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FACULTY OF SCIENCE AND EDUCATION

DEPARTMENT OF CHEMISTRY

ADSORPTION AND KINETICS OF IBUPROFEN FROM WASTE WATER USING ACTIVATED CARBON FROM PINEAPPLE PEELS.

BY

SANDE MERCY

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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.

AUGUST 2026

DECLARATION

I SANDE MERCY declare that this research project is my original work and has not been submitted to any other institution for academic credit.

Signature: ……………………

Date: 27/ 08/2026

APPROVAL

This research with title "ADSORPTION AND KINETICS OF IBUPROFEN FROM WASTE WATER USING ACTIVATED CARBON FROM PINEAPPLE PEELS" project has been submitted with the approval of the supervisor

Supervisor's Name: Dr. Kigozi Moses

Signature: ……………………….

Date: 27/ 08/2026

DEDICATION

I dedicate my research work to my parents Mr. Isaac Chemonges, Mrs. Caroline Chemonges for their spiritual support, FAWE Uganda for all the financial and material support, my siblings Elizabeth, Caleb, Dorcus Joshua and Zipporah, my friends in the struggle Maureen, Margaret, Patience, Rael, Mubaraka, Nancy, Solomon, John ad Ivy.

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ABSTRACT

The increasing occurrence of pharmaceutical pollutants in aquatic environments has become a global concern due their persistence and potential effects on human health and aquatic organisms. Ibuprofen is a widely used non-steroidal anti-inflammatory, anti-pyretic and analgesic drug with occurrence in the aquatic systems of 47 countries. The presence of ibuprofen in aquatic systems poses a threat to the health of both human and aquatic organisms. The current treatment methods for removing ibuprofen from wastewater are often expensive and environmentally friendly leading to a pressing need for alternative solutions. Previous and existing studies have primarily focused on conventional water treatment methods like activated carbon derived from traditional sources without adequately investigating the potential of bio waste materials such as pineapple peels rendering them ineffective in removing ibuprofen, highlighting the need for alternative technologies. Therefore; this study developed pineapple peels activated carbon using H_3PO_4 and carbonization in a furnace of 500-700°C as a three-dimensional adsorbent for aqueous ibuprofen remediation. Pineapple peel's activated carbon was characterized using iodine method to determine the surface area, pore volume and size distribution of the activated carbon, Fourier Transform Infrared Spectroscopy to identify the functional groups present on the surface of the activated carbon using a PerkinElmer Spectrum 100 spectrometer. Batch adsorption studies were carried out from pH 2 to 10, Adsorbent dosages from 1g/L to 5g/L, contact time from 10 to 60 minutes. Maximum adsorption occurred at pH 4 at an ibuprofen concentration 2mg/L, adsorbent dosage of 1g/L. Adsorption followed second order kinetics well (R^2=0.999). The adsorption isotherms almost remained constant with an increase in initial concentration of ibuprofen shown by Langmuir adsorption capacity, qe=19.421mg/g. Pineapple peelings provided an efficient ibuprofen adsorption capacity (with column parameters; pH=4.0, adsorbent dosage=5g/L.). Adsorption of ibuprofen onto activated carbon from pineapple peels involves H-bonding, pore filling with complexation and hydrophobic π-π donor acceptor attractions likely participating. Which allows efficient removal of ibuprofen from water. Affordable costs of pineapples together with excellent adsorption capacity makes pineapple peels activated carbon an efficient low-cost adsorbent for ibuprofen removal. Thus, this study describes a sustainable pineapple waste management strategy as well as treatment of ibuprofen contaminated water.

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LIST OF ABBREVIATIONS

WWTP	Waste Water Treatment Plants

RO	Reverse Osmosis
NF	Nanofiltration
AOPs	Advanced Oxidation Processes
UV-Vis	Ultraviolet Visible
FTIR	Fourier Transform Infrared Spectroscopy
SEM	Scanning Electron Microscope
H_3PO_4	Phosphoric acid
HCl	Hydrochloric acid
NaOH	Sodium Hydroxide
Kf	Freundlich Capacity
Qm	Maximum adsorption capacity
PFO	Pseudo-First Order
RL	Dimensionless Separate Factor
qe	Adsorption Capacity

CHAPTER ONE: INTRODUCTION

1.1 Background of the study

The increasing prevalence of pharmaceuticals, particularly non-steroidal anti-inflammatory drugs like ibuprofen frequently consumed for pain relief, inflammation reduction and fever management (Patel et al., 2022) and in fresh water systems has raised significant environmental concerns such as affecting water quality, potentially impacting drinking water supplies, ecosystems and human health and this is due to their persistence and potential toxicity (Rivera-utrilla et al., 2013). Due to its extensive use, ibuprofen enters aquatic systems through, human excretion (as unmetabolized drug), improper disposal of unused drugs, effluents from pharmaceutical industries, hospital and municipal wastewater discharge(Patel et al., 2022). These pollutants are problematic because they are biologically active and persistent. They are often detected in surface water, ground water and even drinking water at trace concentrations. Even at low levels, its presence in the water can lead to; toxic effects on aquatic organism for example fish and algae, bioaccumulation in the food chain, potential human health risks, including endocrine disruption. Traditional wastewater treatment methods often fail to completely remove these contaminants, prompting the discovery of alternative remedies (Mestre[a] et al., n.d.). Activated carbon, renowned for its high surface area and adsorptive capacity due to its porous structure, is a widely used material for removing pollutants(Aisosa et al., 2020). A sustainable approach that minimizes waste while addressing environmental issues is utilizing agricultural by-products, such as pineapple peels. this approach is widely preferred due to its simplicity, cost effectiveness, high efficiency and ease of operation(Mandal et al., 2024). This proposed study aims to investigate the adsorption characteristics and kinetics of ibuprofen on activated carbon derived from pineapple peels and its crucial because it explains the rate at which ibuprofen is removed from the water, mechanism of interaction between adsorbate and adsorbent using the [pseudo-first order model, pseudo-second order model, intra-particle diffusion model which helps determine whether the adsorption process is controlled by; surface reactions, diffusion processes, chemical interactions(Bbumba, Ssekatawa, et al., 2025). Recent research studies have examined the use of various agricultural residues for pollutant adsorption; However, studies specifically focusing on ibuprofen and the adsorption kinetics using activated carbon made from pineapple peels are limited. This lack of research highlights a crucial gap in understanding the efficiency and mechanisms of such eco-friendly adsorbents. By doing so, we seek to enhance knowledge of sustainable wastewater treatments solutions, bridge the existing gap and contribute to the advancement of effective methods for removing pharmaceutical contaminants from water sources.

1.2 Problem statement

Ibuprofen, an often-used non-steroidal anti-inflammatory drug, acts as an emerging contaminant in water, posing a potential threat to human health and the environment. For example, bioaccumulation in aquatic ecosystems due to their resistance to natural breakdown via mechanisms such as light and heat causing detrimental, sub-lethal effects on aquatic life (Patel et al., 2022). In aquatic environments, the effectiveness of low-cost and sustainable adsorbents remains underexplored. The current treatment methods for removing ibuprofen from wastewater are often expensive and not environmentally friendly leading to a pressing need for alternative solutions (Patel et al., 2022). Previous and existing studies have primarily focused on conventional wastewater treatment methods such as conventional adsorbents like activated carbon derived from traditional sources, without adequately investigating the potential of bio waste materials such as pineapple peels rendering them as ineffective in removing ibuprofen, highlighting the need for alternative treatment technologies (Nordin et al., 2023). Thus, there is a significant gap in knowledge regarding the adsorption capacity and kinetics of ibuprofen using activated carbon produced from pineapple peels, particularly in terms of optimising conditions for maximum ibuprofen removal, thereby providing a sustainable solution for reducing pharmaceutical pollutants and enhancing environmental protection.

1.3 Objectives of the study

1.3.1 General objective

To investigate the adsorption behavior and kinetics of ibuprofen removal from aqueous solution using activated carbon produced from pineapple peels.

1.3.2 Specific objectives

i. To prepare and characterize activated carbon from pineapple peels using appropriate physical and/or chemical activation methods.

ii. To evaluate the adsorption capacity of the prepared activated carbon for ibuprofen removal from aqueous solutions under varying environmental conditions.

iii. To investigate the effect of operational parameters such as pH, contact time, and adsorbent dosage and temperature on the adsorption process.
iv. To analyze the adsorption kinetics by fitting experimental data to kinetic models such as pseudo- first order model and pseudo-second order model.
v. To evaluate adsorption isotherms by applying models such as the Langmuir isotherm and the Freundlich isotherm.

1.4 Research questions

i. Can activated carbon derived from pineapple peelings effectively adsorb ibuprofen from aqueous solutions?
ii. What are the optimal conditions (pH, temperature, adsorbent dosage, contact time) for ibuprofen adsorption onto pineapple peel-derived activated carbon?
iii. How do the physicochemical properties of the activated carbon influence its adsorption capacity?

1.5 Scope of the study

This study focused on the preparation, characterization, and evaluation of activated carbon derived from pineapple peelings for the adsorption of ibuprofen from aqueous solutions. The scope of the study included, - the preparation of activated carbon from pineapple peelings using chemical activation with different activating agents for example H_3PO_4. Characterisation of the prepared activated carbon using techniques, such as Fourier transform infrared spectroscopy (FTIR). Batch adsorption experiments to investigate the effects of pH, temperature, initial ibuprofen concentration, and adsorbent dosage on the adsorption process (Patel et al., 2022). Determination of adsorption kinetics and isotherms using appropriate mathematical models (Al-ghouti & Da, 2020). Analysis of the experimental data to optimize the adsorption conditions and evaluate the performance of the activated carbon. The study was conducted under controlled laboratory conditions using synthetic ibuprofen solutions. Real wastewater samples were not used in this study.

1.6 Significance of the studies

This study has significant implications for environmental sustainability and public health. The successful development of activated carbon from pineapple peelings for ibuprofen adsorption provides a low-cost and environmentally friendly alternative to commercial activated carbon. This has made the adsorption technology more accessible and affordable for wastewater treatment plants (Selvanathan & Subki, 2015), particularly in developing countries like Uganda where resources are limited. The reduction of ibuprofen levels in water bodies helps to protect aquatic ecosystems and minimize the potential risks to human health. Furthermore, this study aims to promote the utilization of agricultural waste, reducing the environmental burden associated with its disposal (Nordin et al., 2023). The findings of this research are valuable to environmental scientists, engineers, and policymakers involved in water resource management and pollution control.

1.7 Conceptual framework

The conceptual framework for this study was based on the principles of adsorption, material science, and environmental engineering. The key concepts included, Adsorption which is the process by which ibuprofen molecules (solute or gas) adhere to the surface of the adsorbent solids such as activated carbon (Aisosa et al., 2020). A porous carbon material with a high surface area, capable of adsorbing organic molecules from aqueous solutions known as activated carbon (Ahmed, 2017). Pineapple peels, an agricultural waste material that can be converted into activated carbon through pyrolysis and activation processes. Physicochemical properties that is; the characteristics of activated carbon, such as surface area, pore size distribution, and surface functional groups, that influence its adsorption performance (Ahmed, 2017). The rate at which ibuprofen molecules are adsorbed onto the activated carbon. Adsorption Isotherms which indicate the relationship between the amount of ibuprofen adsorbed onto the activated carbon and the concentration of ibuprofen in the aqueous solution at equilibrium. The study investigated the relationship between the physicochemical properties of activated carbon derived from pineapple peelings and its adsorption performance for ibuprofen. The experimental data was analyzed using appropriate mathematical models to understand the adsorption kinetics and isotherms (Al-ghouti & Da, 2020). The findings of the study were used to optimize the preparation and application of activated carbon for ibuprofen removal from water.

CHAPTER TWO: LITERATURE REVIEW

2.1 Classification of ibuprofen

Pharmaceuticals, including ibuprofen have been detected in water sources worldwide and they enter water bodies through human and veterinary use, posing a risk to human health and the environment. Their continuous release into aquatic systems has raised concerns because conventional wastewater treatment methods have a limited capacity to remove these contaminants (Rivera-utrilla et al., 2013), highlighting the need for alternative technologies. Adsorption has emerged as a promising technology for removing pharmaceuticals from water by the use of activated carbon which has a high surface area and adsorption capacity (Bbumba, Karume, et al., 2025) hence being widely used for this purpose (Mansouri et al., 2021). The use of agricultural waste as a precursor for activated carbon production offers a sustainable and cost-effective solution (Ogheneochuko et al., 2022). Pineapple peelings, an abundant agricultural waste, have been explored as a potential precursor for the production of activated carbon. Studies have investigated the adsorption of ibuprofen onto activated carbon with varying results. The adsorption capacity of activated carbon is influenced by factors such as surface area, pore size and functional groups (Nordin et al., 2023).

Despite the potential of pineapple peel-derived activated carbon for ibuprofen adsorption, limited research has been conducted on this specific topic. This study aims to investigate the adsorption of ibuprofen onto activated carbon obtained from pineapple peelings, exploring its potential as a sustainable and effective adsorbent.

2.2 Review of pharmaceuticals

The presence of pharmaceuticals in wastewater has become a global concern due to their potential adverse effects on aquatic organisms and human health (Rivera-utrilla et al., 2013). Conventional wastewater treatment plants (WWTPs) are not designed to completely remove these micropollutants, leading to their persistence in the environment (Patel et al., 2022). Several technologies have been developed for the removal of pharmaceuticals from wastewater, including; the Activated Sludge Process, a biological treatment method which relies on microorganisms to degrade organic pollutants (Rivera-utrilla et al., 2013) .However, the removal efficiency of pharmaceuticals such as ibuprofen is often limited. Membrane Filtration, which includes technologies such as reverse osmosis (RO) and nanofiltration (NF), cannot effectively remove pharmaceuticals from wastewater. However, these methods are energy-intensive and can produce concentrated waste streams. Advanced Oxidation Processes (AOPs), such as ozonation, UV irradiation, and Fenton's reagent, can degrade pharmaceuticals through oxidation reactions. However, these methods can be expensive and may produce harmful by-products (Patel et al., 2022).

Adsorption using activated carbon is widely used and it is an effective technique for removing organic pollutants from water. Activated carbon can adsorb pharmaceuticals onto its surface, effectively removing them from the aqueous phase. Each of these technologies has its advantages and disadvantages in terms of cost, efficiency, and environmental impact. Adsorption using activated carbon is considered a promising method due to its high efficiency, relatively low cost, and ease of operation(Patel et al., 2022).

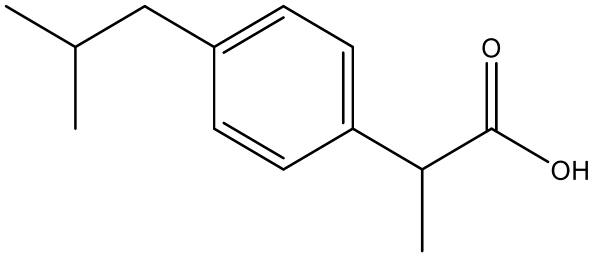
2.3 **Existing ibuprofen adsorption performance and identification of the research gap**

Several studies have investigated the adsorption of ibuprofen onto various types of activated carbon. Commercially available activated carbon has been shown to be effective in removing ibuprofen from aqueous solutions (Aisosa et al., 2020). However, the high cost of commercial activated carbon has prompted research into alternative, low-cost precursors. Agricultural waste materials, such as rice husk, coconut shell, and sugarcane bagasse, have been successfully used to produce activated carbon for ibuprofen adsorption. These studies have demonstrated that activated carbon derived from agricultural waste can be a cost-effective alternative to commercial activated carbon (Ogheneochuko et al., 2022). However, there is a limited number of studies on the use of pineapple peelings as a precursor for activated carbon production and their application for ibuprofen adsorption. While pineapple peelings are abundant and readily available agricultural waste, their potential as a precursor for activated carbon has not been fully explored. Furthermore, the adsorption performance of activated carbon derived from pineapple peelings for ibuprofen removal has not been extensively investigated. This study aims to address this research gap by investigating the effectiveness of activated carbon derived from pineapple peelings for the adsorption of ibuprofen from aqueous solutions. The findings of this study are to provide valuable insights into the potential of pineapple peelings as a sustainable and cost-effective precursor for activated carbon production and its application in pharmaceutical wastewater treatment.

2.4 Ibuprofen adsorption

Ibuprofen is an inflammatory analgesic drug with the IUPAC name 2-(4-isobutylphenyl) propionic acid and molecular formula $C_{13}H_{18}O_2$**.** It is widely consumed globally and frequently detected in wastewater treatment plant effluents. It has moderate solubility in water and a pKa value of approximately 4.9.

2.4.1 The structure of ibuprofen



ibuprofen

Ibuprofen consists of three regions: an aromatic benzene ring (hydrophobic region), isobutyl side chain (hydrophobic tail) and a carboxylic acid group (polar region) all of which indicate the functional groups present. These groups control how ibuprofen interacts with adsorbents such as activated carbon. Activated carbon produced from pineapple peels has a large surface area, aromatic carbon sheets, surface functional groups such as hydroxyl group, carboxyl group and a carbonyl group, which allow interaction with pharmaceutical molecules such as ibuprofen. Adsorption of ibuprofen onto activated carbon from pineapple peels occurs through π-π stacking between aromatic rings, hydrogen bonding between the carboxylic groups, hydrophobic interactions and weak electrostatic attraction, which allows efficient removal of ibuprofen from water (Patel et al., 2022).

CHAPTER THREE: MATERIALS AND METHODS

3.1 Materials

This study utilized the following materials and reagents: Pineapple peeling obtained from a local market ensuring a consistent source, chemical activating agent such as, Phosphoric acid (H_3PO_4), Analytical grade, purchased from a reputable chemical supplier, Ibuprofen a pharmaceutical grade, sourced from a pharmaceutical company to ensure purity and consistency, HCl and NaOH which are Analytical grade, for pH adjustment of ibuprofen solutions, distilled water used for all solution preparations and washing steps.

3.2 Apparatus

UV-Vis Spectrometer	Measuring cylinders
Analytical balance	Beakers
Furnace	Filter paper
pH meter	Magnetic stirrer
Conical flasks	Clamps

3.3 Methods

3.3.1 Precursor preparation

Pineapple peelings were collected from local markets. The peelings were cut and thoroughly washed with tap water to remove surface debris, followed by rinsing with distilled water to eliminate any residual impurities (Aisosa et al., 2020). The cleaned pineapple -peelings were dried under sunshine for six days. The dried pineapple peel was then grinded and sieved using 300µm sieve (Selvanathan & Subki, 2015).

3.3.2 Chemical activation

The dried and sieved pineapple peelings powder was impregnated with the chemical activating agent that is; phosphoric acid at a specific impregnation ratio 1:2, (material: activating agent by weight). The mixture was then stirred continuously for 2 hours to ensure uniform impregnation and pyrolysis was conducted in a dug pit in the absence of oxygen to prevent oxidation nd combustion. The impregnated precursor was heated at an activation temperature carbonized between 500℃ -700ºC. The activated carbon was allowed to cool at room temperature and then it was washed with 0.1 M HCl to remove any residual activating agent and mineral matter. The carbon was then be repeatedly washed with distilled water until the pH of the washing solution is neutral. The washed activated carbon was then dried in an oven at 105°C for 3 hours to remove any remaining moisture. The dried activated carbon was stored in a desiccator to prevent moisture adsorption before further use (Selvanathan & Subki, 2015).

Figure 1: Activated carbon before and after drying

3.4 Activated carbon characterization

The synthesized activated carbon was characterized using the following techniques: such as iodine method to determine the surface area, pore volume, and pore size distribution of the activated carbon using a Micromeritics ASAP 2020 analyzer. Where standard iodine solution was treated two different weights of activated carbon under suitable conditions. The carbon treated solutions were filtered to separate the carbon from the treated iodine solution. The iodine remaining in the filtrate was measured by titration with sodium Thiosulphate. The amount of iodine removed per gram of carbon was taken for each dosage and the resulting data was used to calculate the iodine number.

Fourier Transform Infrared Spectroscopy (FTIR) was used to identify the functional groups present on the surface of the activated carbon using a PerkinElmer Spectrum 100 spectrometer (Bbumba, Ssekatawa, et al., 2025). The pH determination to determine the pH of the activated carbon using a pH meter.

3.5 Adsorption Experiments

3.5.1 Preparation of Ibuprofen Solutions

A stock solution of ibuprofen was prepared by crushing 5 tablets of 200mg Bp ibuprofen and the crushed ibuprofen was dissolved using 20mg of 0.1M NaOH and distilled water was added to the 1000 mark of the volumetric flask. The concentration of the stock solution was then 1000 mg/L. 10mL of the stock solution pipetted in to a 100ml volumetric flask and distilled water was added to the mark and mixed thoroughly. The 100mg/L intermediate solution was used then to prepare working standards of 1-10mg/L concentrations by adding distilled water up to the 100ml mark.

3.5.2 Batch Adsorption Studies

Batch adsorption experiments were conducted to evaluate the effect of various parameters on the adsorption of ibuprofen onto the activated carbon. Experiments used 250ml conical flasks containing ibuprofen solutions, agitated in an orbital shaker at 150rpm to ensure uniform mixing without vortex formation. The parameters to be studied include: Adsorbent Dosage where different dosages of activated carbon 1-5 g/L were added to ibuprofen solutions of a fixed concentration. Initial Ibuprofen concentration in which ibuprofen solutions of different concentrations 1-10mg/L were used to study the effect of initial concentration on adsorption (Mandal et al., 2024). The pH (2-10) of the ibuprofen solutions was adjusted using 0.1M HCl or NaOH solutions. For each, the mixture was filtered using filter papers and the residual ibuprofen concentration was measured using UV-Vis spectrometer at λ-max 222nm, calibration curve 1-10mg/L, R^2= 0.9378), UV detection validated results for selected samples and ensured accuracy, especially at low concentration. The adsorption process were carried out for different contact times, 10-60 minutes to determine the equilibrium time (Mandal et al., 2024). Removal efficiency (%) was calculated as (Co-Ce)/Ce ×100), and equilibrium capacity(qe) as (Co-Ce) × v/m, where Co and Ce are initial and equilibrium concentrations (mg/L), V is the volume of the solution(L), and m is the mass of the adsorbent(g). All experiments were conducted with blanks and controls to correct any degradation.

3.6 Adsorption Isotherms

Adsorption isotherm studies were conducted to determine the relationship between the amount of ibuprofen adsorbed onto the activated carbon and the concentration of ibuprofen in solution at equilibrium. The experimental data was fitted to various isotherm models, such as Langmuir and Freundlich isotherms, to determine the adsorption capacity and mechanism (Mestre[a] et al., n.d.). The experimental data fitted in the Langmuir adsorption isotherms.

3.7 Adsorption Kinetics

Adsorption kinetic studies were conducted to determine the rate of adsorption of ibuprofen onto the activated carbon. The experimental data was fitted to various kinetic models, such as pseudo-first-order and pseudo-second-order models, to determine the rate constants and adsorption mechanism (Mestre[a] et al., n.d.).

3.8 Data modeling and analysis

Characterization data were for the determination of iodine number were analyzed using established model using the equation $\frac{(V_b - V_s) \times N \times 126.93 \times 1000}{W} \times (\frac{Vtotal}{Vpipette})$

To determine whether the activated carbon has a high or low adsorption capacity. Adsorption data were analyzed using established models to elucidate kinetics and equilibrium. Kinetic modeling applied to pseudo-first-order ($\ln (q_e - qt) = \ln q_e - k_1 t$) and pseudo-second-order ($t/qt = 1/ (k_2 q_e^2) + t/q_e$) equations, with best fit determined by R^2 and error functions like chi-square (χ^2). These identified rate-limiting steps, such as surface reaction or pore diffusion. Isotherm data fitted to Langmuir ($C_e/q_e = 1/ (q\text{-max } KL) + C_e/q\text{-max}$) and Freundlich ($\ln q_e = \ln KF + (1/n) \ln C_e$) models to assess monolayer/multilayer coverage and heterogeneity. Data fitting used software like Excel, with statistical validation ($R^2 > 0.95$ targeted)

Concentration of ibuprofen in the solutions before and after adsorption was determined using a UV-Vis spectrophotometer at a specific wavelength 222 nm. The amount of ibuprofen adsorbed onto the activated carbon was then calculated using the following equation:

$$qe = \frac{(Co - Ce).V}{m}$$

Where: Co and Ce are the initial and equilibrium concentrations of ibuprofen, mg L^{-1}; V is the volume of the solution, mL; m is the amount of the activated carbon in grams (Ioannidou et al., 2010).

3.9 Ethical considerations

Environmental protection; This involves proper disposal of ibuprofen solutions that is; following institutional hazardous waste procedures.

Sustainable use of Pineapple peels; Waste should be obtained from waste streams such as markets, households or food processing facilities.

Laboratory safety; This involves safe handling of chemicals during preparation and activation of activated carbon and carbonization, researchers have to wear protective gear like lab coats, gloves and safety goggles for their own safety.

Scientific integrity; Experimental data should be recorded honestly, all results including observations should be documented.

Waste management; Used adsorbent should be carefully disposed off.

Health and safety of the researcher; This involves risk assessments being completed before laboratory work, training in handling of chemicals and lab equipment, exposure to activated carbon dust minimized through masks and proper ventilation.

Ethical reporting and publication; Results should be reported objectively without manipulation, sources of information and previous studies should be properly cited, contributions of supervisors, technicians and collaborators should be acknowledged and limitations to the studies.

Compliance with institutional guidelines; Approval from the relevant department or research committee should be made before commencing the project, lab work should comply with university, environmental and safety regulations.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Introduction

The study investigated the adsorption and kinetics of ibuprofen removal from wastewater using activated carbon prepared from pineapple peels. The determination of the maximum adsorption wavelength of ibuprofen was done at 222nm. The findings demonstrated that pineapple peel activated carbon possesses significant adsorption potential for the removal of ibuprofen from aqueous solutions. The adsorption process was influenced by several operational parameters including pH, contact time, and adsorbent dosage.

4.2 Presentation of results and discussion

4.2.1 Results for characterization of activated carbon

4.2.1.1 Standard method for the determination of iodine number

Volume of pipette: $25.0cm^3$

Mass of activated carbon used = 1.5g

Thiosulphate concentration = 0.1N

Table 1 *Results for characterization of activated carbon using iodine method*

Titre	1^{st} reading	2^{nd} reading
Initial burette reading	0.00	0.00
Final burette reading	10.60	10.90
Volume used	10.60	10.90

4.2.1.1.1 Calculation of the iodine number

The iodine number is a standard indicator of the micro porosity and specific surface area of activated carbon. it is defined as the milligrams of iodine adsorbed per gram of carbon.

Where:

V = 10.60ml

N = 0.1N (normality of Thiosulphate)

126.93 = Equivalent weight of iodine

$m = 1.5$g (mass of activated carbon used)

Iodine number(mg/g) = $\frac{x}{M}$×A

X= (12,693N$_1$) -(279.246N$_2$V)

X = (12,693×0.1) – (279.246×0.1×10.60)

X =1,269.3-296.00076

X=973.29924

$Nr = \frac{N_2 \times V}{50} = \frac{0.1 \times 10.90}{50} = 0.0218$

A = 0.9875

In = $\frac{973.22924}{1.5} \times 0.9875$

In = 640.709 mg/g

4.2.1.1.2 Evaluation of the quality of activated carbon using iodine test.

An iodine number of 640.709mg/g indicates a moderately high development of micro pores within the activated carbon structure. Commercial grade activated carbons typically exhibit values between 500mg/g to 1200mg/g. The fact that pineapple peel achieved a value well within this range demonstrates that the carbonization and subsequent activation process successfully created an extensive network of internal voids.

4.2.1.2 Fourier Transform Infrared Spectroscopy

Surface functional groups of the synthesized pineapple peel activated carbon were measured using an FTIR instrument which gave spectra within a range of 4000cm^{-1} to 400cm^{-1}.

The presence of surface functional groups on the pineapple peel activated carbon was determined by FTIR analysis, as illustrated in figure 1

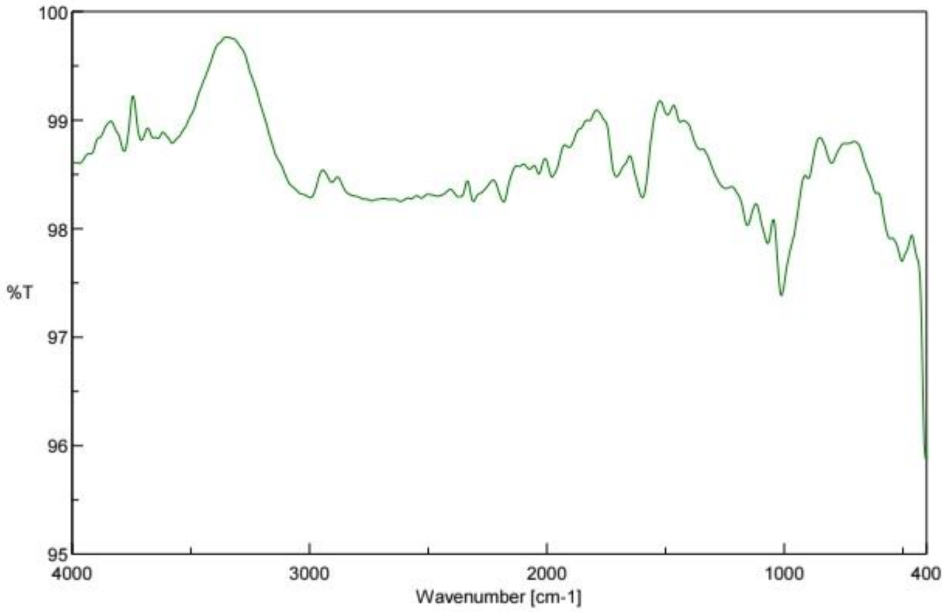


Figure 2: FTIR spectrum of pineapple peel activated carbon

A wavelength of 4000cm^{-1} to 400cm^{-1} was used to detect peaks, which provide an insight to the groups attached to the material. This adjustment provides an overview of the range of functional groups on the adsorbent. FTIR exhibited a broad absorption band at approximately 3400cm^{-1} attributing to O-H stretching vibrations of hydroxyl groups, peaks at approximately 1000cm^{-1} to 1300cm^{-1} corresponded to C-O stretching vibrations, absorption at approximately 1600cm^{-1} to 1700cm^{-1} was attributed to C=O, absorption at near 3000cm^{-1} at approximately 2900cm^{-1} and 2990cm^{-1} was attributed to C-H stretching(Outline, n.d.). The oxygen containing groups above contribute to the strong interaction between ibuprofen and the adsorption surface of activated carbon. The observed peaks are a characteristic of the activated carbon from the literature.

4.2.2 Standard calibration data

Table 2 Standard table for calibration data

Standard number	Concentration(mg/L)	Absorbance
1	0	0
2	1	0.350
3	2	0.463
4	4	0.569
5	6	0.685
6	10	1.236

$$Ce = \frac{Absorbance - intercept}{slope}$$

4.2.2 Analysis of calibration data

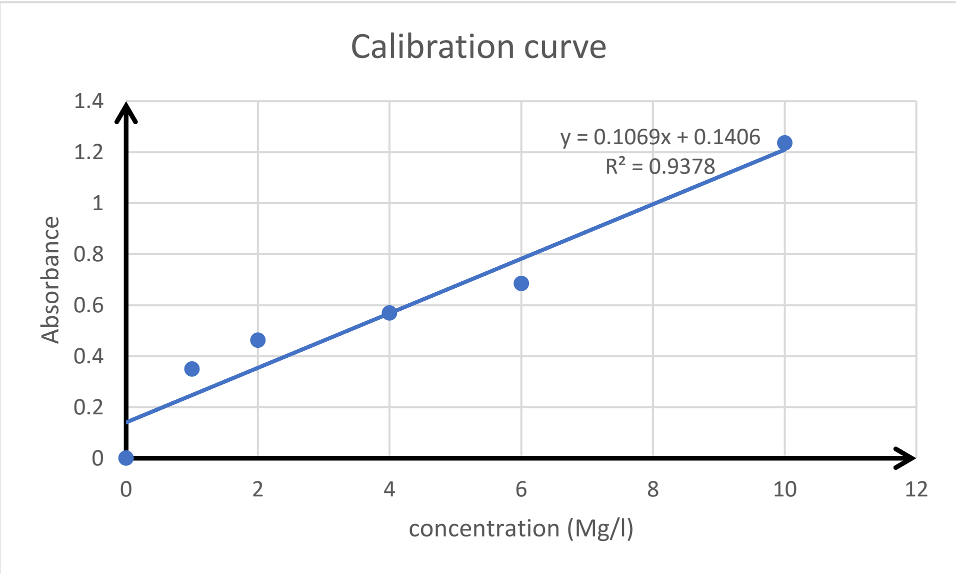


Figure 3: Calibration curve

The calibration curve results showed absorbance increased linearly with increasing ibuprofen concentration. The blank solution produced zero absorbance because it contained no ibuprofen molecules capable of absorbing UV radiation. As the concentration increased from 0mg/L to 10mg/L, the absorbance increased from 0.125

to 1.230. This demonstrated a direct proportionality between concentration and absorbance, confirming compliance with Beer-Lambert law.

The linear relationship indicated that the prepared standard solutions were accurate, the UV-Vis spectrometer was functioning properly, the selected wavelength of 222nm was suitable for ibuprofen analysis, and the concentration range used was within the instrument's linear detection range. The calibration curve was important for determining unknown ibuprofen concentrations during adsorption studies. After adsorption experiments, a calibration curve was plotted with ibuprofen concentration on the X-axis and absorbance on the Y-axis. The graph produced a straight line passing close to the origin, demonstrating linear dependence on concentration.

The linear regression equation was obtained from the graph which was;

$y = 0.106x + 0.1406$

where: y is the absorbance, x is the concentration of ibuprofen. The correlation coefficient from the graph is $R^2 = 0.9378$, which is typically close to R2 = 0.999, indicating excellent linearity and reliability of the calibration curve for quantitative analysis.

4.2.3 Contact time

Table 3 *Effect of contact time on the adsorption of activated carbon*

Time(mins)	Absorbance
10	0.449
20	0.426
30	0.414
40	0.399
60	0.376

4.2.3.1 Analysis of the effect of contact time on adsorption

The adsorption efficiency increased steadily with increasing contact time from 10-60 minutes. Initially, adsorption occurred rapidly because many active adsorption sites were available on the activated carbon surface. During the first stages of adsorption, ibuprofen molecules easily occupied vacant sites, resulting in rapid uptake. As contact time increased, the adsorption rate gradually slowed because the remaining adsorption sites became fewer and more difficult to access. Equilibrium was reached after approximately 40 minutes, where little significant increase in adsorption was observed beyond this time.

And rapid initial adsorption followed by slower adsorption is a common phenomenon in adsorption processes. The initial stage is usually controlled by external surface adsorption, while later stages involve diffusion of the adsorbate molecules into the internal pores of the activated carbon. The equilibrium time obtained in this study indicates that pineapple peel activated carbon exhibits relatively rapid adsorption, making it suitable for wastewater treatment applications.

4.2.4 Initial concentration of pollutant

Table 4 *Initial concentration of the pollutant*

Concentration (mg/L)	Absorbance
1	0.202
2	0.289
4	0.495
6	0.732
10	0.98

4.2.5 pH analysis (Effect of pH on the adsorption process)

Table 5 *Effect of pH on the adsorption of ibuprofen*

Initial pH	Absorbance	Final pH
2	0.527	2.4
4	0.381	4.2
6	0.506	5.9
8	0.426	7.5
10	0.444	9

Initial concentration, C_1 of ibuprofen used = 20 mg/g

Dosage of activated carbon = 1g/L

Time 30 minutes

Table 6 Effect of initial and final pH on adsorption of ibuprofen from activated carbon

Initial pH	Absorbance	Ce	% Removal	qe(mg/g)	Final pH
2	0.527	3.615	81.9	16.39	2.4
4	0.381	2.249	88.8	17.75	4.2
6	0.506	3.418	82.9	16.58	5.9
8	0.426	2.670	86.7	17.33	7.5
10	0.444	2.838	85.8	17.16	9.0

4.2.5.1 Analysis of effect of pH on adsorption of ibuprofen

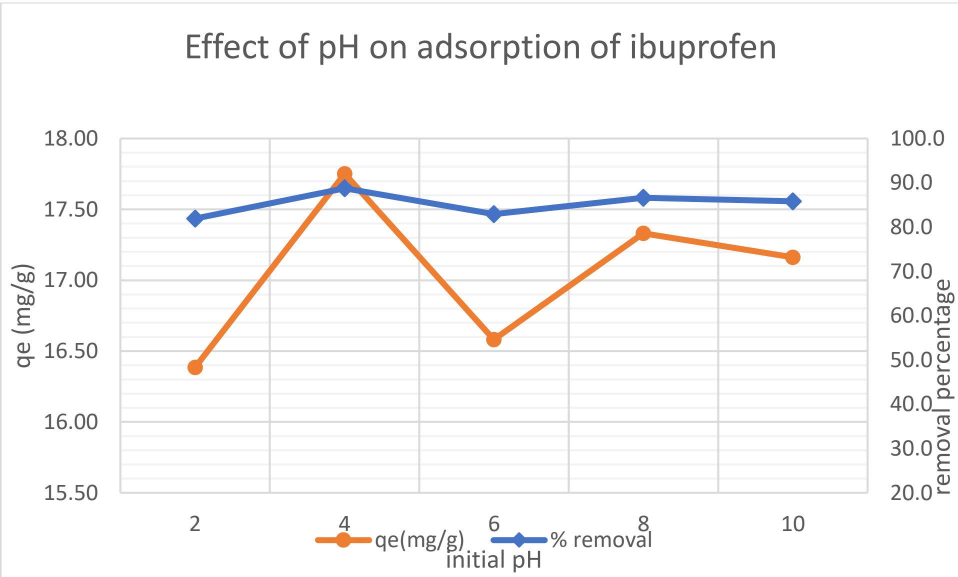


Figure 4: Effect of pH on adsorption of ibuprofen

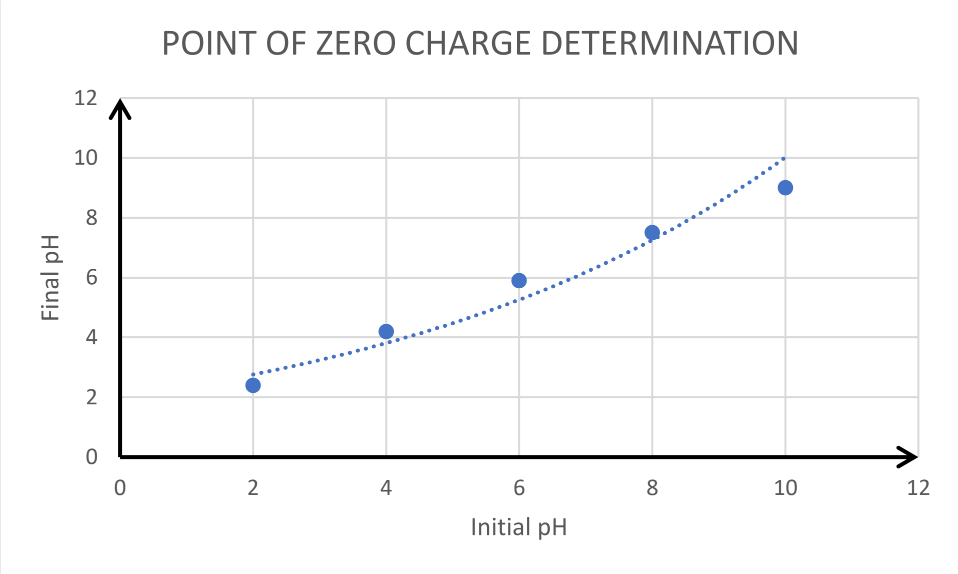


Figure 5:Point of zero charge determination curve

Point of zero charge is 7.0

The pH_{PZC} of 7.0 is the exact reflection point where the net surface charge of pineapple peel activated carbon transitions from positive to negative. The results showed that adsorption efficiency was higher at pH 4. At low pH values, the activated carbon surface the results showed that adsorption efficiency was highest at pH 4. At low pH values, the activated carbon surface became positively charged, enhancing adsorption of ibuprofen molecules. At high pH values, electrostatic repulsion reduced adsorption efficiency.

4.2.5.2 Discussion of results for effect of pH on ibuprofen adsorption.

The adsorption results showed that the highest percentage removal of ibuprofen occurred at pH 4, where approximately 88.8% removal was achieved. Adsorption efficiency decreased progressively as the pH increased from acidic to alkaline conditions.

This behavior can be explained by the ionization properties of ibuprofen and the surface characteristic of activated carbon. ibuprofen and the surface of activated carbon. Ibuprofen is a weak acidic pharmaceutical compound with a pKa value of approximately 4.9. At acidic pH values below the pKa, ibuprofen mainly exists in its non -ionized form, which favors adsorption onto porous activated carbon surface through hydrophobic interactions and van der Waals forces.

At low pH values, the surface of activated carbon becomes protonated and positively charged, thereby enhancing attraction between the adsorbent surface and the ibuprofen molecules. However, at alkaline pH values, ibuprofen becomes negatively charged due to protonation, while the activated carbon surface also acquires negative charges. this causes electrostatic repulsion between the adsorbent and the adsorbate, leading to reduced adsorption efficiency.

These findings therefore indicate that pH is a critical factor controlling adsorption efficiency.

4.2.6 Dosage adsorption table

Table 7 Effect of dosage amounts on adsorption of ibuprofen

mass(g)	dosage(g/l)	Absorbance	Ce	% Removal	Qe
0.1	1	0.8	6.22	68.9	13.78
0.2	2	0.577	4.12	79.4	7.94
0.3	3	0.402	2.47	87.7	5.84
0.4	4	0.339	1.87	90.6	4.53
0.5	5	0.276	1.28	93.6	3.74

Co = 20mg/g, pH = 5.9, Time=30 minutes

4.2.6.1 Analysis of the effect of adsorbent on the adsorption process

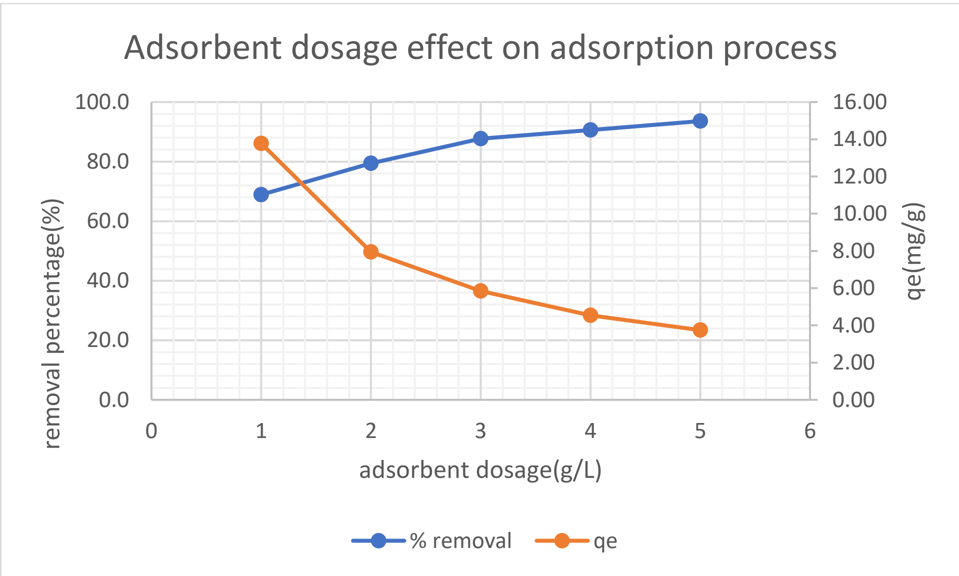


Figure 6: Effect of adsorbent dosage on the adsorption of ibuprofen

4.2.6.2 Discussion of results for adsorbent dosage effect on adsorption process

The results showed that increasing adsorbent dosage from 1g/L to 5g/L increased the percentage removal of ibuprofen from 68.9% to 93.6%.

This increase in adsorption efficiency can be attributed to the increase in the number of available adsorption sites and the larger surface area provided by higher amounts of activated carbon. As more adsorbent was added, more pores and active binding sites became available for adsorption of ibuprofen molecules. Additionally, increasing adsorbent dosage increases the probability of interaction of interaction between ibuprofen molecules and the adsorbent surface, thereby improving removal efficiency. However, although percentage removal increased with dosage, adsorption capacity per unit mass of adsorbent may decrease at very high dosages dur to overlapping or aggregation of adsorption sites. This can reduce the effective surface area available for adsorption. The findings suggest that adsorption dosage is an important operational parameter that should be optimized for economical wastewater treatment.

4.2.7 Kinetics data

4.2.7.1 Pseudo-first order kinetics

4.2.7.1.1 kinetics data for pseudo-first order data

Table 8 *Pseudo-first order data*

Time(mins)	Absorbance	Ce	qt(mg/g)	Qe	In(qe-qt)
10	0.449	2.885	19.551	88.99	4.456
20	0.426	2.670	19.574	88.99	4.458
30	0.414	2.558	19.586	88.99	4.459
40	0.399	2.417	19.601	88.99	4.461
60	0.376	2.202	19.624	88.99	4.463

From PFO, $qt = qe(1-e^{-k1t})$

slope(k) = -0.0002 and intercept, In (qe) = 4.2761

For calculated equilibrium adsorption capacity, $qe = e^{4.\ 2761}$

=71.95mg/g

Therefore 71.95mg/g is far from the tabular value of maximum equilibrium adsorption implying that the data does not follow pseudo-first order.

4.2.7.1.2 Kinetics data analysis

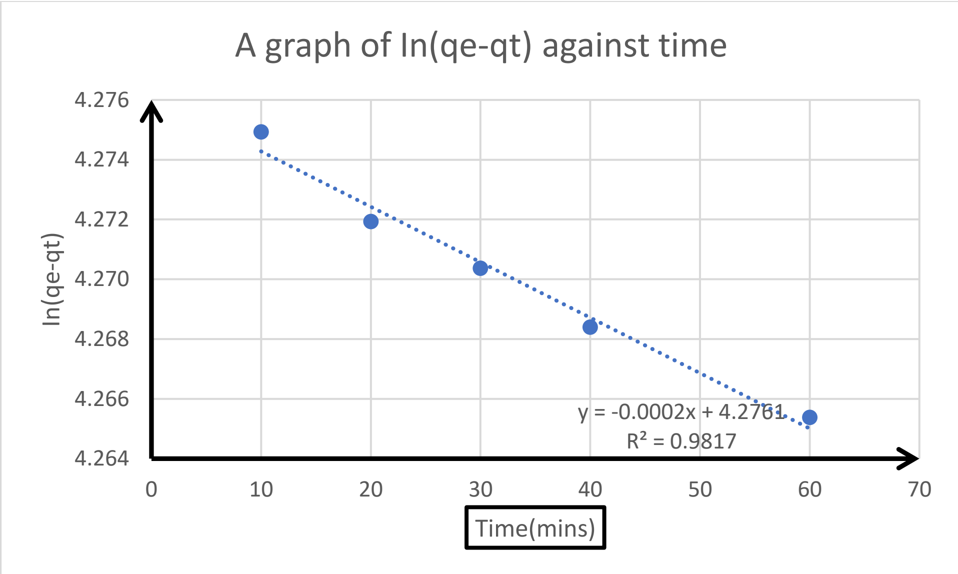


Figure 7: Modelling of experimental results on activated carbon by pseudo-first order model

Increasing adsorbent dosage increased adsorption efficiency due to the availability of more active adsorption sites.

From PFO, qt = qe(1-e^{-k1t})

slope(k) = -0.0002 and intercept, In (qe) = 4.2761

For calculated equilibrium adsorption capacity, qe = $e^{4.\ 2761}$

=71.95mg/g

4.2.7.1.3 Discussions of pseudo-first order kinetics results

The value 71.95mg/g is far from the tabular value of maximum equilibrium adsorption implying that it does not follow pseudo-first order.

4.2.7.2 Pseudo- second order kinetics table

***Table 9** Pseudo-second order data*

Time(mins)	Absorbance	Ce	%Removal	qt(mg/g)	t/qt(g.min/mg)
10	0.449	2.885	85.575	17.115	0.584
20	0.426	2.670	86.651	17.330	1.154
30	0.414	2.558	87.212	17.442	1.720
40	0.399	2.417	87.914	17.583	2.275
60	0.376	2.202	88.990	17.798	3.371

4.2.7.2.1 Analysis of Pseudo-second order kinetics data

Removal efficiency R (%) = $\frac{(Co-Ce)}{Co} \times 100$

Adsorption capacity = $\frac{(Co-Ce)}{m} \times V$

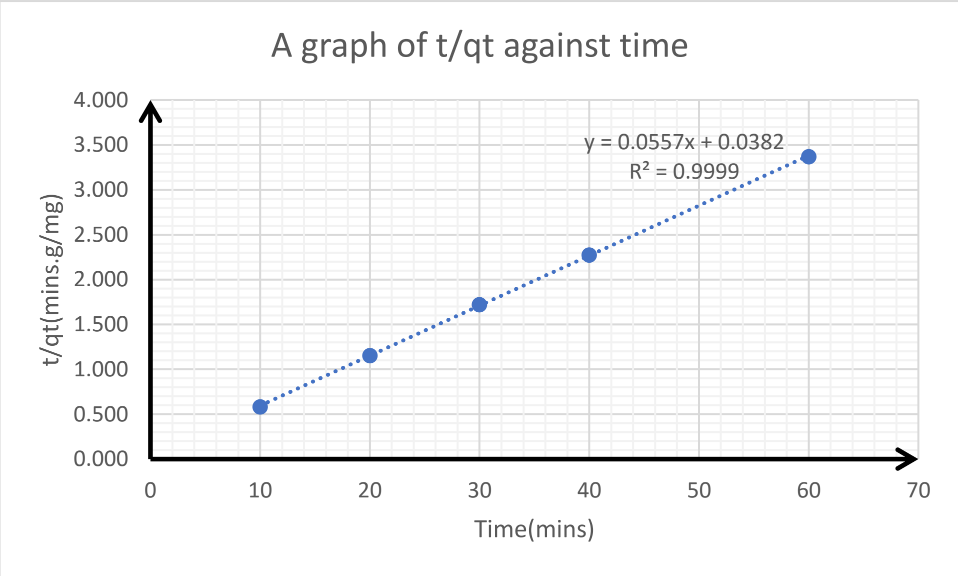


Figure 8: Modelling of experimental results on activated carbon by pseudo-second order model

From;

qt = $\frac{qe^2 k_2 t}{1+k_2 qet}$ Slope = $\frac{1}{qe}$ Intercept = $\frac{1}{k_2 qe^2}$

Calculated equilibrium capacity, qe (theoretical) = $\frac{1}{slope} = \frac{1}{0.0557}$ = 17.95mg/g

The value represents the maximum amount of ibuprofen can hold at equilibrium for this concentration (20mg/L)

4.2.7.2.2 Pseudo-second order rate constant (K_2)

From the graph, the pseudo-second order rate constant can then be obtained which is as below.

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

$K_2 = \frac{(0.0557^{2})}{0.0382}$

=0.0382g/mg.min

This constant indicates how fast the adsorption reaches equilibrium.

4.2.7.2.3 Initial adsorption rate (h)

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

$h = K_2 \times qe2$

$= \frac{1}{inteecept} = \frac{1}{0.0382}$

=26.178mg/g

4.2.7.2.4 Discussion for Pseudo-second order model results

The pseudo-second-order model assumes that adsorption occurs mainly through chemisorption involving electron sharing or exchange between the adsorbent surface and adsorbate molecules(Ahmed, 2017). The good agreement of experimental data with this model suggests that chemical interactions played a significant role in the adsorption of ibuprofen onto pineapple peel activated carbon. The kinetic analysis showed that the pseudo-second order kinetic model provided a better fit for the adsorption data than pseudo-first order model because R^2 value of pseudo-second order was higher and close to 0.995 than for pseudo-first order.

4.2.8 The adsorption isotherms data

4.2.8.1 The Freundlich isotherm equation

Non-linear form, $qe = K_f Ce^{1/n}$

Linear form $\log qe = \log K_f + \frac{1}{n} \log Ce$

Table 10 Freundlich adsorption isotherm data

Concentration (mg/L)	Absorbance	Ce	% Removal	Qe (mg/L)	Ce/qe	Log Ce	Log qe
1	0.202	0.579	97.104	19.421	0.030	-0.237	1.288
2	0.289	1.400	93.000	18.600	0.075	0.146	1.270
4	0.495	3.343	83.283	16.657	0.201	0.524	1.222
6	0.732	5.579	72.104	14.421	0.387	0.747	1.159
10	0.98	7.919	60.406	12.081	0.655	0.899	1.082

From the graph, the slope is used to calculate the adsorption intensity, as follows.

Slope $=\frac{1}{n}$, slope= -0.169 and intercept =1.2745

Adsorption intensity(n) = $\frac{1}{-0.169}$ = -5.917

Since n is not between 1 and 10, the absorption is considered unfavourable.

Freundlich capacity (K_f)

Intercept = log K_f

log K_f = 1.2745 K_f= 10 $^{1.2745}$

18.8148(mg/g) $(L/mg)^{1/n}$ represents maximum adsorption capacity.

The Freundlich model assumes adsorption on a heterogeneous surface with sites of different energies and allows for multilayer adsorption. Data was fitted, which gave a lesser correlation (R^2= 0.8563)

4.2.8.1.1 Analysis of Freundlich adsorption isotherm data

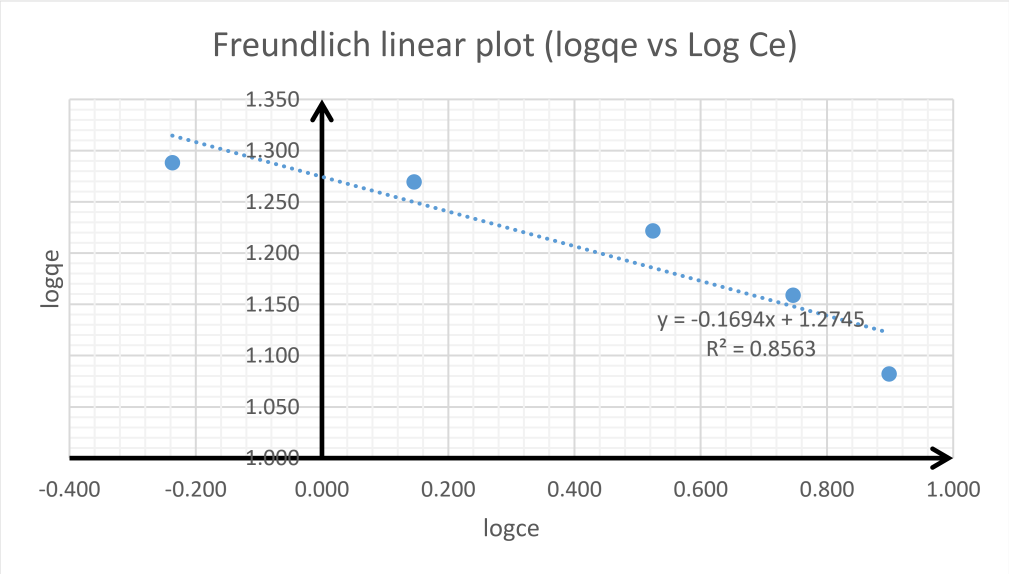


Figure 9: Modelling of experimental results of the activated carbon on Freundlich adsorption isotherm

Since n is not between 1 and 10, the absorption is considered unfavorable.

Freundlich capacity (K_f)

Intercept = log K_f

log K_f = 1.2745 K_f= 10 $^{1.2745}$

18.8148(mg/g) $(L/mg)^{1/n}$ represents maximum adsorption capacity.

4.2.8.2 Langmuir isotherm model (monolayer adsorption)

This model assumes adsorption occurs on a homogeneous surface with a finite number of identical sites.

4.2.8.2.1 Langmuir isotherm equations

Nonlinear form, qe = $\frac{Q_m K_f C_e}{1+K_f C_e}$

Standard linear form (Hanes-Woolf)

$$\frac{Ce}{qe} = \frac{1}{Qm}\, Ce + \frac{1}{Q_e\, K_L}$$

Table 11 *Langmuir adsorption isotherm data*

Concentration (mg/L)	Absorbance	Ce	% Removal	Qe(mg/g)	Ce/qe
1	0.202	0.579	97.104	19.421	0.030
2	0.289	1.400	93.000	18.600	0.075
4	0.495	3.343	83.283	16.657	0.201
6	0.732	5.579	72.104	14.421	0.387
10	0.98	7.919	60.406	12.081	0.655

4.2.8.2.2 Langmuir adsorption isotherm

Nonlinear form, qe = $\frac{Q_m K_f C_e}{1+K_f C_e}$

Standard linear form (Hanes-Woolf)

$$\frac{Ce}{qe} = \frac{1}{Qm}\, Ce + \frac{1}{Q_e\, K_L}$$

4.2.8.2.3 Analysis of Langmuir adsorption isotherm model

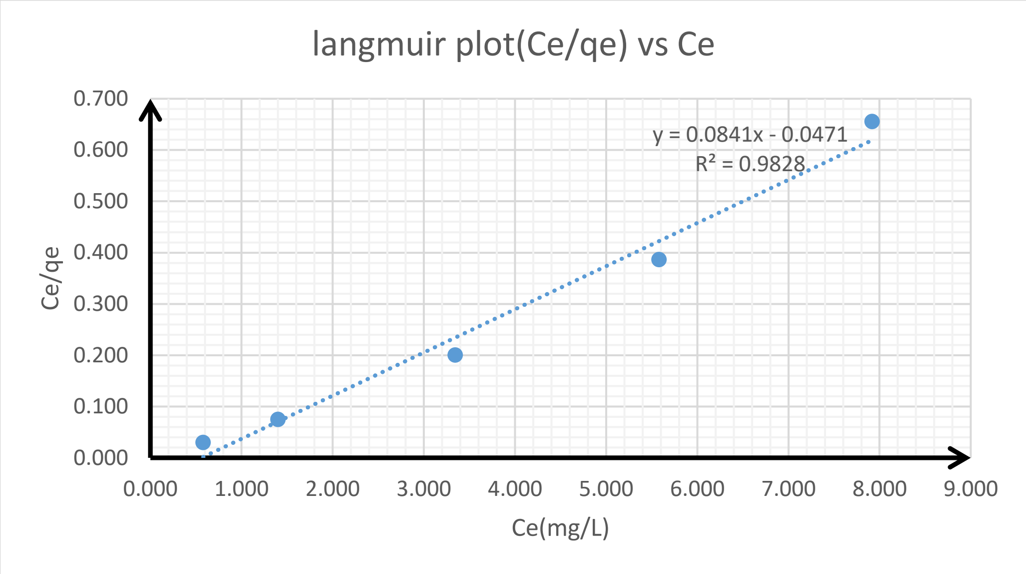


Figure 10: Modelling of the experimental results of the activated carbon on the Langmuir adsorption isotherm

Maximum capacity (Qm) = $\frac{1}{slope}$ but slope = 0.0841

$= \frac{1}{0.0841}$

=11.891mg/g

Langmuir constant (KL) = $\frac{1}{Slope \times intercept}$ but intercept = - 0.0471

$= \frac{1}{0.0841 \times -0.0471}$

= -252.454

The K_l value 252.454 represents the ratio of the adsorption rate to the desorption rate. it suggests that;

The adsorbate has a very high affinity for the active sites on the adsorbent that is strong binding

The surface will reach its maximum capacity (Q_m) even at very low equilibrium concentration (Ce).

Dimensionless separation factor (RL) the value indicates the favorability of the process. because the K_l is high, the values of R_L will be very close to zero across all concentration ranges

$$R_L = \frac{1}{1+K_L C_i}$$

For example, even at low initial concentration Ci of 0.1

$$R_L = \frac{1}{1+(-252.454\times 0.1)}$$

= - 0.04124

Since 0< R_L< 1, the adsorption is highly favorable thus very strong chemisorption. (q_m) = -252.454 represents the total amount of adsorbate required to occupy every available site on the surface exactly once. (monolayer)

4.2.8.1.2 Discussion of results obtained from adsorption isotherms

The Freundlich model assumes adsorption describing the reversible and non-ideal process. It is not restricted to monolayer formation in which multilayer formation is possible. In this isotherm model, adsorption heat and affinities does not need to be uniformly distributed on a heterogenous surface with sites of different energies and allows for multilayer adsorption (Al-ghouti & Da, 2020). This model defines the heterogeneity of the surface as well as the exponential distribution of the active sites and the active sites energies. It works in a way that the stronger binding sites will be occupied and then an exponential decline in the adsorption process. This isotherm model has linearized and non-linearized forms of its equation and its parameters can be found when log qe is plotted vs log Ce yielding a straight line with 1/n as the slope and log(kf) as an intercept. Fitted the data giving a less correlation (R^2= 0.8563) as seen in figure 7.

The Langmuir model gave a higher correlation coefficient of determination (R^2=0.9828) indicating that the adsorption process follows monolayer adsorption on a relatively uniform surface(Foo & Hameed, 2010).

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This study modified biomass from pineapple peel by physical and chemical methods. Activated carbon prepared from pineapple peels efficiently removed ibuprofen from wastewater through adsorption. The adsorption efficiency was influenced by pH, contact time, and adsorbent dosage. Batch studies showed that optimal adsorption occurred at pH 4, Batch adsorption experiments were best fitted to the Langmuir adsorption isotherm which assumed monolayer adsorption following pseudo-second order chemisorption kinetics(Ogheneochuko et al., 2022). Pineapple peel activated carbon can therefore serve as a low- cost and environmentally friendly adsorbent for wastewater treatment. This study demonstrates the potential advantage of pineapple peels when used in their modified form, especially by carbonization for the remediation of real water contaminated by ibuprofen

5.2 Recommendations

1. Surface characterisation techniques, such as SEM, should be used to analyse the adsorbent.

2. The effect of temperature on the adsorption of ibuprofen should be investigated.

3. Real urban wastewater samples should be tested.

4. Regeneration and reuse of the adsorbent should be investigated.

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APPENDICES

Appendix 1: Sample calculations

Percentage removal

Given:

Initial concentration = 20mg/L

Final concentration = 5.2mg/L

% Removal = $\frac{Co-Ce}{Co} \times 100$

$= \frac{20-5.2}{20} \times 100$

=74%

Adsorption capacity

Given:

Co = 20mg/L

Ce = 2.88 mg/L

V = 0.1 L

m = 0.2g

qe = $\frac{Co-Ce}{m} \times V$

$= \frac{20-2.88}{0.2} \times 0.1$

qe = 8.56mg/g

Appendix II: Safety precautions

1. Wear gloves, googles, laboratory coats during experiments.
2. Handle phosphoric acid and sodium hydroxide carefully.
3. Avoid inhalation of activated carbon dust.
4. Dispose chemical wastes properly.

5. Operate the furnace carefully to avoid burns.

6. Pour concentrated acids only from the fume hood.