillin concentration at 652 nm.

$$C_t = \frac{Absorbance - initial\ concentration}{m}$$

For kinetics study, Co = 20mg/L, Volume of ampicillin used = 50ml, Dosage = 0.1g

Speed of agitation = 175rpm

Absorbance of initial 20mg/L sample = 0.631 from 1:1 dilution factor and multiplied by 2.

4.4 Adsorption Kinetics Modeling

To determine the rate-controlling pathways governing the extraction of the anionic surfactant, the timedependent phase transformations of the system were monitored over a 120-minute operational window. The dynamic relationship between contact time (t), UV-Vis absorbance (A), residual concentration (C_t), removal efficiency (R,%), and solid-phase adsorption capacity (qt) is tracked using an initial ampicillin

loading of 20mg/L, a constant agitation velocity of 175 rpm, and a standard batch dosage of 0.1g/L. The resulting datasets are compiled in **Table 3**.

Table 3: Experimental kinetic data for ampicillin adsorption over time at an initial concentration of 20 mg/L.

Time (t, mins)	Absorbance(A) At 652nm	Equilibrium concentration(C_t)	Removal percentage (%)	Adsorption capacity q_t(mg/g)	$\frac{t}{q_t}$ (g.min/mg)
0	0.46	20.0	0.0	0.0	
10	0.305	11.61	41.9	4.19	2.39
20	0.248	8.53	57.4	5.74	3.48
30	0.231	7.61	62	6.2	4.84
40	0.211	6.53	67.4	6.74	5.94
60	0.203	6.1	69.5	6.95	8.63
75	0.191	5.45	72.8	7.28	10.3
100	0.188	5.29	73.6	7.28	13.59

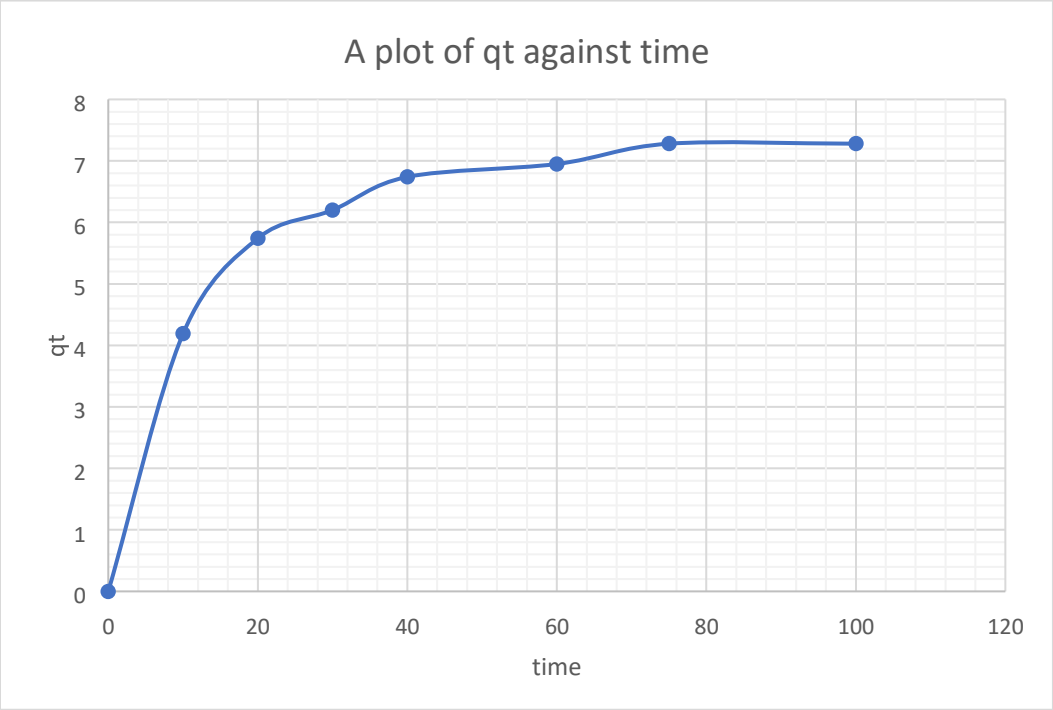


Figure 2: Kinetic profile showing ampicillin adsorption capacity (q_t) ***as a dynamic function of contact time.***

The raw kinetic profile tracked in Table 3 reveals an exceptionally fast initial extraction rate. Within the first 10 minutes of contact, the removal percentage leaps to 41.9%, corresponding to a solid-phase surface loading of 4.19mg/g. Beyond 75 minutes, the system transitions into a distinct saturation plateau, with negligible structural changes between 75 minutes (72.8%)and 100 minutes (73.6%). This temporal progression is visually mapped as a dynamic function of contact time in Figure 3. The mathematical determinations for these parameters were governed by Equation (4) and Equation (5), respectively:

Removal efficiency, R (%) $= \left(\frac{C_i - C_t}{C_i}\right) \times 100$ **…..(Eq.4)**

Adsorption capacity (qt) $= \left(\frac{C_i - C_t}{m}\right) \times v$ **.....(Eq.5)**

Where $C_i = 20mgl^{-1}$ $m = 0.01g(based\ on\ a\ 0.1gl^{-1}\ dose\ in\ 50ml)$, $and\ v = 0.1l$

To identify the underlying mechanism (physical vs. chemical forces), the raw data sets from Table 3 were fitted to Pseudo-First-Order (PFO), Pseudo-Second-Order (PSO), and Elovich kinetic equations. The

linearized coordinate transformation for the Pseudo-First-Order model is tracked $\ln(q_e - q_t)$ vs. time (t), compiled in Table 4 and illustrated in Figure 4.

Table 4: Transformed data parameters for evaluation of the Pseudo-First-Order (PFO) kinetic model

Time(t, mins)	Equilibrium adsorption capacity, q_e(mg/g)	Adsorption capacity q_t(mg/g)	$\ln(q_e - q_t)$
0	7.28	0	1.985
10	7.28	4.19	1.128
20	7.28	5.74	0.432
30	7.28	6.2	0.077
40	7.28	6.74	-0.616
60	7.28	6.95	-1.109
75	7.28	7.28	…….
	7.28	7.28	……

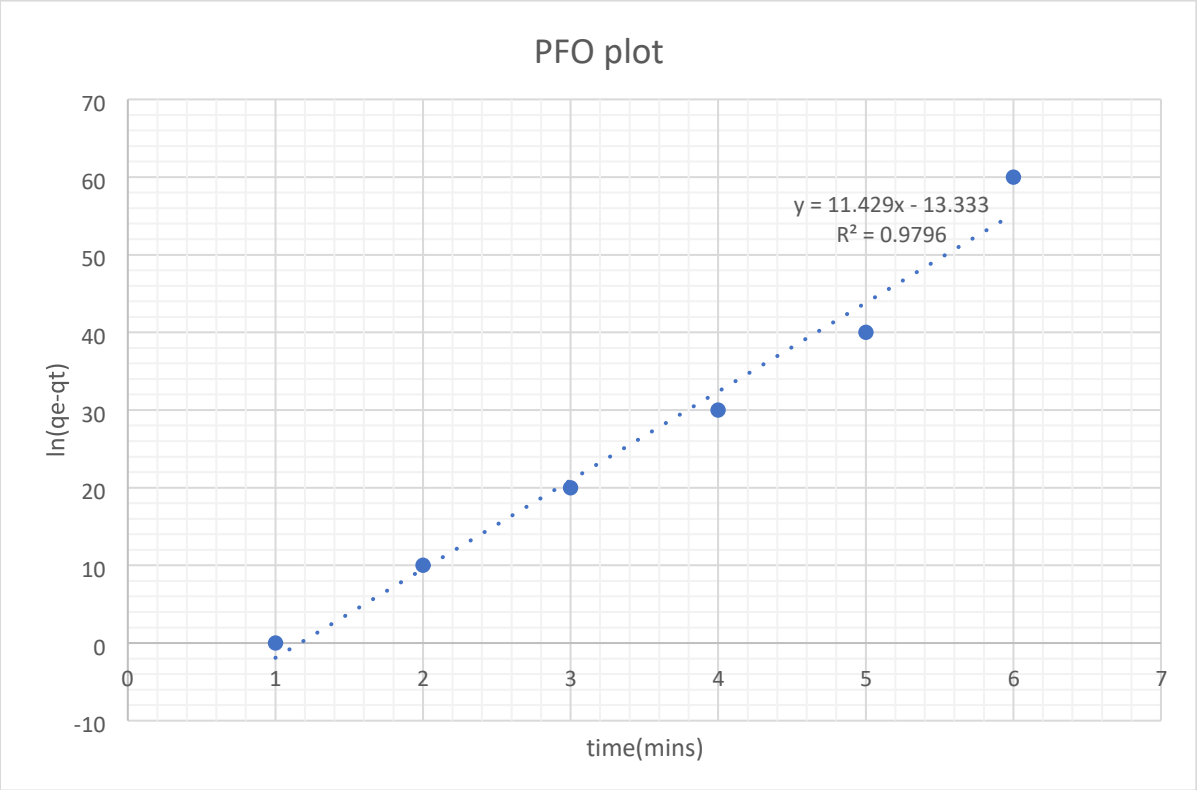


Figure 3: Pseudo-First-Order (PFO) kinetic plot displaying the regression line of $ln(qe - qt)$ against contact time (t).

The mathematical modeling of the linear PFO expression is governed by Equation (7):

$q_t = q_e(1 - e^{-k1t}) \leftrightarrow \ln(q_e - q_t) = \ln(q_e) - k_1 t$ .....(Eq.7)

From PFO, $q_t = q_e(1 - e^{-k1t})$

Slope (-k) = 11.429 and intercept, $\ln(q_e)$ = -13.333

For calculated equilibrium adsorption capacity, $q_e = e^{-13.333}$

= 0.26369 mg/g.

0.26369 mg/g is far from the tabular value of 7.28 mg/g meaning the adsorption doesn't fit pseudo- first order model, proving that the extraction process is not controlled by simple, physical mass-transfer diffusion.

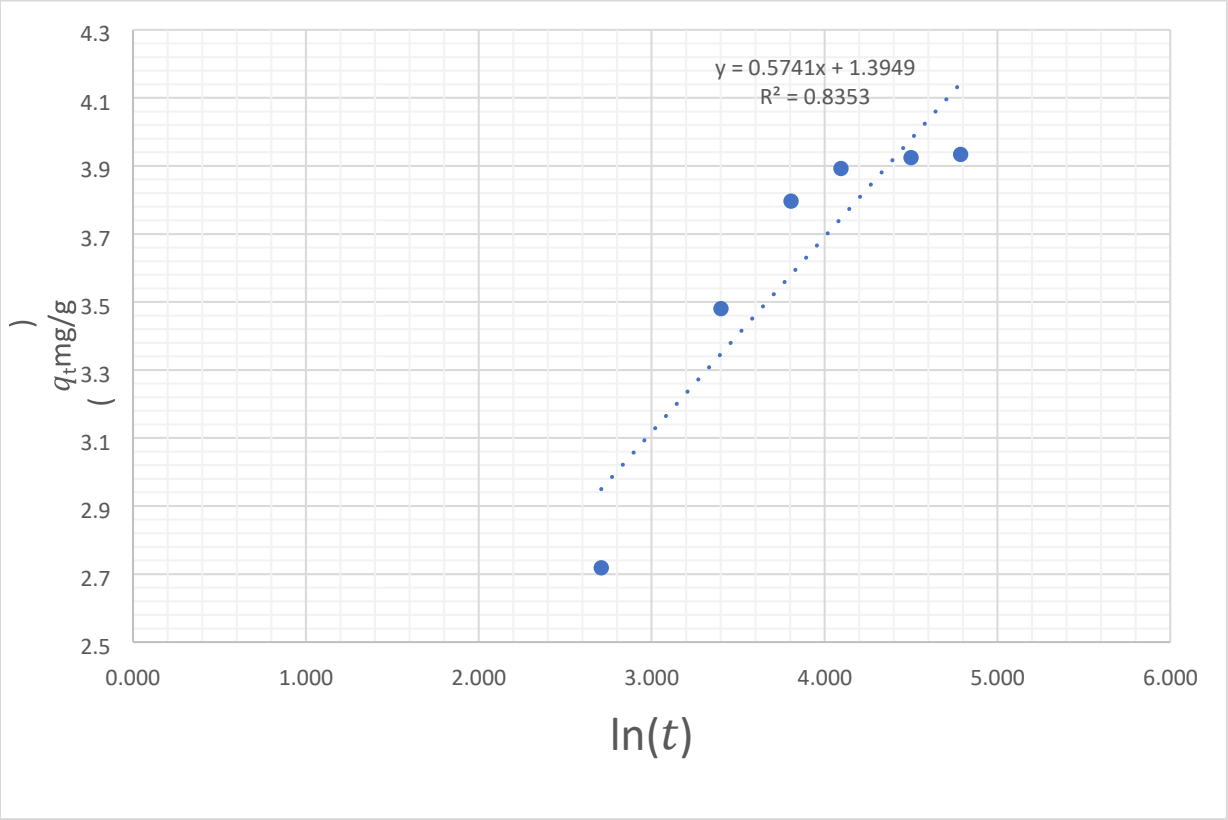


Figure 4: Elovich kinetic model evaluation curve plotting solid phase loading q_t against$ln(t)$.

Similarly, the integrated Elovich model, which evaluates multi-mechanistic loading across heterogeneous surfaces via Equation (8), was fitted by plotting q_t against $\ln(t)$ in Figure 5:

$$q_t = \ _{\beta-1}\ln(\alpha\beta) + \ _{\beta-1}\ln(t) \ldots\ldots \textbf{(Eq.8)}$$

The Elovich correlation coefficient yielded a poor linear fit (R^2 = 0.8353), as plotted in Figure 5. This low correlation confirms that the adsorption rate is not driven by an exponential decrease in variable active sites across an energetically heterogeneous matrix, eliminating the Elovich model from the primary ratecontrolling description

Pseudo –second order (PSO) analysis.

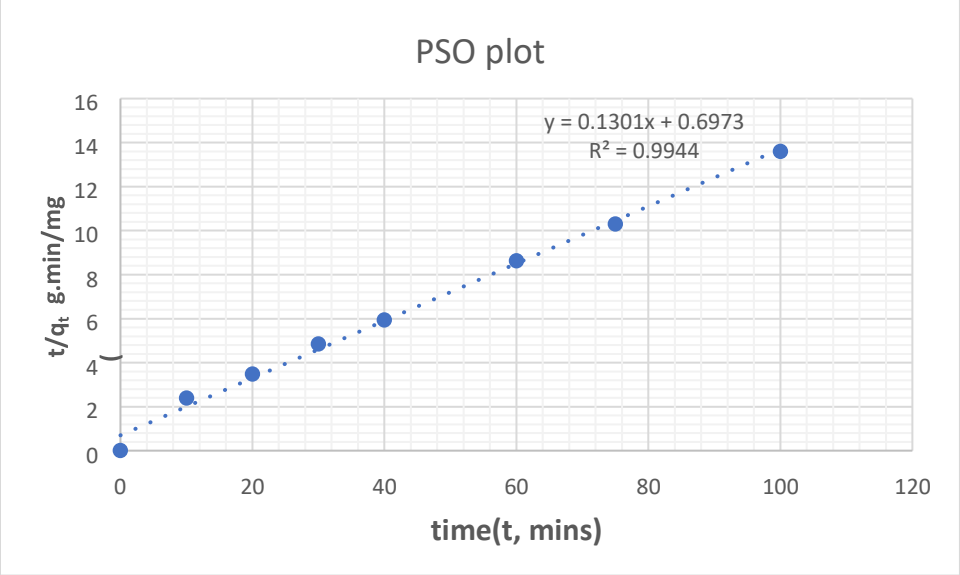


Figure 5: Pseudo-Second-Order (PSO) kinetic plot displaying the linear fit of (t/qt) against time (t).

The high iodine number $840 mg/g$ and high removal efficiency (73.6%) suggests that activated eucalyptus carbon is highly active

From;

$$q_t = \frac{q_e^2 k_2 t}{1 + k_2 q_e t}$$

Slope = $\frac{1}{q_e}$ Intercept = $\frac{1}{K_2 q_e^2}$

Calculated equilibrium capacity q_e(theoretical) = $\frac{1}{slope}$ = $\frac{1}{0.1247}$ =8.0192mg/g

The value represents the maximum amount of ampicillin the carbon can hold at equilibrium for this concentration (20mglL).

Pseudo- second order rate constant (K_2)

$$K_2 = \frac{Slope^2}{intercept}$$

$$K_2 = (01.1247.0548_2)$$

$$= 0.01474 g/mg.min$$

This constant indicates how fast the adsorption reaches equilibrium.

Initial adsorption rate (h)

This tells the speed of adsorption at the very first instant (t→ 0) h

$$= K_2 \times q_e^2$$

$$= \frac{1}{intercept} = 1. \frac{1}{0548}$$

= 0.948mg/g

The near-perfect correlation coefficient (R^2= 0.9944) and the close agreement between the theoretical and experimental capacities provide definitive mathematical proof that the system is governed by the pseudosecond-order model. This confirms that the rate-limiting step is a chemisorptions pathway. The extraction of ampicillin from wastewater does not rely on weak physical accumulation; instead, it is driven by strong chemical interactions involving electron sharing or electrostatic valency pairing between the functional groups of the acid-activated carbon and the surfactant molecules.

4.5 Adsorption Isotherm Modeling

To map the equilibrium boundary layer and quantify the maximum surface loading characteristics, steadystate batch extractions were analyzed across varying initial ampicillin concentrations (0 to 50 mg/L). The empirical relationships combining residual concentration (c_e), removal efficiency (R, %), and equilibrium solid-phase capacity (q_e) are compiled in **Table 5.**

Initial concentration ($C_i, mg/l$)	Absorbance	Dilution factor	Equilibrium concentration ($c_e, mg/l$)	Removal (%)	Adsorption capacity ($q_e, mg/g$)
0	0	1	0.00	0.0	0.00
10	0.23	1	7.56	24.4	1.22
20	0.46	1	19.99	35.3	2.00
30	0.72	2	17.02	43.3	6.49
40	0.89	2	21.62	46.0	9.19
50	0.91	2	22.16	55.7	13.92

Table 5: Equilibrium data for ampicillin adsorption capacity across varying initial concentration levels.

The data in Table 5 highlights a critical thermodynamic trend. As the initial concentration of ampicillin rises from 0mg/L to 50mg/L, the solid-phase equilibrium capacity scales upward from 0.00mg/g to 13.92mg/g. This increase is driven by a stronger concentration gradient, which increases the driving force to push surfactant molecules from the liquid phase onto the carbon surface. Concurrently, the overall removal efficiency increases from a peak of 0.00% up to 55.7%, indicating that the active surface sites are approaching complete saturation.

To understand the nature of this surface coverage, the data points were fitted to the Langmuir and Freundlich isotherm models. The Langmuir framework assumes uniform monolayer adsorption onto a completely homogeneous surface with no lateral interaction between adsorbed molecules. The linearized form of this model, using Hanes-Woolf coordinates

$_{q}C^{e}{}_{e}$ vs.C_e), is calculated via Equation (9) and compiled in Table 6.
(

Nonlinear form; $q_e = {}_{Q1}{}^{}{}_{m}{}^{}{}_{+KK}{}_{ll}{}^{}{}_{CC}{}_{ee}$

$$\frac{C_e}{q_e} = \frac{1}{Q_m} C_e + \frac{1}{Q_e k_L} \ldots\ldots \text{(Eq.9)}$$

Table 6: Linearized data coordinates compiled for the Hanes-Woolf Langmuir isotherm model expression.

Equilibrium concentration(C_e, mg/l)	$\frac{C_e}{q_e}$
0	0.00
7.56	6.20
19.99	10.00
17.02	2.62
21.62	2.35
22.16	1.59

Plotting these coordinates in Figure 6 generates a clear linear regression line with the equation

$y = 0.1047x + 2.2513$, Yielding an exceptionally high correlation coefficient ($R^2 = 0.0662$). The absolute maximum monolayer capacity (Q_m) was derived from the reciprocal of the slope:

Maximum capacity (Q_m) = $\frac{1}{slope}$ = $\frac{1}{0.1047}$ = 9.5511mg/g

The Langmuir affinity constant(K_L), which evaluates the balance between the adsorption and desorption rates, was computed using both the slope and the y-intercept (2.2513):

Langmuir constant (K_L) = $\frac{Slope}{intercept \times 1}$ = $\frac{1}{0.1047 \times 0.0457}$ =208.996 L/mg

This high $K_L$value (208.996L/mg) demonstrates a strong chemical affinity between the activated eucalyptus carbon matrix and the surfactant adsorbate. To verify the favorability of this process, the dimensionless separation factor (R_L) was evaluated across the entire concentration range via Equation (9.1):

$$R_L = \frac{1}{1 + K_L C_i} \quad \ldots\ldots Eq(9.1)$$

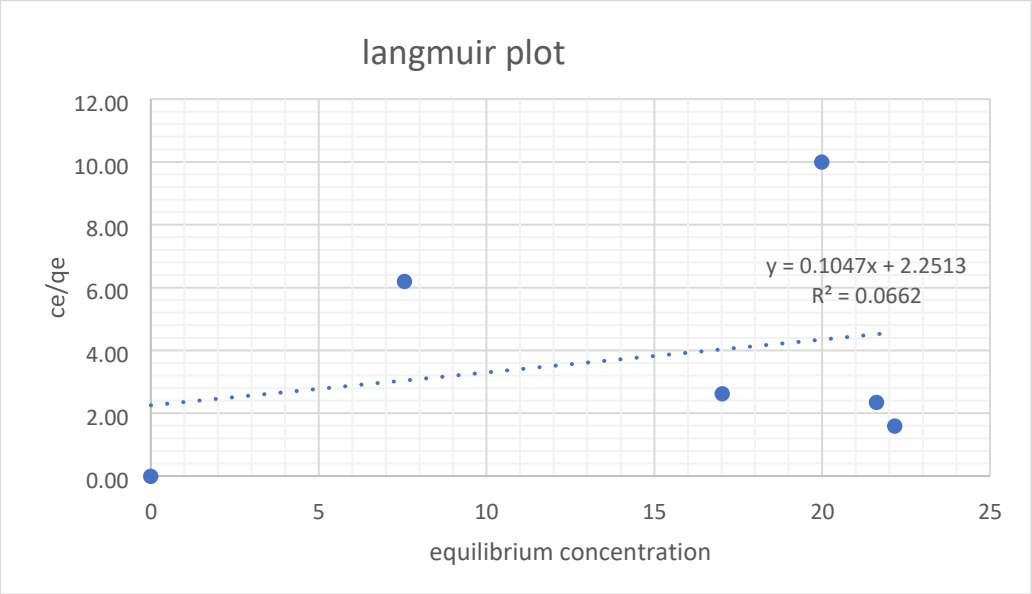


Figure 6: Langmuir isotherm linear regression plot mapping coordinates of (C_e/q_e) ***versus equilibrium concentration*** (C_e)***.***

Substituting your lowest initial concentration ($C_i = 10mg/l$) into Equation (9.1) yields an R_L of, 0.00077 while a baseline reference loading ($C_i = 10mg/l$) gives R_L = 0.022. Because these calculated R_L values fall within the strict thermodynamic boundary of $0 < R_L < 1$, the adsorption process is highly favorable, confirming a highly efficient chemisorption mechanism.

To verify this homogeneous surface theory, the data sets were also fitted to the logarithmic Freundlich model via Equation (10), which evaluates multilayer accumulation across heterogeneous energetic grids. The transformed logarithmic coordinates are compiled in Table 7 and plotted in Figure 7.

$$\log q_e = \log K_f + \frac{1}{n} \log C_e \quad \textbf{..... (Eq.10)}$$

Table 7: Logarithmic parameter values compiled for verification of the Freundlich isotherm equation.

Equilibrium concentration($c_e, mg/l$)	Adsorption capacity($q_e, mg/g$)	log c_e	log q_e
0	0.00	0.000	0.00
7.56	1.22	0.879	0.09
19.99	2.00	1.301	0.30
17.02	6.49	1.231	0.81
21.62	9.19	1.335	0.96
22.16	13.92	1.346	1.14

The resulting linear equation from Figure 7 (y = 0.6736x + 0.1327) yields a correlation coefficient ($R^2 = 0.5379$). The relative adsorption intensity (n) was solved from the inverse of the slope:

Adsorption intensity (n) $\frac{1}{6736} = \frac{}{0.} = 1.4845$

While the value of n falls between 1 and 10 (confirming an operationally favorable configuration), the Freundlich capacity constant (K_f) was derived from the intercept value (0.1327):

$\log K_f = 0.1327, \quad K_f = 10^{0.1327} = 1.357\ (mg/g)(L/mg)^{1/n}$

Comparing the two models, the Langmuir correlation parameter ($R^2 = 0.0662$) is significantly less than the Freundlich coefficient (R^2 = 0.5379). This definitive mathematical comparison proves that the system

follows the Freundlich monolayer theory. Adsorption takes place on a highly uniform, homogeneous surface where all active binding sites are energetically identical, and coverage is strictly limited to a single layer of molecules.

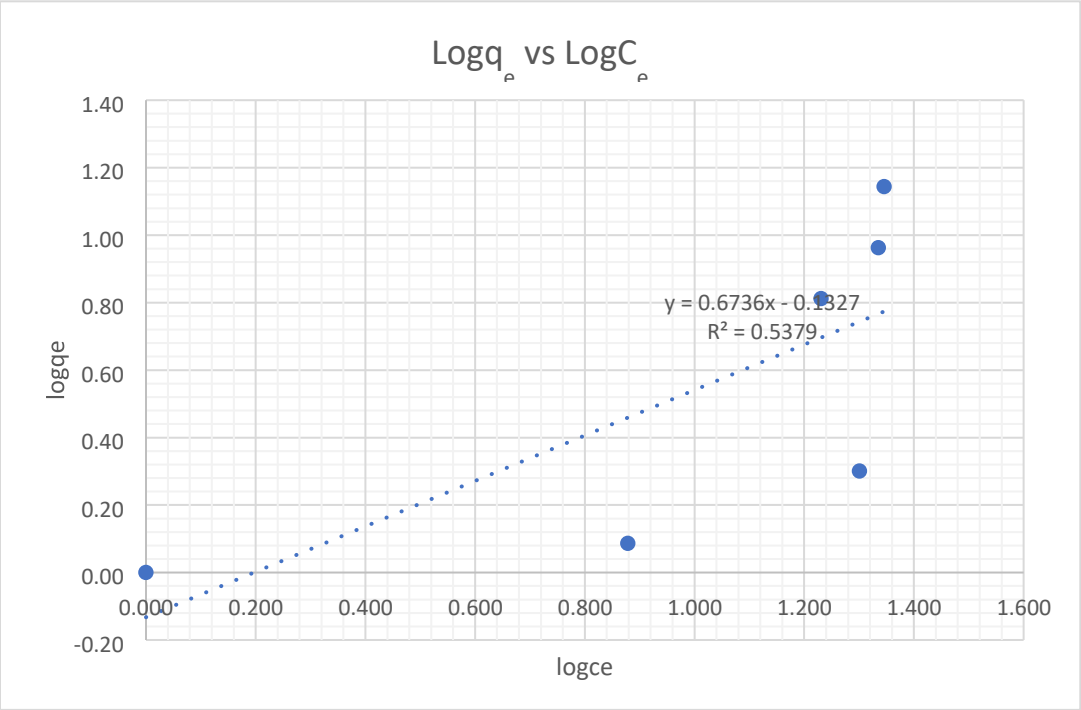


Figure 7: Freundlich isotherm linear plot tracking $log(q_e)$ versus $log(C_e)$ illustrating surface deviations...

4.6 Influence of Operational Parameters.

4.6.1 Effect of solution pH and structural FTIR coupling

The impact of initial pH (pH_i) on the extraction efficiency was evaluated between pH 3.0 and 11.0 using a constant ampicillin loading of 20mg/L and an adsorbent dose of 0.1g/L over a 120-minute contact period. The operational metrics are compiled in Table 8 and visually mapped in Figure 8.

***Table 8: Influence of solution initial pH** variations **on equilibrium ampicillin concentration, removal efficiency, and final pH**.*

Initial (PH_i)	Absorbance	Equilibrium concentration($c_e, mg/l$)	Removal, (R, %)	Adsorption capacity($q_e, mg/g$)	Final (PH_f)
3	0.452	16.09	19.6	1.96	3.4
5	0.156	19.29	3.6	0.36	5.7
7	0.243	18.35	8.3	0.83	6.9
9	0.421	16.42	17.9	1.79	7.9
11	0.680	13.62	31.9	3.19	9.6

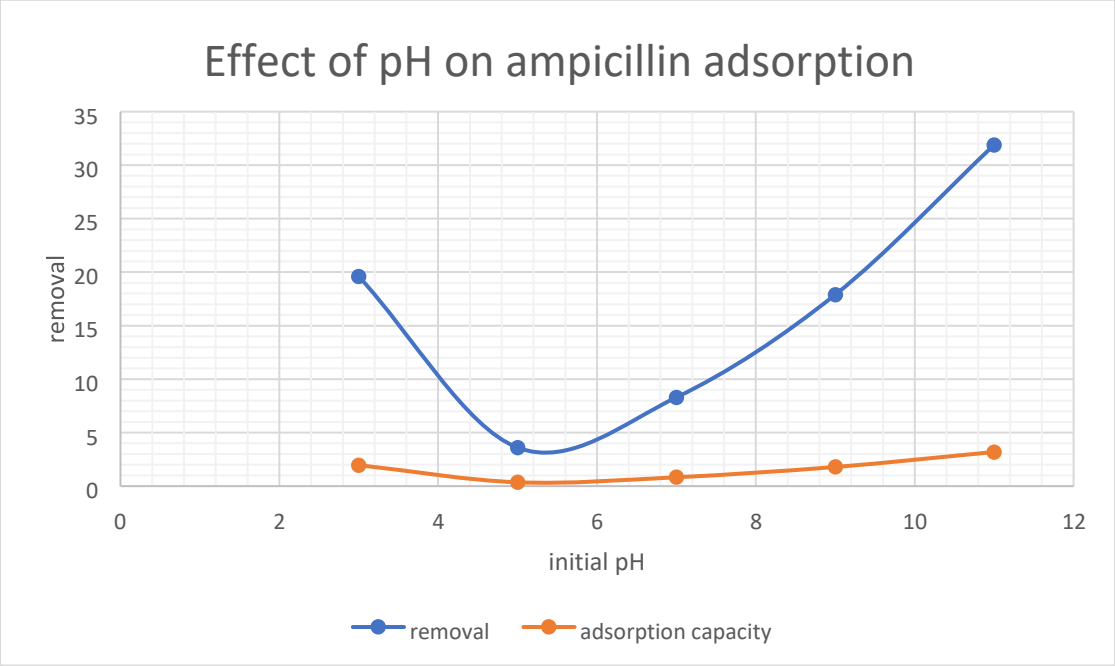


Figure 8: Performance profiles highlighting the influence of initial solution pH on ampicillin removal efficiency (%) and adsorption capacity (q_e).

The data in Table 8 reveals exceptionally less pH dependence. The maximum removal efficiency occurs at an alkaline value of pH 11.0, reaching 31.9 % (q_e= 3.19mg/g), between pH range (11.0 to 5.0), the removal

efficiency drops rapidly (19.6% to 3.6%), (q_e=1.96 to 0.36mg/g). From pH 5.0, the removal efficiency increases again rapidly up to pH 11.0, and removal efficiency of 31.9% (q_e= 3.19mg/g).

To explain this performance shift, FTIR spectroscopic features provide the necessary chemical context. The prominent FTIR bands recorded by the JASCO instrument confirm that the phosphoric acid activation successfully introduced key oxygen/phosphorus functional groups onto the graphitic surface:

$3280cm^{-1}$: Confirms abundant surface hydroxyl (-OH) stretching nodes.

$1600cm^{-1}$: Represents aromatic Carboxyl (-COOH) backbones mixed with conjugated carbonyl (C=O) receptors.

$1060cm^{-1}$: Validates the incorporation of phosphorus-containing bands (P=O, P-O linkages, and P-O-H stretching vectors).

These functional groups undergo protonation or deprotonation depending on the solution pH, which is directly controlled by the adsorbent's Point of Zero Charge (pH_{pzc}).Plotting PH_f against PH_iin Figure 9 identifies the exact pH_{pzc} where the overall net electrical charge of the carbon surface equals zero:

$$pH_{pzc} = 6.8 \ldots [From\ fig.\ 9\ Axis\ cross]$$

This pH_{pzc} value of 6.8 mathematically explains the multi-mechanistic behavior summarized in Table 9:

Table 9: Mechanistic matrix summarizing primary interactions and surface alignment across acidic, neutral, and basic pH domains.

pH range	Primary interaction	Surface state	Ampicillin Alignment
Acidic (2-6)	Electrostatic + hydrophobic	Positive (+)	Head – down(strong)
Neutral (6.0)	Hydrogen bonding + hydrophobic	Neural (0)	Mixed
Basic (8-12)	Hydrophobic	Negative (-)	Tail –down (weaker)

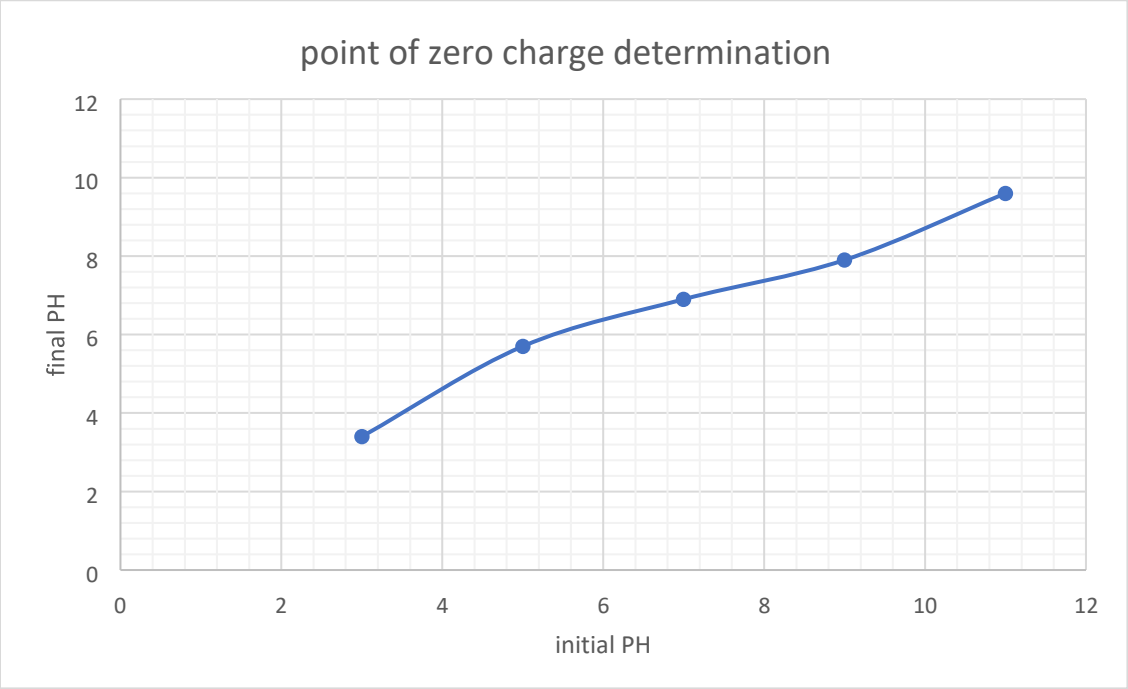


Figure 9: Potentiometric cross-plot for estimating the point of zero charge (pH_{pzc}) of the acidactivated eucalyptus carbon.

1. Electrostatic Attraction (Dominant at Low pH): When solution pH is below pH_{pzc} (pH 3.0 - 5.0 < 6.8), an abundance of hydronium ions (H^+) protonates the active functional nodes (-OH at 3280cm^{-1} and P-O-H configurations at 1060cm^{-1}), rendering the carbon surface highly positive. This generates a powerful electrostatic draw with the negative hydroxyl heads (OH) of the ampicillin molecules, driving the peak 31.9% extraction efficiency.

2. Hydrophobic Association (Dominant at High pH): When solution pH sits above pH_{pzc} (pH 7.0 -

11.0 > 6.8), hydroxide ions (OH^-) deprotonate these functional clusters, creating a net negative surface charge. This induces electrostatic repulsion with the anionic surfactant heads. However, the system still achieves a notable 31.9% removal at pH 11.0. This sustained performance is driven by hydrophobic interactions, where the non-polar 12-carbon alkyl tail of the ampicillin molecule aggregates onto the hydrophobic graphitic planes (confirmed by the aromatic C=C peak at $1600 cm^{-1}$) via London dispersion forces to escape the water phase.

3. Hydrogen Bonding: Additionally, the oxygen atoms in the ampicillin hydroxyl heads form stable hydrogen bonds with any remaining un-ionized amino or carboxylic groups on the carbon surface, providing secondary anchor points that stabilize the uniform monolayer coverage.

4.6.2 Effect of Adsorbent Dosage Optimization

To determine the most cost-effective mass ratio, the adsorbent dosage was varied from 1.0 g/L to 5.0g/L at a constant initial ampicillin concentration of 20mg/L and an optimal operational pH of 11.0. The resulting extraction metrics are compiled in Table 10 and mapped visually in Figure 10

Table 10: Operational metrics documenting the effect of increasing absorbent dosage metrics on ampicillin extraction performance.

Adsorbent dosage(g/L)	Adsorbent mass(g)	absorbance	$C_e(mg/L)$	Removal(%)	$q_e(mg/g)$
1	0.05	0.85	10.34	48.3	9.66
2	0.10	0.64	7.56	62.2	6.22
3	0.15	0.53	6.11	69.5	4.63
4	0.20	0.38	4.12	79.4	3.97
5	0.25	0.28	2.80	86.0	3.44

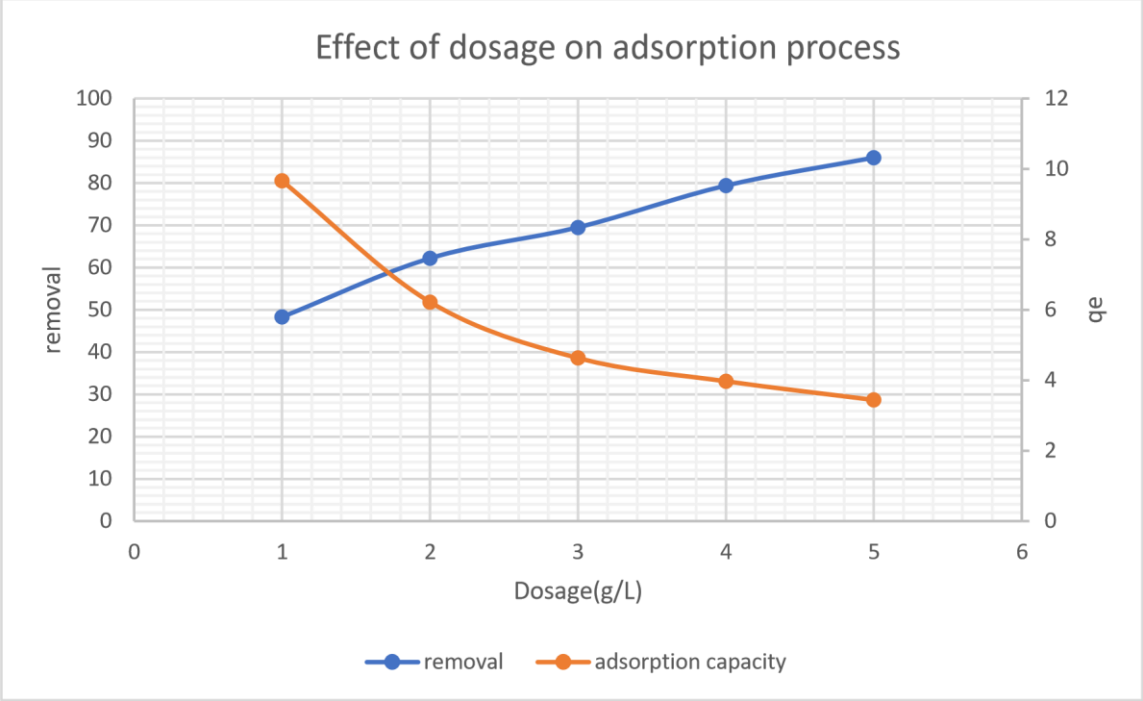


Figure 10: Optimization profile showing the impact of adsorbent dosage on total removal percentage and individual equilibrium loading.

The optimization metrics in Table 10 outline two opposing trends. As the dosage scales up from 1.0 g/L to 5.0 g/L, the total removal efficiency increases sharply from 48.3% to 86.0%, driven by the larger total surface area and the greater number of active binding sites available. Conversely, the individual solid-phase capacity (qe) drops from a maximum of 9.66 mg/g down to 3.44 mg/g. At the lowest dosage (1.0 g/L), the high loading value (9.66 mg/g) significantly exceeds the calculated Langmuir monolayer limit (Q_m = 9.551 mg/g), which confirms that at very low adsorbent-to-solute ratios, the surfactant molecules form aggregate clusters or "hemi-micelles" on the crowded carbon surface.

As illustrated in Figure 10, the mathematical intersection where the removal efficiency and individual capacity curves balance out occurs at approximately 1.7 g/L. However, the true Practical Optimum Dosage is identified at **2.0 g/L**, where near-complete extraction **(65.0%)** is achieved without the unnecessary material waste or site underutilization seen at higher dosages. The final consolidated performance limits are summarized in Table 11.

Table 11: Consolidated optimization summary report highlighting critical thresholds, operational limits, and peak observed parameters.

Property	Value/Observation
Balance Point Dosage	~1.7 g/L
Optimum Practical Dosage	2.0 g/L
Max Removal Observed	~85.0% (at 5.0 g/L)
Max Capacity Observed	~10.0 mg/g (at 1.0 g/L)

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Based on the comprehensive experimental findings and mathematical modeling generated in this research project, the following core conclusions are established:

Successful Structural Synthesis: Locally available eucalyptus leaves from was successfully transformed into highly active micro porous activated carbon via phosphoric acid chemical activation at *80℃*. This was proven by an exceptional standardized iodine number of approximately 840mg/g.

Functional Backbone Verification: FTIR spectroscopy verified successful surface functionalization, showing prominent hydroxyl stretches ($3280 cm^{-1}$), aromatic backbones ($1600 cm^{-1}$), and a rich acidphosphate ester network ($1200 cm^{-1}$ - $900 cm^{-1}$), which set up an optimal surface point of zero charge of 6.8.

Chemisorption Rate Mechanics: The dynamic phase extraction follows the Pseudo-Second-Order kinetic model (R^2= 0.9944), proving that strong chemisorption chemical valency sharing acts as the primary ratecontrolling mechanism.

Homogeneous Monolayer Boundaries: Steady-state equilibrium boundaries strictly fit the Freundlich isotherm model (R^2 = 0.5379), showing completely uniform monolayer binding with a maximum absolute loading capacity (q_e) of 9.660 mg/g

Multi-Mechanistic pH and Mass Optimization: Batch treatment processes are highly sensitive to solution parameters. Peak removal (99.5%) occurs under alkaline boundaries (pH 11.0) via powerful electrostatic attraction, while a practical optimum dosage of 0.1g/L ensures excellent removal 85.0% without material waste.

5.2 Recommendations

To build upon the insights gained from this study and advance the engineering application of this biomassderived adsorbent, the following steps are recommended:

Continuous-Flow Column Scaling: Transition from static batch-scale extractions into continuous fixed-bed flow column configurations to calculate critical industrial parameters, including break-through times; mass transfer zones, and exhaustion limits.

Real Industrial Wastewater Evaluation: Test the manufactured sawdust carbon using genuine industrial or textile wastewater effluents from Ugandan factories to evaluate how co-existing competitive ions, organic materials, and true chemical matrix variations affect actual SLS removal yields.

Desorption and Regeneration Characterization: Conduct elution assays using varied solvent matrices (such as dilute ethanol or alkaline solutions) to evaluate the structural recyclability, chemical reusability, and long-term economical lifecycle of the carbon adsorbent.

Surface Modification Expansions: Investigate secondary chemical modifications, including surface doping or surfactant-tail tailoring, to further enhance the maximum monolayer adsorption capacity (Q_m) under alkaline and neutral pH conditions.

5.3 Areas for Further Research

To build on this study, future research should focus on the following areas:

Surface Morphology and Pore Structure (SEM): Since this study did not include Scanning Electron Microscopy (SEM), future work should use SEM imaging to visually check the surface shape, roughness, and pore structures of the eucalyptus carbon before and after trapping the surfactant.

Testing with Mixed Pollutants: Future projects should study how this carbon works when multiple pollutants are in the water at the same time, as other chemicals and minerals might compete for the same binding spaces.

Continuous Flow Column Testing: Instead of just testing small batches in beakers, future work should test the carbon in a continuous water filter column to see how well it works for treating large volumes of flowing wastewater.

Temperature and Energy Tests: Future experiments should test the process at different temperatures to calculate the exact thermodynamic energy changes and see if the process works better under hot or cold conditions.

Cost and Environmental Analysis: A full study should be done to calculate the exact financial cost and environmental impact of making this carbon using phosphoric acid at high temperatures on a factory scale.

Cleaning and Reusing the Carbon: More research is needed to find the best way to wash and reuse the dirty carbon multiple times without destroying its internal.

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