FACULTY OF SCIENCE AND EDUCATION

DEPARTMENT OF CHEMISTRY

ADSORPTION AND KINETICS OF 2,4-DICHLOROPHENOXYACETIC ACID (2,4-D) FROM WASTE WATER USING ACTIVATED CARBON DERIVED FROM CASSAVA PEELS.

BY

OWOR BALAAM

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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

AUGUST 2026

DECLARATION

I Owor Balaam, 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 project with title "ADSORPTION AND KINETICS OF 2,4-DICHLOROPHENOXYACETIC ACID (2,4-D) FROM WASTE WATER USING ACTIVATED CARBON DERIVED FROM CASSAVA PEELS" has been submitted with the supervisor's approval.

Supervisor's Name: Dr Kigozi Moses

Signature: .....

Date: 27th/08/2026

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ABSTRACT

The increasing use of herbicides in modern agriculture has contaminated water bodies, posing serious environmental and public health concerns. Among these herbicides, 2,4-Dichlorophenoxyacetic acid (2,4-D) is widely used for weed control but is persistent in the aquatic environment and can negatively affect non-target organisms at excessive concentrations. Conventional methods for removing herbicides from waste water are often expensive and less sustainable, creating the need for low-cost and environmentally friendly alternatives. Agricultural wastes such as cassava peels can be converted into activated carbon and utilized as an efficient adsorbent for pollutant removal. This study investigated the adsorption and kinetics of 2,4-D removal from aqueous solutions using activated carbon derived from cassava peels. The main objective was to prepare and characterize activated carbon from cassava peels using the chemical activation method for 2,4-D removal, and to determine the adsorption kinetics governing the process. Activated carbon was prepared through chemical activation of cassava peels. Batch adsorption experiments were conducted under varying conditions of contact time, PH, adsorbent dosage, and initial herbicides concentration(Jordana Georgin et al. 2022). The adsorption data were analyzed using kinetic models including pseudo-first order and pseudo-second order equations. The results indicated that cassava-peels activated carbon possessed high adsorption capacity due to its porous structure and large surface area. Adsorption efficiency increased with increased contact time and adsorbent dosage but decreased with increasing initial concentration of 2,4-D. Maximum adsorption was observed under acidic to neutral PH conditions. The kinetic analysis showed that the adsorption process followed pseudo-second-order kinetic model more closely than the pseudo-first-order suggesting that chemisorption was controlling the adsorption. The activated carbon demonstrated rapid uptake of 2,4-D during the initial stages followed by equilibrium. In conclusion, activated carbon derived from cassava peels is an effective, low-cost, and sustainable adsorbent for removal of 2,4-D from contaminated water.

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2,4-D:	Dichlorophenoxyacetic acid
POP:	Persistent Organic Pollutant
SDG:	Sustainable Development Goal
CPAC:	Cassava peel activated carbon
AOP:	Advanced oxidation processes

CHAPTER ONE: INTRODUCTION

1.1 Background of the study

The widespread use of herbicides in agriculture has contaminated water sources, posing a significant environmental and health risks. Among these herbicides, 2,4-dichlorophenoxyacetic acid(2,4-D) is a commonly used selective herbicide for broadleaf weed control .Despite its effectiveness in weed control, it's a persistent organic pollutant (POP) and a potential carcinogen(Landrigan et al. 2020) . The highest 2,4-D contamination of the fields and water bodies is estimated to occur during the planting period of each season (Gaaied et al. 2020). During this time, farmers intensively apply herbicides to control weeds in their fields. For example, flooding of rice fields after applications may carry 2,4-D residues to surface waters via runoff(Aryee et al. n.d.). If applicators have low awareness of environmental contamination. 2,4-D application has resulted in its detection in surface water, ground water, and even drinking water sources. It's a moderately persistent chemical with a half-life ($t_{1/2}$) between 20 and 312 days depending upon the environmental conditions(Meftaul et al. 2020). The herbicide is directly applied to soil or sprayed onto crops, and from there often reaches surface water and sediments. Due to low adsorption coefficients and high solubility in water, 2,4-D has usually been detected in surface and ground water, which means a crucial environmental problem and health hazard (Pinto et al. 2021). About 91.7% of 2,4-D eventually ends up in water(Debebe et al. 2023). This contamination threatens the life of exposed vegetation and animals. Additionally, herbicides are carried by water runoff into local river systems, wells and ponds, thereby threatening the health of aquatic life. Unfortunately, 2,4-D has non-specific weed targets(Landrigan et al. 2020). 2,4-D can cause various health effects including eye, skin and gastrointestinal irritation from acute exposure, reduce growth rates, induce reproductive problems and produce changes in appearance or behavior or cause the death of non-target species, including plants, animals and microorganisms. It is also known as an endocrine disruptor, affecting developmental processes even at low concentrations.

In Uganda Vision 2040, the government aims "to improve the health, sanitation, hygiene, promote commercial and low consumption industrial setups. Government will construct and extend piped water supply to all parts of the country". To accomplish this, the Ministry of Water outlines "improved water quality" and "reliable water quantity" as actionable targets for 2040. This will examine extending water treatment capacity to meet all (SDG) 6, which focuses

on sustainable access to clean water and sanitation. This may involve removing pollutants such as 2,4-D from water streams(Yasir et al. 2024).

Traditional methods of 2,4-D removal, such as chemical oxidation and biological degradation often incur high operational costs, result in incomplete degradation and produce toxic byproducts. Considering these significant concerns, there is a need for a method that addresses 2,4-D pollution in agricultural water ways, while remaining user-friendly. In general, 2,4-D removal from aqueous streams can be achieved using a common adsorption technique. Adsorption stands out as the most favorable option due to its affordability, efficiency, simplicity, and capacity to remove even trace levels of herbicides. Among various adsorbents, activated carbon (AC) is widely used due to its cost-effectiveness and efficacy(Gaaied et al. 2020). However, commercial AC may be expensive, prompting research in to low-cost alternatives derived from agricultural waste such as cassava peels, which are rich in carbonaceous material and can be easily converted into activated carbon by thermochemical processes. 2,4-D is a weak organic acid, its charge depends on the pH of the solution to which its put. . Therefore, the choice of activation method specifically chemical activation using agents like Phosphoric acid (H_3PO_4) is helpful because it's known to introduce and enhance these functional groups while improving yield and developing targeted porosity.

2,4-Dichlorophenoxyacetic acid structure

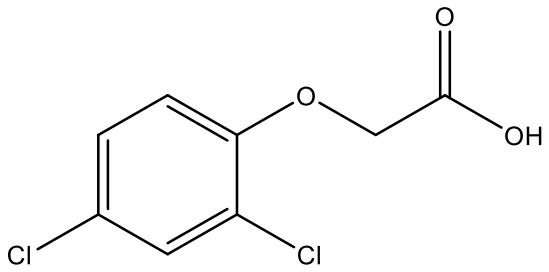


Figure 1.1: Structure of 2,4-Dichlorophenoxyacetic acid

1.2 Problem statement

The widespread and extensive use of 2,4-dichlorophenoxyacetic acid (2,4-D) herbicide in agriculture has led to frequent contamination of surface and ground water sources, posing significant environmental and human health risks due to its potential toxicity, moderate persistence, and low biodegradability under certain conditions. Traditional water treatment methods often fail to remove these organic pollutants completely(Herrera-García et al. n.d.). While commercial activated carbon (AC) is an effective adsorbent, its high cost and non-renewable nature limit its use in developing regions.

Agricultural waste materials, such as cassava peels, are abundant, low-cost, and potentially viable precursors for producing activated carbon with high adsorption capacity. However, there is a need to systematically investigate the performance of activated carbon derived from cassava peels (CPAC) for removing 2,4-D from water with a specific focus on its adsorption capacity and the underlying kinetic mechanisms(J Georgin et al. n.d.). The challenge lies in optimizing production and application parameters (like, activation method, pH, contact time, adsorbent dosage) to ensure efficient, cost-effective removal of 2,4-D, thereby transforming an agricultural waste product into in to a sustainable water-purification solution(Aryee et al. n.d.).

This study addresses the need to develop an effective, sustainable, and low-cost method for the remediation of 2,4-D contaminated water using an environmentally friendly adsorbent derived from cassava peels, and to understand the adsorption processes, equilibrium and kinetic behaviors.

1.3 Objectives of study

This study was guided by the general objectives and specific objectives shown below.

1.3.1 General objective

To evaluate the effectiveness and efficiency of activated carbon derived from cassava peels as a sustainable low-cost adsorbent for the removal of 2,4-dichlorophenoxyacetic acid (2,4-D) from contaminated water.

1.3.2 Specific objectives

i. To prepare and characterize activated carbon from cassava peels using the chemical activation method.
ii. To analyze the adsorption kinetics by fitting the experimental data to kinetic models like the Langmuir model and the Freundlich model.
iii. To analyze cassava peels activated carbon efficiency for 2,4-D removal.

1.4 Research questions

i. How effective is activated carbon derived from cassava peels in removing 2,4-Dichlorophenoxyacetic acid from contaminated water?
ii. How do factors such as contact time, pH, adsorbent dosage, and initial concentration affect the adsorption of 2,4-D?

iii. Which adsorption kinetic model best describes the adsorption process of 2,4-D onto cassava peel activated carbon?

1.5 SCOPE OF THE STUDY

The study will Centre on developing a cost-effective, sustainable, and efficient method for removing the common herbicide 2,4-D from contaminated water using activated carbon derived from cassava peels, an abundant agricultural waste product. Optimizing the production of activated carbon from cassava peels for example, activation method, temperature among others. Characterizing the produced activated carbon for, example, morphology via SEM, functional group via FTIR among others. Conducting batch adsorption experiments to determine optimal operational parameters like pH, contact time, adsorption dosage, initial 2,4-D concentration, among others. Analyzing adsorption isotherms (like Langmuir, Freundlich) and kinetic (like pseudo first-order) to understand the adsorption mechanism and rate-controlling steps(Meftaul et al. 2020).A typical time frame for this research project was for about 3 to 4 months for laboratory scale studies, covering material preparation, experimentation, data analysis and documentation. The study was conducted within the laboratories of Busitema University. Cassava peels used in the study were sourced from Nagongera Town Council.

1.6 Significance of the study

The primary justification lies in addressing SGD 6, which aims is to improve water quality by reducing pollution, eliminating dumping and minimizing the release of hazardous chemicals and materials. The research directly addresses the removal of 2,4-D a persistent and widely used herbicide that poses significant risks to human health and aquatic ecosystems. Effective adsorption using the developed activated carbon helps reduce the concentration of this hazardous chemical, contributing to safer water sources and protecting water-related ecosystems. Studying the adsorption kinetics is crucial for designing cost-effective water treatment systems(Herrera-García et al. n.d.). This technical data enables practical application in real-world scenarios thereby contributing to sustainable water management.

CHARPTER TWO: LITERATURE REVIEW

2.1 2,4-dichlorophenoxyacetic acid; classification, application and environmental risks

2,4-Dichlorophenoxyacetic acid is a systemic herbicide belonging to the phenoxy family that primarily targets broadleaf weeds(dicots) while leaving most grasses and cereal crops (monocots) unaffected. Generally, it's considered low in toxicity to humans for oral, dermal, and inhalation routes, though the pure acid and salt forms are highly toxic to eye tissue(Baari, Rudi, and Harimu 2025).

2,4-D is used extensively to control over 1500 broadleaf weed species in various settings. These include agricultural uses in crops. pastures, and orchards, as well as residential and turf applications on lawns and recreational areas. When 2,4-D is applied on lawns, trees, shrubs and flowering plants, both short and long-term health problems results in many people, animals, insects, wildlife, and fish(Brito et al. 2020). This contamination occurs through multiple pathways, including surface runoff, leaching into the soil, wind erosion, aerial applications, industrial discharge, and other sources, resulting in the presence of pesticides in water bodies across different countries worldwide

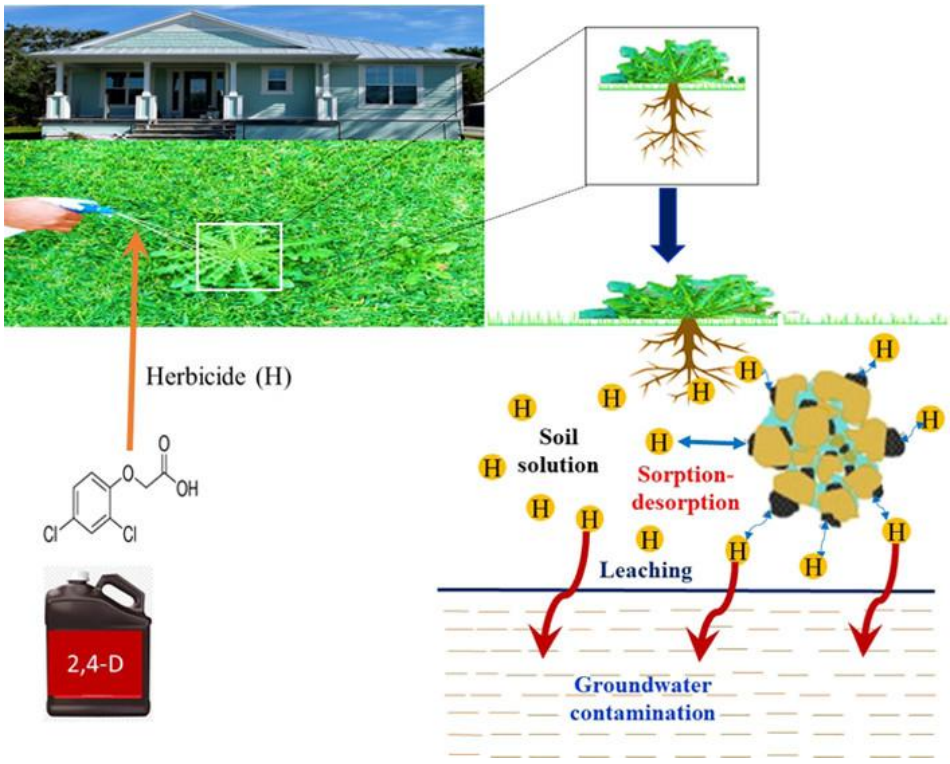


Figure 2.1: Conceptual frame work of 2,4-D contamination

The environmental risk, upon exposure, contaminates soil, water, and air affecting non-target plants, aquatic life, and potentially birds/mammals. While its persistence varies with conditions, posing risks to biodiversity and human exposure and health, the international Agency for Research on cancer (IARC) classifies 2,4-D as possible human carcinogen.

2.2 Review of 2,4-D wastewater treatment technologies.

The treatment of wastewater contaminated with 2,4-D involves a range of physical, chemical, and biological technologies, with advanced oxidation processes (AOPs) and biological method being particularly prominent. The choice of the method often depends on herbicide concentration, cost, and desired treatment efficiency(Baari, Rudi, and Harimu 2025).

Physical and chemical methods are often effective for high contaminant concentrations but may have higher operational costs or generate residues. Some of the physical and chemical methods of removal of 2,4-D pollutant from waste water include; coagulation and flocculation, membrane filtration, among others and the chemical and biological methods includes, ion exchange and adsorption(Baari, Rudi, and Harimu 2025).

2.2.1 Coagulation-Flocculation Technique

The coagulation-flocculation technique is a technique which involves mainly three steps: coagulation, flocculation and decantation. Coagulation is achieved by adding a coagulant that aims at destabilizing the colloidal suspensions through neutralizing their charges. Flocculation is achieved by adding a flocculant leading to formation of flocs in the second step, also called the slow step. In this step, the small particles already destabilized during the first step are grouped to form flocs which sediment and separate easily from the water during the third and final stage called decantation (sedimentation). The present work focusses on the use of a bentonite-based coagulant and cactus-based flocculant (Opuntia Ficus indica (OFIP)) in the elimination of methylene blue dye from waste water. Bentonite clay is known for its high specific surface area, negative surface charge density as well as its high cation exchange capacity and these properties show that it can contribute in the coagulation process(Adam, Treatment, and 2023 n.d.). Opuntia Ficus indica act as a bio-flocculant and the molecules involved in the flocculation mechanism are macromolecular quercetin (a flavonoid with polyphenol groups) and water-soluble polysaccharides (starch)

The coagulation-flocculation technique is a simple and easy way to treat effluents from pharmaceuticals however; the method has some drawbacks, like excessive usage of chemical

coagulants in highly colored wastewater, resulting in the creation of a large amount of harmful chemical sludge.

2.2.2 Membrane Separation Techniques

The membrane separation is one of the effective methods for removal of amoxicillin from the wastewater. The techniques of membrane separation include; Reverse osmosis (RO), electrodialysis, Ultrafiltration (UF) and Nanofiltration. Reverse osmosis involves the movement of water molecules from a region of higher concentration of the solute to a region of lower concentration of the solute (or pure water) through a semi-permeable membrane and application of hydrostatic pressure greater than the osmotic pressure. Electro-dialysis is the removal of ionic components from aqueous solutions through ion exchange membranes under the driving force of an electric current. Electro-dialysis is like reverse osmosis except for it, current rather than pressure is used to separate ionic contaminants from water in which different ionic selective exchange membranes are used that allow only a specific type of ions to go through them(Landrigan et al. 2020). Ultrafiltration (UF) is a type of membrane filtration that separates particles based on their size using a semipermeable membrane that has a pore size that is fine enough to retain colloidal particles, viruses or large molecules. Suspended solids and solutes of high molecular weight are retained in the so-called retentate, while water and low molecular weight solutes pass through the membrane in the permeate. Nanofiltration (NF) is a membrane separation technique that uses nanometer-sized pores of pore sizes 1-10 nm to separate molecules based on size. It is a later invention among all the membrane processes that operates in the realm between reverse osmosis and ultrafiltration. Nanofiltration membranes have smaller pore size than those used in microfiltration and ultrafiltration, but slightly bigger than those in reverse osmosis. The membranes are predominantly made of polymer thin films such as polyethylene terephthalate or metals such as aluminum. The pore dimensions are controlled by pH, temperature, and time during development with pore densities ranging from 1 to 106 pores per cm^2.

However, in these processes dense ceramic or polymeric membranes have been used, resulting in low permeability, thus to get the desired throughput (permeate flux), high operating pressure is required and even the commercially available polymeric membranes are very expensive and regeneration and reuse is a difficult task.

2.2.3 Ion-Exchange Process

Ion-Exchange process is the process which involves exchanging the 2,4-D ions with other ions that are bound to the resin which is usually made of a polymer matrix that contains functional groups that can attract and hold onto specific ions and in this case, the resin would be designed to attract and hold onto the 2,4-D ions and are always cation-exchange resin. ammonium phosphomolybdate (APM) particles synthesized under ambient conditions can be used as cation-exchange resin for removal of Amoxicillin from waste water as long as the pH range permitted the pollutant to retain its cationic behavior. This is attributed to ion-exchange between ammonium ions in APM with cationic amoxicillin moieties and removal efficiency of 94.6% could be retained up to 16^{th} cycle(Landrigan et al. 2020).

The efficiency of the ion-exchange process depends on several factors, including the type of resin used, the concentration of the 2,4-D in the wastewater, and the flow rate of the wastewater through the column. This method is effective though expensive, introduces other impurities like cations in the water, the ion exchange resin itself can sometimes become the source of organic contamination and other draw backs may be experienced.(Jordana Georgin et al. 2022).

2.2.5 Adsorption

Adsorption is the phenomenon of attracting and retaining the molecules of a substance on the surface of a liquid or solid resulting in to higher concentration of the molecules on the surface. As contrast with different methods of 2,4-dichlorophenoxyacetic acid removal from waste water, adsorption method is prominent because of its straightforwardness and also accessibility of extensive variety of cheap adsorbents which may be from industrial wastes or agricultural wastes (natural adsorbents) like activated alumina, activated carbon, activated alumina coated silica gel, calcite, activated saw dust, activated coconut shell powder, activated fly ash, groundnut shell, coffee husk, rice husk and others(J Georgin et al. n.d.). Biochar are efficient adsorbents for removal of contaminants from aqueous solution, have low energy cost, and can be obtained from renewable and abundant precursors unlike comparison with industrial wastes and others. Banana peelings can be toxic if left to accumulate in the environment and the alternative to this environmental pollution is to make the waste product into a valuable product; in this case, the peelings can be used as a precursor material for making hydrocars when modified using modifiers like potassium hydroxide, zinc chloride and others enhancing the adsorption efficiency and effectiveness(Debebe et al. 2023).

2.2.6 V-Vis Spectrophotometry in Determination of 2,4-D Concentrations

UV-Vis spectroscopy is an analytical technique that measures the absorbance or transmittance at discrete wavelengths of UV or Visible light through a sample, compared to a reference or blank sample.

The method uses light at different wavelengths to analyze and identify substances by locating the specific wavelengths corresponding to their maximum absorbance. The machine employed in this technique is the UV/Vis spectrophotometer which may be a single beam or double beam spectrometer. The spectrophotometer consists of five major components which include; the light source, wavelength selector, sample, detector and computer to process output(CHEBII 2024).

The most commonly used light sources in the technique are the tungsten lamps for visible light and deuterium lamp for UV light. The choice of wavelength selector will always depend on the sample type and analyte. The most commonly used wave length selectors are the monochromators which are usually fitted with filters to narrow their wavelength selection and also improve on the signal-to-noise ratio(Baari, Rudi, and Harimu 2025).

2,4-dichlorophenoxyacetic acid has a strong absorption band centered at ($\wedge_{max}$)230-250nm. The peak absorption of 2,4-D using cassava peels activated carbon (CPAC) is ($\wedge_{max}$)250nm. An appropriate light source and wavelength selector is chosen and the light passes to the sample placed in a cuvette. For this case distilled water will be used as a blank sample and then 2,4-D is the analyte of interest. It is advisable to use quartz cuvettes because quartz is transparent to most of the UV light. Plastics are discouraged for examination because plastic generally absorbs UV light. Light having passed through the sample; the detector converts the light into a readable signal(Baari, Rudi, and Harimu 2025).

The UV – Vi's spectroscopy information may be represented as a graph of absorbance, optical density or transmittance as a function of wave length. The wave length is always on the x – axis and the former on the y – axis. The graph is typically called a spectrum. The absorbance (A) is equal to the logarithm of the fraction of light intensity before passing through the sample (*IO*) divided by light after passing through the sample (*I*). The fraction *I* divided by *IO* is called transmittance (*T*), which expresses how much light passed in the sample(Aryee et al. n.d.).

The concentration of an analyte in solution can be determined by measuring its absorbance at a specific wavelength and applying the Lambert– Beer Law.

$$A = \varepsilon\, lc = \log\left(\frac{I_o}{I}\right) = log\left(\frac{I}{T}\right) = -log(T)$$

2.3 Mechanism of Adsorption of 2,4-D on CPAC

The adsorption of 2,4-D onto CPAC was based on physical or chemical processes. In the physical adsorption mechanism, the forces of attraction existing between adsorbate and adsorbent were weak van der Waals forces and the 2,4-D molecules attached onto the adsorbent surface under the influence of van der Waals forces. The CPAC provide a porous surface with functional groups that can attract and bind 2,4-D molecules through interactions such as electrostatic forces, hydrogen bonding and Van der Waals force. 2,4-D molecules carry a positive charge and the CPAC surface has regions with opposite charge which lead to electrostatic interactions. In chemical adsorption mechanism the forces of attraction existing between adsorbate particles and adsorbent are almost of the same strength as chemical bonds, the functional groups on the CPAC surface such as hydroxyl, carboxyl, and other oxygen-containing groups form bonds with the 2,4-D molecules(Adam, Treatment, and 2023 n.d.).

As contrast with different methods of 2,4-D removal from waste water, adsorption method is prominent because of its straightforwardness and also accessibility of extensive variety of cheap adsorbents which may be from industrial wastes or agricultural wastes (natural adsorbents) like activated alumina, activated alumina coated silica gel, calcite, activated cassava peels, activated saw dust, activated coconut shell powder, activated fly ash, activated groundnut shell, coffee husk, rice husk and others. Bio-chars are the efficient adsorbents in the removal of contaminants from aqueous solution, have a low energy cost, and can be obtained from renewable and abundant precursors in comparison with industrial wastes and others(Aryee et al. n.d.). Cassava peelings can be toxic if left to accumulate in the environment and the alternative to this environmental pollution is to make the waste product into a valuable product; in this case, the peelings can be used as a precursor material for making hydrocars when modified using modifiers like potassium hydroxide, zinc chloride and others enhancing the adsorption efficiency and effectiveness(Adam, Treatment, and 2023 n.d.).

The targeted literature review reveals a stark contrast between the reported performance of cassava peel-activated carbon against 2,4-D removal and the demonstrated potential of optimized biomass adsorbents.

While activated carbon from cassava peels has been extensively studied for dyes, heavy metals and pharmaceuticals, studies specifically optimizing cassava peel activated carbon (CPAC) for 2,4-D removal are limited.

Direct comparative studies analyzing the 2,4-D adsorption capacity of CPAC against standard commercial activated carbon.

2.4 Precursors and activation.

The production of activated carbon (AC) from agricultural biomass is a globally established practice that promotes sustainability and reduces costs. Precursors from agricultural biomass are abundant, rich in carbon, low-cost, and renewable. The components decompose during carbonization forming a porous carbon structure suitable for adsorbing organic pollutants.

The activation processes of cassava peel carbon are presented, including both physical and chemical activation methods. Some studies have demonstrated the effects of combining both approaches, this section includes reviews of activating cassava peels under chemical activation. Chemical activation consists preparing raw materials and impregnating them with activating agents such as Phosphoric acid, Zinc Chloride, Potassium Hydroxide among others. This is advantageous because it requires a lower activation temperature, provides a high surface area, and results in shorter processing time(Adam, Treatment, and 2023 n.d.).

2.5 ADSORPTION ISOTHERMS

2.5.1 Langmuir Adsorption Isotherm

The Langmuir adsorption isotherm is used to describe the equilibrium between the adsorbate and adsorbent system. The adsorbate adsorption is limited to one molecular layer at or before a relative pressure of unity is reached. It is assumed that the adsorption sites have equal affinities for molecules of adsorbate and that the presence of adsorbed molecules at one site will not affect the adsorption of molecules at an adjacent site. The Langmuir isotherms are useful for determining the efficiency of adsorbent at higher temperature(Aryee et al. n.d.). It explains the formation of monolayer adsorbate on outer surface of the adsorbent quantitatively, and after that no further adsorption takes place. The theoretical Langmuir isotherm is valid for adsorption of solute from a liquid solution as monolayer adsorption on a surface containing a large number of identical sites. The linear form of Langmuir equation is as follows;

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

Where; q_e is the amount of adsorbate absorbed per unit, q_m is the maximum adsorption capacity for monolayer adsorption, c_e is the equilibrium adsorbate concentration in solution and K_L is Langmuir constant.

The plot of $\frac{1}{q_e}$ against $\frac{1}{C_e}$ gives a straight line where the vertical intercept = $\frac{1}{q_m}$ and slope = $\frac{1}{K_L q_m}$ from which constants; K_L and q_m can be calculated.

2.5.2 Freundlich Adsorption Isotherm

The Freundlich isotherms are applicable only at lower temperatures to get an idea about the adsorption phenomena and monolayer coverage of the adsorbent. It is basically empirical but is often useful as a means for data description. The equation generally agrees with the Langmuir equation and experimental data over moderate ranges of concentration. It is also commonly used to describe the adsorption characteristics for the heterogeneous surface(Baari, Rudi, and Harimu 2025). Freundlich isotherm assumes unlimited sorption sites which is correlated with better heterogeneous surface of the adsorbent media. The linear form of Freundlich equation is as follows;

$$\log q_e = \log K_f + \frac{1}{n(\log C_e)}$$

Where; K_f is the Freundlich adsorption coefficient and n is the adsorption constant, q_e is the amount of 2,4-D adsorbed per unit weight of adsorbent and C_e is the equilibrium adsorbate concentration in solution.

A plot of log q_e versus log C_e gives a linear graph with slope = $\frac{1}{n}$ and vertical =logK_f.

2.5.3 Kinetic Models

Kinetic models are used to test experimental data so as to examine the controlling mechanism of adsorption processes such as mass transfer and chemical reaction. There are several kinetic models proposed for the mechanism by which 2,4-D is adsorbed on the surface of adsorbents. To analyze the adsorption kinetics of 2,4-D onto the activated cassava peels (PBC), the pseudo-first-order and pseudo-second-order kinetic models are used to process the data(Gaaied et al. 2020).

2.5.4 Pseudo First Order Model

The pseudo-first order rate model is used as a rate equation for assigning the rate of adsorption of an adsorbate into adsorbent. The linear form of the pseudo-first-order kinetic model is represented by the equation;

$$\frac{dqt}{dt} = K_1(q_o - q_t)$$

And the integrated pseudo first order rate equation is;

$$log(q_o - q_t) = \log q_e - \frac{K_1}{2.303}t$$

A linear graph of log $(q_e - q_t)$ against time, t must be obtained for the data to fit the pseudo-first order rate mode.

2.5.5 Pseudo Second Order Model

The kinetic rate equation for the pseudo-second order adsorption reaction is expressed as;

$$\frac{dqt}{dt} = K_2(q_o - q_t)^2$$

And the integrated pseudo second order rate equation is;

$$\frac{1}{q_o - q_t} = \frac{1}{q_o} + K_2 t$$

Pseudo-second order kinetic expression for describing the adsorption of some ions onto the adsorbent is also useful for determining q_o and K_2 values from the graph of $\frac{t}{qt}$ against t after rearrangement of the above equation as;

$$\frac{t}{qt} = \frac{1}{K_2 {q_o}^2} + \frac{t}{q_o}$$

A linear graph of $\frac{t}{qt}$ against time, t must be obtained for the data to fit the pseudo-second order rate model. The slope of the graph = $\frac{1}{q_o}$ and the vertical intercept = $\frac{1}{K_2 {q_o}^2}$ hence q_o and K_2 values can be determined from the graph Where q_O and q_t in mg/g are the amount of adsorbed 2,4-D at equilibrium and at any time t respectively, K_1 and K_2 are equilibrium rate constants of pseudo first and second order respectively(Debebe et al. 2023).

CHAPTER THREE: MATERIALS AND METHODS

3.1 Materials

Fresh cassava peels (Manihot esculenta species) were locally gathered as abundant agricultural waste around Busitema University Nagongera Campus gardens and households within the Nagongera Town Council in Tororo district. 2,4-D of an analytical grade was purchased from a recognized agrochemical supplier and used as the model contaminant. pH meter, thermally isolated magnetic stirrer, orbital shaker, 250 mL Erlenmeyer conical flasks, beakers, measuring cylinders, pipettes, stopwatch, dry soft lint-free tissue (toilet paper), vortex mixer, magnetic stirrer MS7-H550-S, Oven and Autoclave reactor. Weighing balance of precision 0.1 mg and capacity of 210 g.

UV-Vis spectrophotometer Jenway 7305 with a wavelength range of 230-250 nm and bandwidth 0.02 – 4.0 nm controlled using a computer software. 40% of Phosphoric acid was prepared by dissolving 47.1ML of 85% pure Phosphoric acid in 100 ML of distilled water

1M Sodium hydroxide solution was made by dissolving 56 g in sufficient deionized water to make 1L of solution and will be stored in a tightly sealed polyethylene bottle. Deionized water, and other necessary chemicals will be obtained from Busitema laboratory stores.

3.2 Methods

3.2.1 Preparation of activated carbon

Fresh cassava peels were thoroughly cleaned with tap water then distilled for several times to remove all impurities, air dried and subsequently oven-dried (150 ^{O}C) at constant weight for 6hours. The dried biomass was crushed and ground to a narrow particle size of 1.5mm using a sieve to ensure consistency in chemical preparations and thermal processing.

3.2.2 Chemical Activation

The prepared cassava peel powder was impregnated with 40% Phosphoric acid at a predetermined impregnation ratio (acid: biomass weight). This mixture was stirred thoroughly to ensure uniform penetration of the activating agent and then dried in an oven at approximately 200 ^{O}C to remove excess moisture. The resulting AC was allowed to cool to room temperature; the product was washed severally with distilled water and 0.1 normal HCl to remove residual activating agents until a neutral PH was obtained. The washed AC was oven dried at 80^{o}C for 6hours. The modified dry activated carbon was stored in the desiccators for subsequent use.

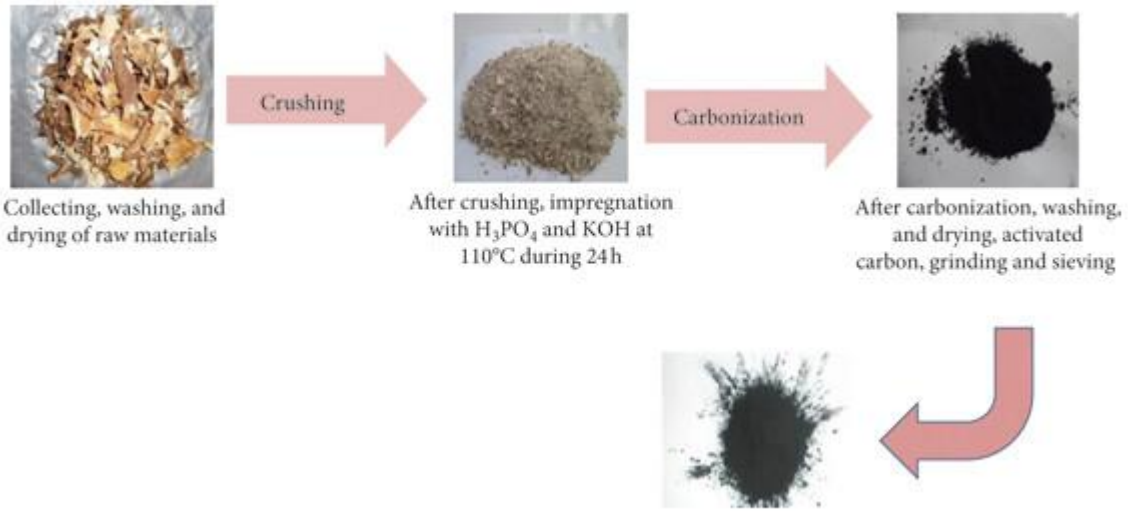


Figure 3.2.2: Conceptual framework of cassava peels activation process

3.2.3 Activated carbon characterization.

Characterization of the produced activated carbon was essential to relate its physicochemical properties to adsorption performances. The AC was characterized using the following.

3.2.3.1 Iodine Number (IN)

The iodine number (IN) is a relative indicator of porosity in activated carbon. The iodine number was measured according to the procedure established by the American Society for Testing and Materials (ASTM D2866-94). It is the number of milligrams of iodine adsorbed by 1.0 g of carbon when the iodine concentration of the filtrate is 0.02 N. The iodine number is accepted as a fundamental parameter used to characterize activated carbon performance. Iodine number was employed in this study as a test for microporosity via volumetric analysis. This fundamental ability test for activated carbon determines its microporosity to ≤2 nm.

3.2.3.1.1 Standardization of Iodine Solution

10 mL of 0.02 N iodine solutions (from Merck at 99.95% purity) was measured and put into a conical flask, and 2-3 drops of a starch solution were added to it. The pale-yellow color of the iodine solution turned blue and was titrated against a 0.005 N sodium thiosulphate solution (from Fischer Scientific International at 99.8%) until the mixture became colorless.

3.2.3.1.2 Determination of Iodine Number

0.1 g of activated carbon was weighed m_{AC} and carefully introduced into a dry screw cap conical flask. 30 mL of 0.02 N iodine solutions was then added. The flask was magnetically stirred for 3 hours, and the content was filtered into a dry conical flask. Then, 10 mL of the filtrate was titrated against sodium thiosulphate solution (5×10^{-3} M) ($Na_2S_2O_3$ from Across organics at 99% purity) using starch as indicator until a clear solution was observed according to equation (CHEBII 2024). The volume delivered by the burette was then noted V_n. The iodine number for the sample was then calculated according to equation.

$$\text{iodine number} = \frac{25.4 \times (30 - V_n)}{m_{\text{AC}}}, \quad (6)$$

where m_{AC} (g) is the mass of the activated carbon and V_n(mL) is the volume of the sodium thiosulphate solution at the equivalence point.

These analyses provided insight into the surface chemistry and structural features responsible for 2,4-D adsorption.

3.2.3.2 Preparation of the stock solution and calibration standards of 2,4-D

The stock solution of 2,4-D was prepared by dissolving 1ml of 720g/l of pure 2,4-D solution in a 1L volumetric flask and distilled water was added to the mark while stirring. 50ml of 1000mg/L of the stock solution was diluted to 100ml using distilled water in a 500ml volumetric flask to obtain 500mg/l of the standard solution. Series of calibration standards were prepared by pipetting 5.0, 10.0, 15.0, 20.0, and 25.0ml of the 500mg/l standard solution and then diluted with distilled water to make 50.0, 100.0, 150.0, 200.0, 250.0 mg/l of 2,4-D calibration standards respectively using the technique of $\mathbf{C_1V_1 = C_2V_2}$,Where C_1 is the initial concentration, V_1 initial volume, C_2 final concentration and V_2 final volume respectively.

3.2.3.3 Calibration of UV-Vis Spectrophotometer and Measurement of 2,4-D Concentrations

A blank solution (deionized water) was used as a reference and placed in a cuvette (10 mm long), then the cuvette was inserted into the spectrophotometer and a maximum absorption wavelength for 2,4-D, $\wedge_{\max}$ = 250nm was set to record the baseline absorbance so as to ensure accurate baseline readings. The corresponding absorbances of freshly prepared 2,4-D calibration standards of 50.0, 100.0, 150.0, 200.0, and 250.0mg/L were then measured one at a

time by the UV-Vis spectrophotometer at wavelength of 250nm so as to generate a calibration curve, starting with that of a low concentration to the highest. The concentrations of the 2,4-D samples were obtained by referencing the absorbance values of the samples to the calibration curve obtained at 250nm. In each measurement, the cuvettes and spectrophotometer components were thoroughly cleaned and dried using a dry soft toilet paper to avoid contamination.

3.2.4 BATCH ADSORPTION EXPERIMENTS

3.2.4.1 Effects of contact time on 2,4-D removal

5 samples of 25.0 mL of 250 mg/L 2,4-D concentration with absorbance of 2.32 at $\wedge c = 250$nm was made by serial dilution and then placed in different Erlenmeyer flasks. To each flask, 2g of CPAC was added and then the mixtures shaken using the orbital shaker at 100 rpm. The samples from the different flasks were picked after 10, 20, 30, 40, and 50 minutes. After the specific time, each 2,4-D sample was separated from the CPAC by filtering using a filter paper and then the filtrate was analyzed by UV-Vis spectrophotometer at the wavelength for maximum absorbance of 2,4-D, $\wedge_{max}$ = 250nm to determine the concentration of 2,4-D adsorbed and the results recorded are to be in Table 1

3.2.4.2 Effect of initial 2,4-D concentration on 2,4-D removal

5 samples of 10 mL of 5.0, 10.0, 15.0, 20.0, and 25.0mg/L of 2,4-D was prepared and placed in different Erlenmeyer flasks. To each flask, 2 g of CPAC was added and then the setups were left to stand for 30 minutes while shaking constantly. After 30 minutes, each 2,4-D sample was separated from the CPAC by filtration and then the filtrate analyzed by UV-Vis spectrophotometer at the wavelength for maximum absorbance of 2,4-D, $\wedge_{max}$ =250nm to determine the concentration of 2,4-D adsorbed and the results recorded are to be in table.

3.2.4.3 Effect of adsorbent dosage on 2,4-D removal

A sample of 10 mg/L 2,4-D solution with absorbance of 0.27 at, $\wedge_{max}$ =250nm was prepared by serial dilution. To different Erlenmeyer flasks containing 25mL of this solution was added 0.5, 1.0, 1.5, 2.0, and 2.5g of the CPAC in powder form. The setup was left to stand for 30 minutes while shaking constantly at 200 rpm using an orbital shaker. After 30 minutes, each 2,4-D sample was separated from the CPAC by filtration and then the filtrate was analyzed by UV-Vis spectrophotometer at the wavelength for maximum absorbance of 2,4-D, 250nm to

determine the concentration of 2,4-D adsorbed(Brito et al. 2020) and the results were recorded in Table3.

3.2.4.4 Effect of pH on 2,4-D removal

5 samples of 20 mL of 10 mg/L 2,4-D concentration with absorbance of 0.27 at, $\wedge_{max}$ =250nm was prepared and placed in different Erlenmeyer flasks. The samples in the flasks were adjusted to pH values of range 2-11 using 0.1 M hydrochloric acid and 0.1 M sodium hydroxide solution. 2.0g of CPAC in powder form was separately added in the different flasks containing the samples and then the different mixtures shaken at 200 rpm in the orbital shaker for 30 minutes. After 30 minutes, each 2,4-D sample was separated from the CPAC by filtration and then the filtrate was analyzed by UV-Vis spectrophotometer at the wavelength for maximum absorbance of 2,4-D, $\wedge_{max}$ 250nm to determine the concentration of 2,4-D adsorbed(Debebe et al. 2023) and the were recorded in Table4.

3.2.5 Determination of adsorption capacity

Adsorption capacity was calculated using;

$$Qe = \frac{(\mathrm{Co} - \mathrm{Ce})}{\mathrm{m}} V$$

Where; $Qe -$ adsorption capacity

$Co -$Initial concentration of 2,4-D (mg/L)

$Ce -$Equilibrium concentration of 2,4-D (mg/L)

$V -$Volume of solution

$m -$Mass of adsorbent (g)

Percentage (%) removal $= \frac{\mathrm{Co}-\mathrm{Ce}}{\mathrm{Co}} * 100$

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 INTRODUCTION

This section presents and explains the findings from the adsorption and kinetics of 2,4-dichlorophenoxyacetic acid (2,4-D) using activated carbon made from cassava peels. It looks at how well the prepared activated carbon adsorbs the substance. It also examines how factors such as contact time, adsorbent dosage, pH, and initial 2,4-D concentration affect the removal efficiency of 2,4-D from water. Additionally, this section discusses the physical and chemical properties of cassava peel activated carbon, including surface area, pore structure, and functional groups. These characteristics affect the adsorbent's adsorption capacity. Kinetic studies, such as pseudo-first order and pseudo-second order, are included to assess the rate and mechanism of adsorption(Adam, Treatment, and 2023 n.d.). Overall, this section offers a thorough interpretation of the experimental results and highlights the potential use of cassava peel activated carbon in wastewater treatment.

4.2 Presentation of results and discussion.

4.2.1 Characterization of cassava peel activated carbon

The prepared activated carbon was characterized to determine its physicochemical properties crucial for adsorption. Techniques used included:

Scanning Electron Microscopy (SEM) was employed to visualize the surface morphology. Fourier-Transform Infrared (FTIR) spectroscopy was used to identify and characterize the functional groups present on the activated carbon surface. In addition, the iodine number method was applied to evaluate the micropore content and adsorption capacity of the activated carbon, providing a comprehensive assessment of its structural and chemical properties.

The activated carbon prepared from cassava peels exhibited a dark black porous structure, indicating successful carbonization and activation. The adsorbent possessed a large surface area and numerous pore structures which are essential for adsorption processes. Surface morphology. The activated carbon showed irregular pores and cavities formed during activation. These pores provide active sites for adsorption of 2,4-D molecules.

Titration data parameters for sawdust activated carbon iodine number calculation.

Titer value	1	2	3
Initial burette reading(ml)	0.00	0.00	0.00
Final burette reading (ml)	11.40	11.20	11.20
Net volume of sodium thiosulfate used (ml)	11.40	11.20	11.20

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 11.40mL, Trials 2 and 3 demonstrated ideal reproducibility at 11.20mL. Establishing the average operational volume based on the highly reproducible duplicate runs yielded:

$$\text{Average volume of sodium thiosulfate used} = \frac{11.20+11.20}{2}$$

$$= 11.20 \text{ ml}$$

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

$$N_r = \frac{N_2 \times V}{50} \ldots\ldots\ldots \text{(Eq.1)}$$

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 (11.20mL) from Table 1. Substituting these empirical values into Equation (1) yields:.

$$N_r = \frac{0.1 \times 11.20}{50}$$

$$N_r = 0.0224$$

This calculated value for $N_r(0.0224N)$ 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):

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

Where $N_1$is the initial normality of the stock iodine solution (0.1N). By populating **Equation (2)** with our baseline metrics ($N_1 = 0.1N, N_2 = 0.1N, and\ V = 11.20ml$), the quantitative mass capacity was calculated as follows:

$$X = (12693 \times 0.1) - (279.246 \times 0.1 \times 11.20)$$

$X = 956.54448$mg/g

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

$I_n = \frac{X}{M}.A$**…. (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:

$$I_n = \frac{956.54448 \times 0.9825}{1.0}$$

$$\approx 940mg/g$$

An iodine number of approximately $940mg/g$ explicitly demonstrates that the phosphoric acid activation process 800℃ successfully degraded the lignocellulosic structural matrix of the sawdust. 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 SLS

1FTIR Spectroscopic surface analysis

To identify the specific surface functional groups responsible for trapping the anionic surfactant, Fourier-Transform Infrared (FTIR) spectroscopy was performed on the synthesized cassava peels activated 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 450 cm^{-1} be structurally mapped

Figure 4.2 **A graph from FTIR**

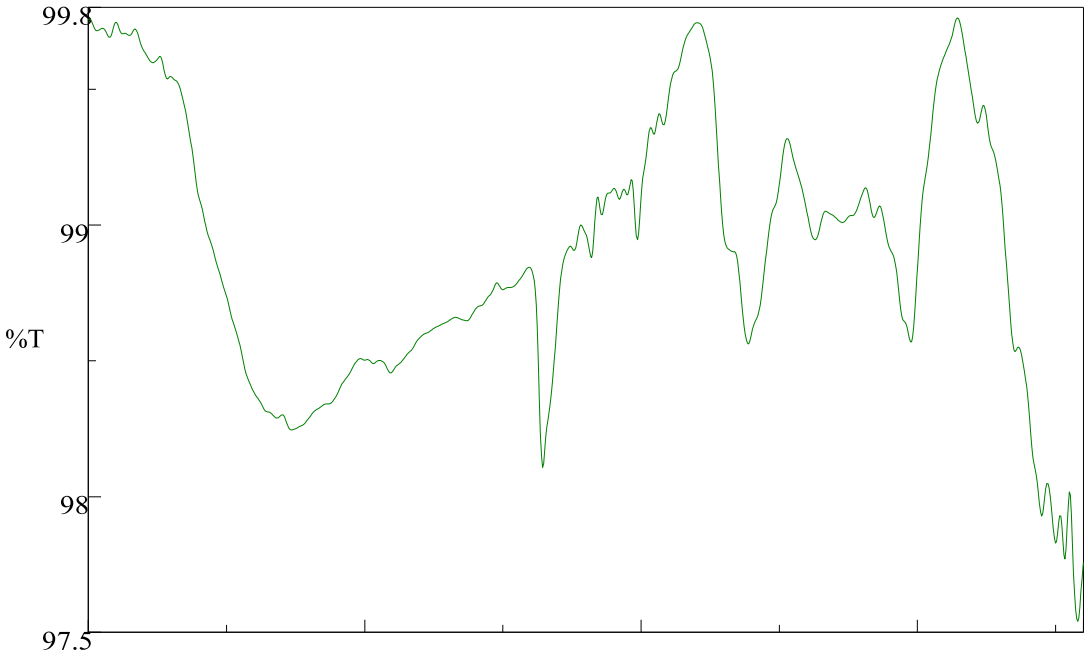
4.2.2 Contact time

Like with other adsorption processes, 2,4-D adsorption is time dependent. The longer the contact time the higher the absorptivity. This is due to ample time for the diffusion of 2,4-D molecules to the adsorbent surface. Contact time in many studies has been studied with the equilibrium (when the adsorption rate is constant) as the termination point. Although in practice this seems to be a single process, kinetically it is step-wise and there are critical stages that determine the longevity and effectiveness of the entire process. Physical adsorption occurs within a short time whereas chemical adsorption takes a relatively longer time. Generally, the contact/equilibrium time varies with the adsorbent and adsorbate characteristics like the adsorbate charge, adsorbent porosity, temperature and presence of competing adsorbates among others.

Contact time

Table 4.2.2 Variation of 2,4-D adsorption with time

Time (minutes)	Absorbance (nm)	Ce (mg/L)	Qe (mg/L)	% removal
20.0	0.53	57.1	2411.25	77.16
40.0	0.30	32.3	2721.25	87.08
60.0	0.15	16.2	2922.5	93.52
80.0	0.08	8.6	3017.5	96.56



100.0	0.053	5.7	3053.75	97.72

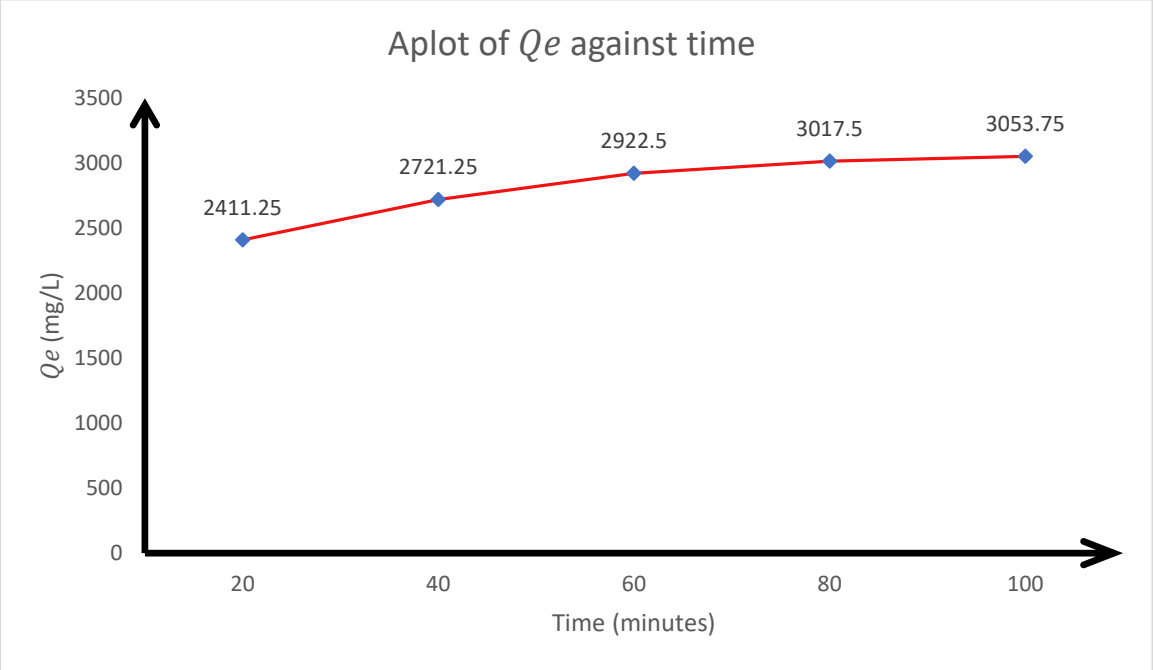


Figure 4.2.2 A plot of *Qe* against time

4.2.3 Effect of 2,4-D concentration

Adsorption capacity increased with increasing initial 2,4-D concentration, due to stronger driving forces for mass transfer. As the initial concentration of 2,4-D increases, the driving force (concentration gradient) for herbicide molecules to move toward the adsorbent surface increases. This results in a higher adsorption capacity until the active binding sites become fully saturated limiting further adsorption. At lower concentrations, there are plenty of available active sites relative to the number of 2,4-D molecules, allowing for a high percentage removal. As the concentration increases, the number of 2,4-D molecules exceeds the available adsorption sites, leading to a drop in overall removal efficiency as shown in table3.

The herbicide initial concentration plays a major role in overcoming mass transfer resistance of the adsorbate between the aqueous and solid phase. Present study was performed at a varying low concentration of 2,4-D herbicide, the concentration normally was detected in water resources, whereas other study using higher initial concentration of the herbicide found the opposite effect.

Table 4.2.3: Effect of 2,4-D concentration

Initial 2,4-D concentration (mg/L)	Initial Absorbance (nm)	Final Absorbance (nm)	Ce (mg/L)	Qe (mg/g)	% removal
5.0	0.18	0.005	0.14	24.3	97.2
10.0	0.27	0.02	0.74	46.3	92.6
15.0	0.48	0.054	1.69	66.6	88.7
20.0	0.54	0.071	2.63	86.85	86.9
25.0	0.90	0.14	3.89	105.6	84.4

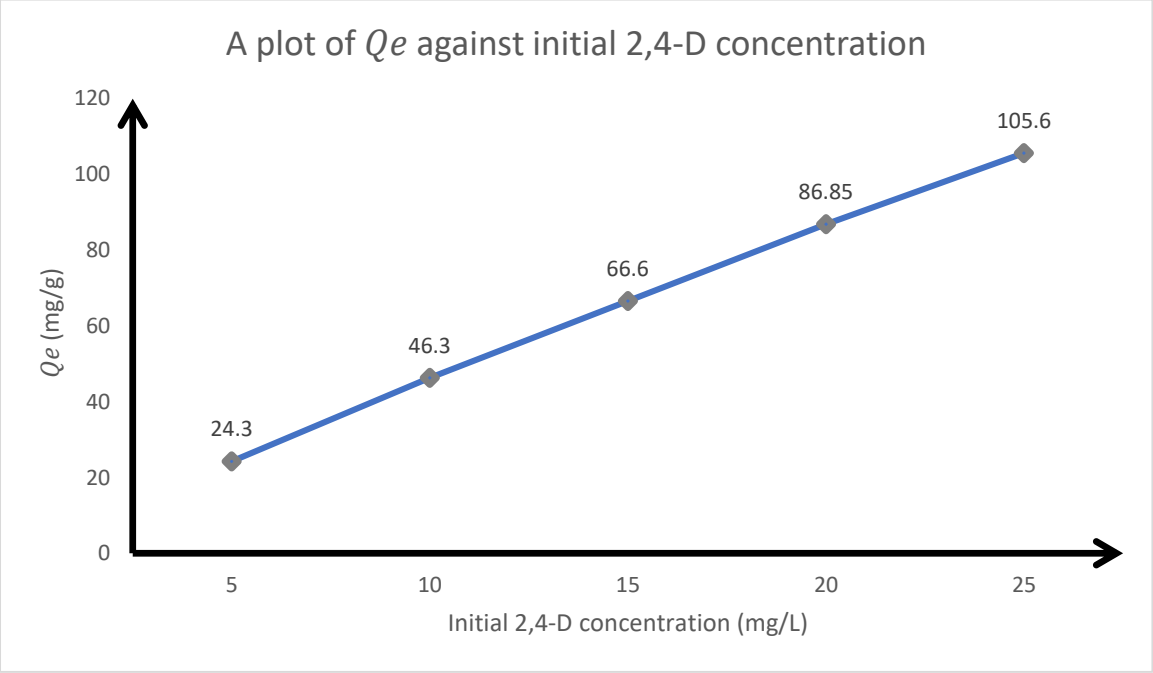


Figure 4.2.3: plot of Qe against initial 2,4-D concentration

4.2.4 Absorbent dosage

Increase of adsorbent dosage increases the adsorption of 2,4-D on to the activated carbon. Increasing the adsorbent dosage raises the total percentage of 2,4-D removed, but it decreases the amount of 2,4-D adsorbed per unit mass of the adsorbent. The amount of adsorbent used directly controls the number of available binding sites and the overall removal efficiency of 2,4-dichlorophenoxyacetic acid (2,4-D). Increasing the adsorbent dose introduces more surface

area This creates a surplus of vacant binding sites and consequently, a much higher percentage of 2,4-D is removed from the solution.

Table 4.2.4: Effect of absorbent dosage

Absorbent dosage (g)	Absorbance (nm)	Ce (mg/L)	Qe (mg/g)	% removal
2.0	0.127	4.70	66.25	53
2.5	0.084	3.11	68.9	68.9
3.0	0.015	0.56	78.7	94.4
3.5	0.008	0.30	69.3	97
4.0	0.003	0.11	61.8	98.9

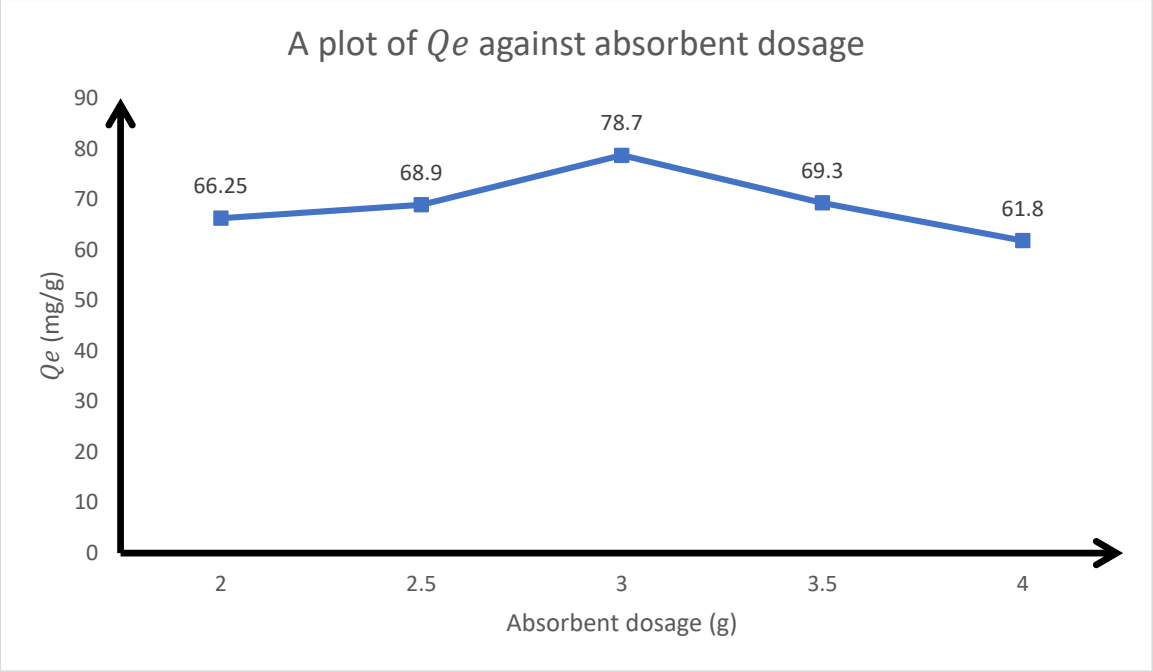


Figure 4.2.4: A plot of Qe against absorbent dosage

4.2.5 Effect of pH on 2,4-D adsorption

The variations of pH on the rate of adsorption of 2,4-D by modified granular activated carbon were shown on table 5 and figure 4. According to Figure 4, the maximum adsorption capacity

of 2,4-D by modified granular activated carbon (91.5 mg/g) and the reduction of 91.5% was achieved in an acidic range (pH = 2)

The 2,4-D adsorption increases at a lower pH range and decreases as the pH increases. The pKa of 2,4-D is **2.73**. When the solution pH is below this value, the herbicide exists primarily in its **undissociated (neutral/molecular) form**. Neutral molecules encounter minimal resistance when migrating from the liquid phase to the carbon pores, maximizing uptake(Yasir et al. 2024).

As pH rises, 2,4-D loses a proton and converts into its **anionic (negatively charged) form**. Anions are highly water-soluble, meaning they prefer to stay dissolved in water rather than adhere to the carbon surface. The primary reason for poor adsorption at high pH is **electrostatic repulsion**. In alkaline environments, both the activated carbon surface and the 2,4-D molecules carry negative charges. They strongly repel one another, preventing the herbicide from accessing the active binding sites.

Table 4.2.5: Effect of pH

pH of 2,4-D	Absorbance (nm)	Ce (mg/L)	Qe (mg/g)	% removal
2.0	0.023	0.85	91.5	91.5
3.0	0.038	1.41	85.9	85.9
5.0	0.066	2.44	75.6	75.6
8.0	0.108	4	60	60
11.0	0.178	6.6	34	34

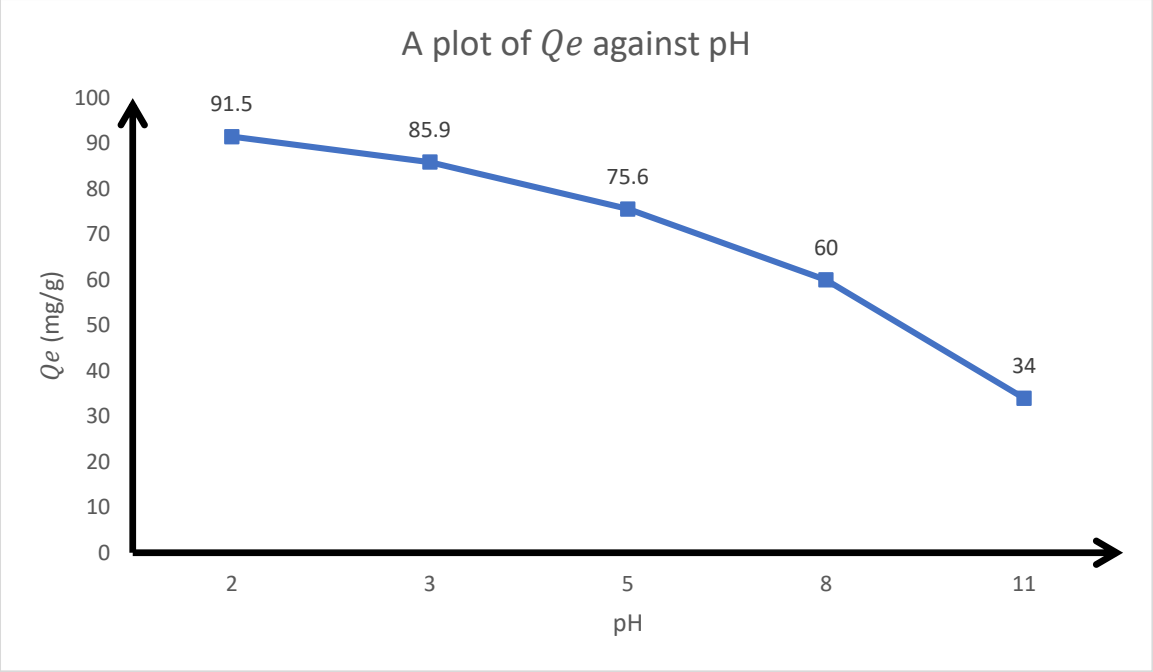


Figure 4.2.6: A plot of *Qe* against pH

The effect of initial 2,4-D concentration on its rate of adsorption by cassava peel activated carbon

Table 4.7.2: The effect of initial 2,4-D concentration on its rate of adsorption by cassava peel activated carbon

PH =2 contact time = 80 minutes Adsorbent dosage = 4g									
Initial concentration *Co*, (mg/L)	***Ce* (mg/L)**	**% removal**	***Qe* (mg/g)**	**1/Ce**	$\frac{1}{Qe}$	$\frac{Ce}{Qe}$	***LnCe***	***LogCe***	***LogQe***
5.0	0.14	97.2	24.3	7.1429	0.0412	0.0058	-1.966	-0.854	1.386
10.0	0.74	92.6	46.3	1.3514	0.0216	0.0160	-0.301	-0.131	1.666
15.0	1.69	88.7	66.6	0.5917	0.0150	0.0254	0.525	0.228	1.823
20.0	2.63	86.9	86.85	0.3802	0.0115	0.0303	0.967	0.420	1.939
25.0	3.89	84.4	105.6	0.2571	0.0095	0.0368	1.358	0.590	2.024

4.3 Adsorption isotherm

4.3.1 Langmuir (Type I) isotherm for 2,4-D adsorption by modified granular activated carbon.

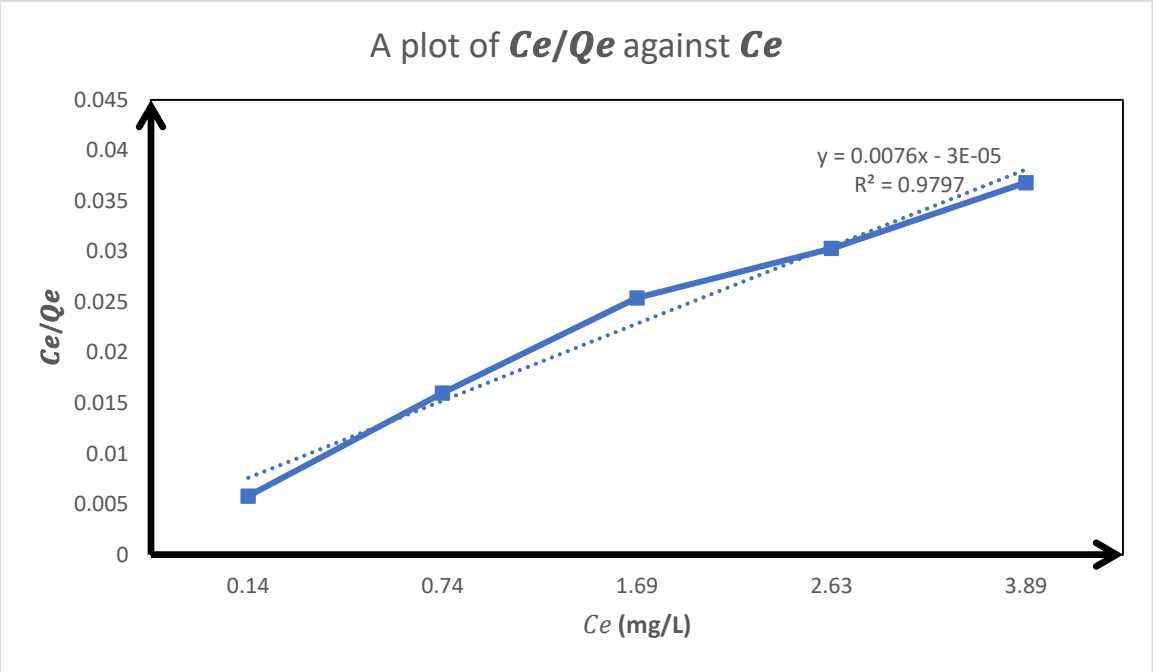


Figure 4.3: A plot of *Ce*/*Qe* against *Ce*

4.3.2 Freundlich isotherm for 2,4-D adsorption by the activated carbon.

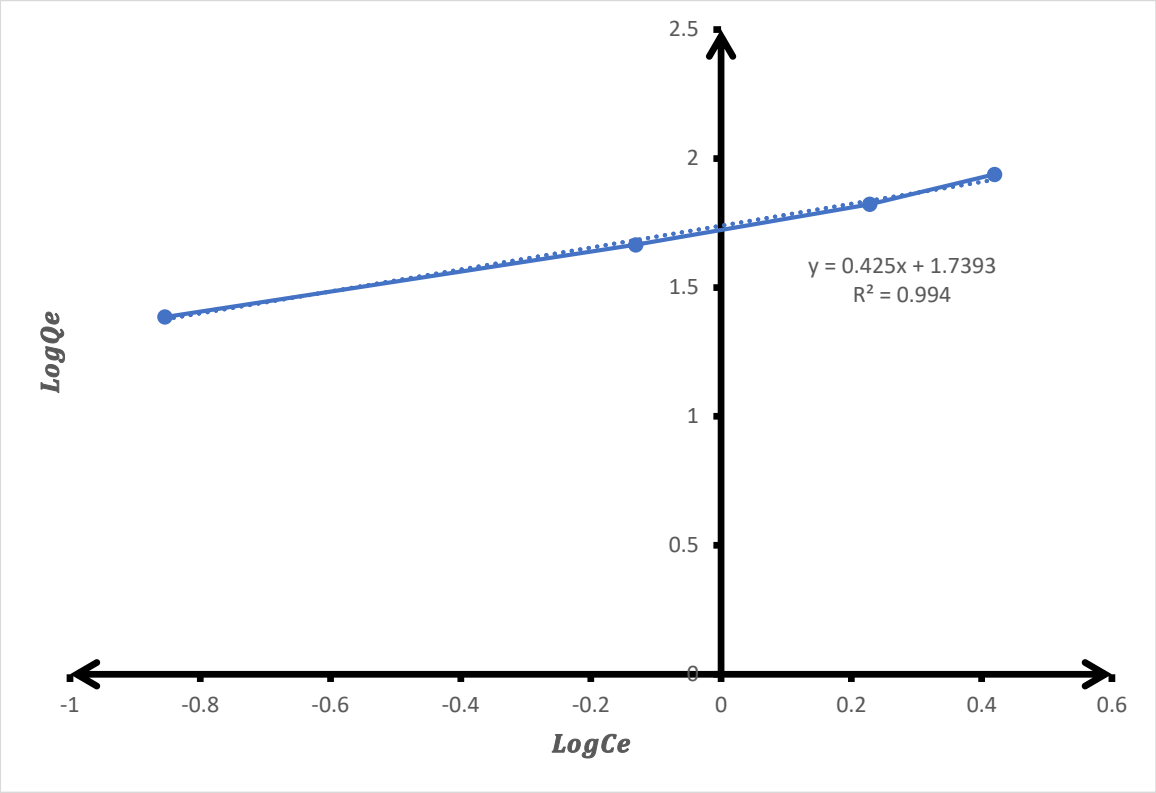


Figure 4.3.2: Freundlich isotherm for 2,4-D adsorption by the activated carbon

4.3.3 Langmuir (Type II) isotherm for 2,4-D adsorption by modified granular activated carbon

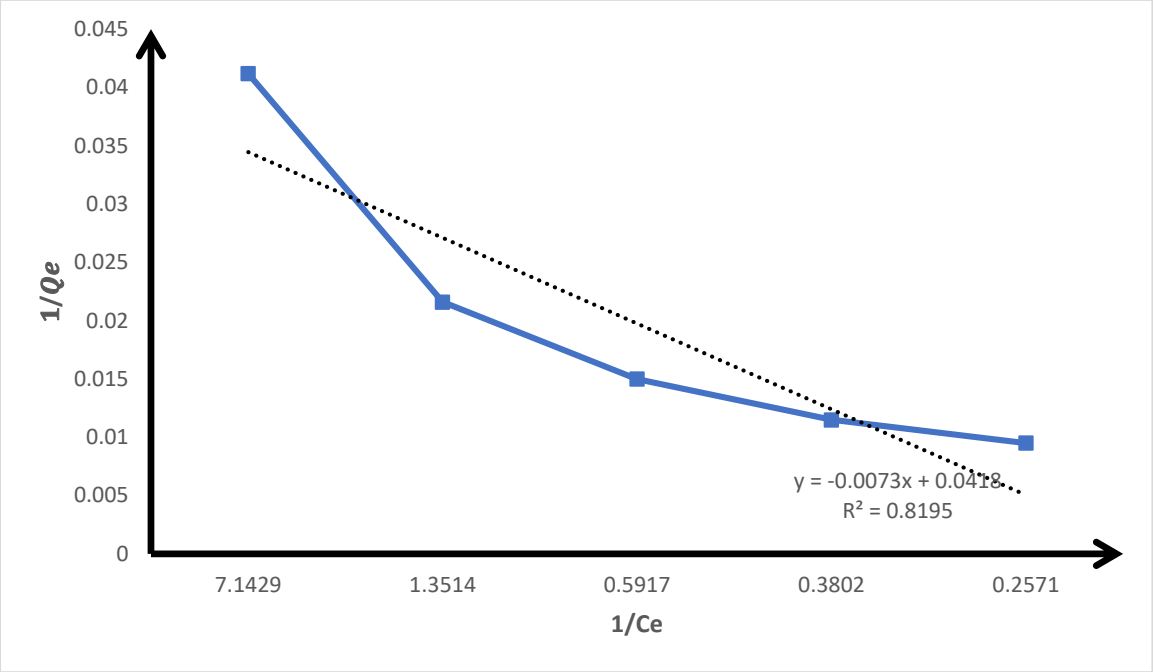


Figure 4.3.3: Langmuir (Type II) isotherm for 2,4-D adsorption by modified granular activated carbon

Over varying range of 2,4-D concentration, Langmuir adsorption isotherm was observed for the herbicide. Many other researchers have found that 2,4-D adsorption conformed to Langmuir isotherm. The conformity of the data to various isotherms can be compared using correlation coefficient (R^2). The adsorption coefficient ($\boldsymbol{Qe}$) and the adsorption constant (K_L) for Langmuir adsorption isotherm for 2,4-D are 24.3 (mg/g) and 3.94E-3 L/mg, respectively. At the equilibrium, the fit to Langmuir isotherm ($R^2 = 0.9797$) was less than Freundlich isotherm ($R^2 = 0.994$). Langmuir isotherm model is utilized for monolayer adsorption with a limited number of adsorption sites(Pinto et al. 2021).

Parameters of 2,4-D adsorption on the activated carbon		
Freundlich isotherm		
Kf	54.8656	
n	2.3529	
R^2	0.994	
Langmuir isotherm type II		**Langmuir isotherm type I**
Qm	23.9234	33333.3
$KlQm$	136.9863	131.6
Kl	5.726	3.94E-3
R^2	0.8195	0.9797

Langmuir (type II) adsorption > Langmuir (type I) > adsorption Freundlich adsorption.

Table 4.3.4: Parameters of 2,4-D adsorption on the activated carbon

Co (mg/L)	Ce (mg/L)	t	$\frac{t}{Ce}$	$Co - Ce$	$\log(Co - Ce)$
5.0	0.14	20.0	142.8571	4.86	0.6866
10.0	0.74	40.0	54.0541	9.26	0.9667
15.0	1.69	60.0	35.5030	13.31	1.1242
20.0	2.63	80.0	30.4183	17.37	1.2398
25.0	3.89	100.0	25.7069	21.11	1.3245

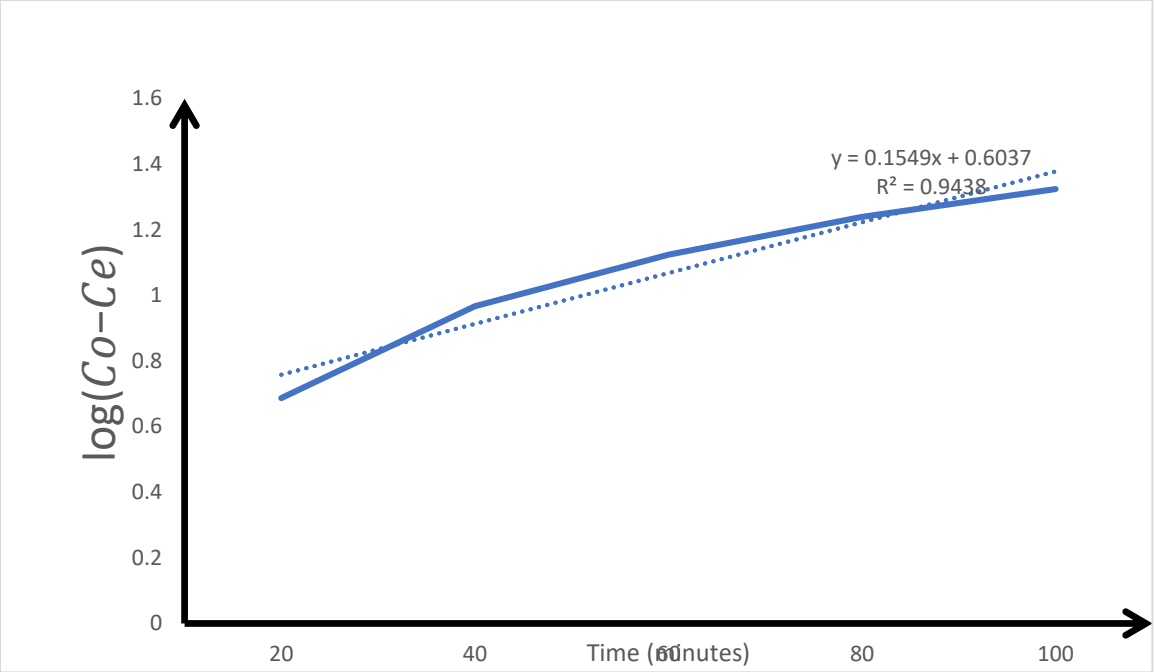
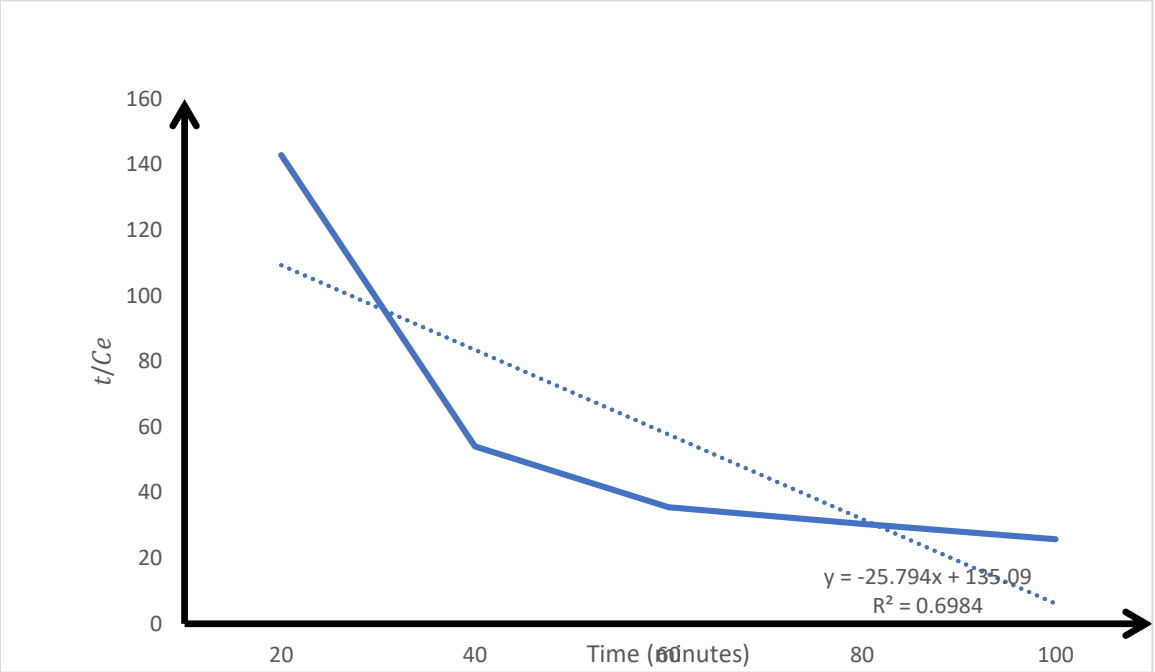


Figure 4.3.3: A plot of log($Co-Ce$) of against time



4.3.4. First order and second order kinetics parameters for the adsorption of 2,4-D on cassava peels activated carbon.

Kinetic models examined with obtained data showed the coefficients of correlation as well as the kinetic parameters of 2,4-D adsorption on cassava peels activated carbon as presented in Table 9. From the data obtained in this research, the correlation coefficient of the first order

kinetic for the adsorption of 2,4-D was (R^2 =0.6984) and that of second order kinetic model was (R^2 =0.9438). However, the correlation coefficient of the first order kinetic model was low for adsorption. Therefore, the adsorption process of herbicide on modified granular activated carbon follows the second order rate kinetic, this suggests that chemisorption may be the dominant mechanism controlling adsorption

Kinetic models of 2,4-D adsorption on activated carbon	
Pseudo first order	
Ce	4.01513
$\frac{-\mathrm{K1}}{2.303}$	0.1549
$K1$	-0.3567
R^2	0.6984
Pseudo second order	
$\frac{1}{Co}$	25.794
Co	0.0388
$\frac{1}{K2Co^2}$	0.00742
$K2$	4.9171
R^2	0.9438

Table 4.3.5: Kinetic models of 2,4-D adsorption on activated carbon

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

In conclusion, the activated carbon derived from cassava peels was successfully prepared and demonstrated effective adsorption of 2,4-D from aqueous solutions. the results reported in the adsorption of 2,4-D by the modified granular activated carbon revealed that 2,4-D in liquid phase was effectively and rapidly retained by the solid phase. The adsorption of 2,4-D was increased with decreasing initial concentration of 2,4-D and increasing the adsorbent dosage(Ospino et al. 2022). Therefore, 2,4-D adsorption in the aqueous solution was relatively high at pH = 2 and contact time = 80 min. Although, 2,4-D adsorption data showed a highly significant fit to Langmuir, and Freundlich isotherms, the fit to Freundlich isotherm proved to be more suitable, as compared with Langmuir. The reduction rate of 2,4-D from aqueous solutions was more than 68% at optimal conditions(Njoku et al. n.d.). According to data obtained in the current study, the level of 2,4-D concentration using modified cassava peel activated carbon was not exceeded the standard limit for drinking water. Therefore, the modified cassava peel activated carbon can be used as efficient and cost-effective method to remove 2,4-D from water resources. It is highly recommended that the dynamic column testing using modified cassava peel activated carbon to remove 2,4-D for different underground water qualities to be performed.

5.2 Recommendations

Additional characterization techniques, such as BET analysis, should be employed.

Comparative studies with other commercial activated carbon should be conducted.

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