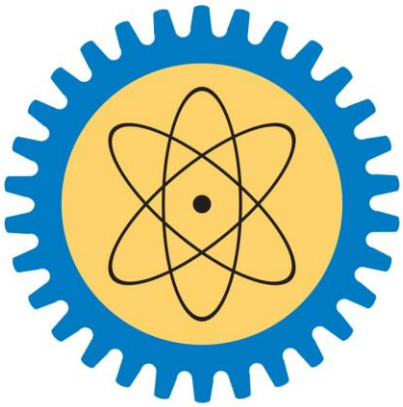

BUSITEMA UNIVERSITY

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FACULTY OF SCIENCE AND EDUCATION

DEPARTMENT OF CHEMISTRY

ADSORPTION AND KINETICS OF THIAMETHOXAM FROM WASTEWATER USING ACTIVATED CARBON FROM RICE STRAWS BIOMASS

BY

MUWANGUZI JOSHUA

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A RESEARCH 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, Muwanguzi Joshua, declare that this research project is my original work and has not been submitted to any other institution for academic credit.

Signature: _____

Date: 28/04/2026

APPROVAL

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

Supervisor's Name: Dr. MOSES KIGOZI

Signature: _____

Date: 28/08/2026

DEDICATION

This research report is dedicated to my lovely father Batuta Fred Pamba, my lovely mother Taaka Annet Kugonza, my siblings Wandera Ronald, Ajambo Everline, Mukisa Emmanuel Batuta, Mulungi Precious, Tumwebaze Nafula Pristine, Talemwa Gideon, my friends and my lecturers in the Chemistry department at Busitema University whose support, encouragement and prayers have helped me complete my studies successfully. Special gratitude goes to Mrs Mutawee Ritah Mubiru, the head teacher of Naalya SS, Lugazi, and Mr Nansera Ronald Martin for offering me a secondary education; my Aunt Wanyama Margaret Gimugu, Pastor Saul Gimugu and his entire family; and all the Chemistry students of Busitema University.

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ABSTRACT

Thiamethoxam (TMX) is a highly toxic neonicotinoid pesticide, and its entry into water sources endangers both human and aquatic life, necessitating the development of a low-cost, eco-friendly adsorbent for its removal. In this study, we examined the adsorption of Thiamethoxam from Aqueous solutions using Rice straw Activated Carbon (RSAC) as a low-cost and environmental friendly adsorbent. The main objective of this study was to evaluate the effectiveness of Rice Straw Activated Carbon in removing Thiamethoxam under varying operational conditions including contact time, adsorbent dosage, initial concentration and solution pH. Batch adsorption experiments were carried out and residual concentrations were determined using a UV-Vis spectrometry based on a calibration curve. The results showed that adsorption efficiency increased with contact time reaching equilibrium at approximately 120 minutes. Adsorption was enhanced by increasing adsorbent dosage, while higher initial Thiamethoxam concentrations resulted in reduced percentage removal due to saturation of active sites. The optimum adsorption occurred at pH 6, a contact time of 120 minutes, and a dosage of 0.5 g adsorbent, with a maximum removal efficiency of 84.6%. Characterisation of the Rice Straw Activated Carbon using the Scanning Electron Microscope revealed a highly porous and heterogeneous surface structure. At the same time, Fourier Transform Infrared Spectroscopy (FTIR) confirmed the presence of functional groups such as OH and C-O, which facilitated adsorption interactions. Equilibrium data were best described by the Langmuir Adsorption Isotherm, suggesting monolayer adsorption. Kinetic studies showed that Pseudo Second Order model provided the best fit, indicating that chemisorption was the dominant rate controlling mechanism. The findings demonstrated that Rice Straw Activated Carbon is an effective, low cost, and sustainable adsorbent for removal of Thiamethoxam from contaminated Water.

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AC- Activated Carbon

WHO -World Health Organization

UV-VIS -Ultra Violet Spectrophotometer

BET- Brunner Emmett Teller

PFO- Pseudo First Order

PSO- Pseudo Second Order

NWSC- National Water and Sewage Corporation

TMX- Thiamethoxam

RSAC- Rice Straw Activated Carbon

AOP- Advanced Oxidation Process

CAC -Commercial Activated Carbon

CHAPTER ONE: INTRODUCTION

1.1 Background of the study

The increase in the world's population has necessitated large-scale food production. This has been possible through modern farming, the use of fertilisers, and the use of pesticides. Pesticides are substances used to kill or control pests. They include herbicides for controlling weeds, insecticides for controlling insects, and fungicides for preventing the growth of fungi and bacteria. Water pollution caused by pesticides is a major environmental issue worldwide. These pesticides endanger not only the target organisms but also non-target organisms, particularly in aquatic environments and in humans, due to properties such as bioaccumulation and poor degradation. According to the World Health Organisation (WHO) and International Labour Organisation (ILO), an estimated 70,000 agricultural workers die due to acute and chronic poisoning caused by pesticides (Santana et al., 2016).

The presence of pesticides in water has raised concerns, highlighting the need for effective removal methods. Thiamethoxam (TMX) is one of the most commonly detected pesticides in water. Poor disposal and overdoses of TMX facilitate the entry of this contaminant into water, thus polluting surface and groundwater. The concentrations of TMX in different water sources vary, but the permitted maximum concentration of TMX in water for human consumption in most countries is 0.1 μg/L. TMX is a neutral Neonicotinoid insecticide used to control sucking and chewing pests in crops like vegetables, cereals, rice, and cotton among others. TMX has a high mobility in soil and persistence in water, making it a serious threat to aquatic biodiversity. Thiamethoxam affects the central nervous system of pests by blocking Acetylcholine receptors, ultimately leading to their death. Non-target species have reported adverse effects such as developmental abnormalities and reproductive challenges from exposure to TMX. (Fadel & Khdaim, 2024). In humans, exposure to pesticides like TMX occurs primarily through direct skin contact, inhalation, and inadvertent ingestion from improper handling. The secondary forms of exposure are through aerial spraying and the consumption of contaminated food and water.

Various treatment technologies have been studied for pesticide removal, including precipitation, coagulation, photocatalysis, and adsorption. However, these methods often face disadvantages, including high operational and maintenance costs and the production of potentially harmful byproducts that can pollute the environment. Adsorption is a widely used water purification technique for persistent organic pollutants such as TMX. This method is

favoured for its low operational costs, high efficiency and simple implementation. Adsorption is a phenomenon where molecules of an adsorbate substance attach to the surface of an adsorbent substance through intermolecular forces. Activated carbon is widely used in adsorption processes due to its high surface area, porosity, and affinity for organic compounds (Satyam & Patra, 2024).

The shift towards environmentally sustainable engineering has prioritised the utilisation of Agricultural waste as precursor materials for the production of high-performance activated carbon. Rice straw is a plentiful agricultural residue produced after rice harvesting, often discarded or burnt, which contributes to environmental pollution. Rice straws are made up of cellulose (32 - 47%), hemicellulose (19-27%), and lignin (5-24%)(Pattananandecha, Ramangkoon, Sirithunyalug, Tinoi, & Saenjum, 2019).

Almost half of the farmers in Eastern Uganda, in the districts of Bugiri, Busia, Tororo, Iganga, and Butaleja, among others, grow rice. After rice harvesting, a significant amount of rice straw remains in the garden. However, due to the chemical composition of rice straw, we can use it to produce high-performance rice straw activated carbon for TMX removal. Converting rice stalks into Activated carbon offers a practical solution for waste management and pollution control while providing a low-cost adsorbent for pesticide removal (Devi, Aggarwal, & Saravanamurugan, 2020).

1.2 Problem statement

Uganda is one of the least developed countries, where most people in rural areas have limited access to treated water supplied by the National Water and Sewerage Corporation. Most people living in these rural areas rely on groundwater and surface water, which are contaminated with pesticides (Sakaya, Niwagaba, Katukiza, & Lüthi, 2025). The increased use of pesticides to manage crop pests and enhance Agriculture has led to greater pollution in water bodies, creating environmental and public health risks. Thiamethoxam (TMX), a major component in a pesticide locally known as Striker, is predominantly used in the Eastern region of Uganda. According to recent studies, it has broad-spectrum effectiveness against various insects and aquatic life (Qamar et al., 2023). Although various water treatment technologies have been used, their high operational costs limit their adoption in developing countries like Uganda. While adsorption using activated carbon is effective, the cost of commercial activated carbon limits its application (Crini & Lichtfouse, 2019). Rice stalks are readily available agricultural

waste, but their potential to produce high-performance AC for TMX adsorption has not been fully explored.

Additionally, there is limited information on the adsorption kinetics of the AC derived from rice straw biomass. This knowledge gap hinders the development of sustainable and affordable water treatment methods. Therefore, there is a need to develop an effective, locally available, low-cost adsorbent to remove TMX from wastewater. This research project will address the problem of water pollution by removing pesticides from water sources and waste management by repurposing rice stalks.

1.3 Objectives of the study

1.3.1 General objective

To synthesize high-performance activated carbon from rice straws through optimized chemical activation and conduct a thorough study on its adsorption kinetics for Thiamethoxam removal from water.

1.3.2 Specific objectives

i. To prepare modified Rice Straw Activated Carbon.
ii. To characterize the modified Rice Straw Activated Carbon using different techniques.
iii. To find out how parameters like contact time, adsorbent dosage, initial TMX concentration and solution pH affect the effectiveness of Adsorption.
iv. To model the adsorption process using standard kinetics models.

1.4 Research questions

I. What are the optimal preparation conditions for synthesizing rice stalks AC for maximum adsorption of Thiamethoxam (TMX?)
II. What is the optimum pH, adsorbent dosage, and contact time required to achieve the maximum removal of Thiamethoxam?
III. How do the textural and chemical properties of the synthesized rice stalks AC influence its adsorption performance?
IV. Which kinetic and isotherm model best describes the adsorption rate of Thiamethoxam onto rice stalks AC, and is the process limited by pore diffusion or surface reaction.

1.5 Scope of the study

The study focused on the laboratory-scale preparation and characterisation of activated carbon from rice straw biomass, with a primary focus on optimisation through the chemical activation process and batch adsorption experiments using synthetic TMX solutions. Adsorption analysis

was done using a UV-Vis spectrometer. Kinetic, isotherm and thermodynamic models applied; the study did not involve real water systems.

1.6 Justification

This study was important due to the urgent need for affordable and sustainable water treatment solutions in Eastern Uganda. The research also supports Sustainable Development Goal 6, which focuses on clean water and sanitation. Using rice straws to produce AC reduces wastes and provides a cost-effective pesticide removal method aligning with Sustainable Development Goal 12, which emphasizes responsible consumption and production.

1.7 Significance of the study

This study will benefit the local communities in eastern Uganda by offering a low-cost approach to improving water quality. The study proposes a practical solution for managing neonicotinoid pollution, ensuring that runoff from agricultural-sprayed farms does not cause long-term ecological harm. This study will also expand academic knowledge of the adsorption behaviour of TMX using rice-stalk-activated carbon biomass, allowing future researchers to build on these findings. The repurposing of rice straw into AC will reduce environmental pollution from open-field burning, which contributes to greenhouse gas emissions.

1.8 Conceptual framework

The independent variables are operational parameters, including, initial TMX concentration, adsorbent dosage, solution pH, and contact time. These factors influence the dependent variable, which is the adsorption capacity (qe). Adjusting the independent variables optimizes adsorption efficiency (dependent variable).Higher activation temperatures and larger alkali impregnation ratios increase surface area and micro porosity.

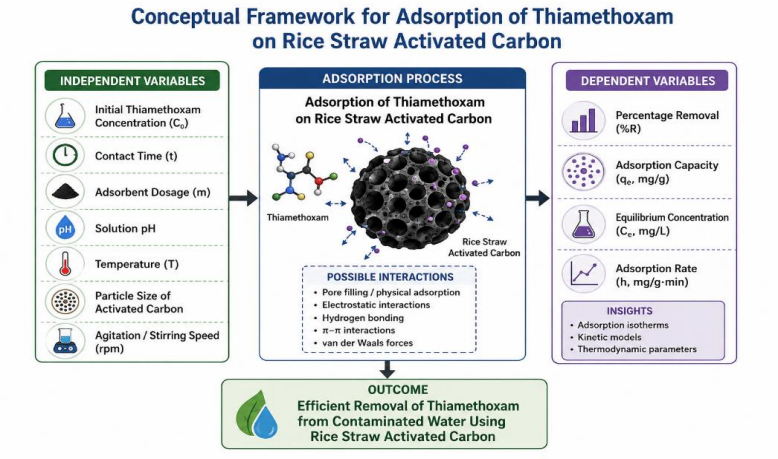


Figure 1 shows Conceptual framework for Adsorption of TMX onto RSAC

CHAPTER TWO: LITERATURE REVIEW

2. INTRODUCTION

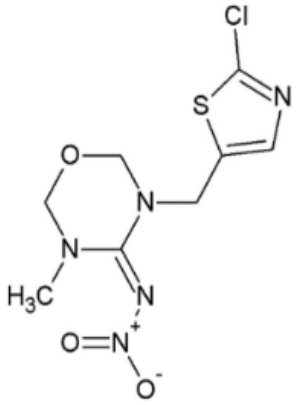
This chapter talks about other previous studies concerning adsorption on Rice Straw Activated Carbon and other related biomass

2.1 TMX classification, Application and Environmental risk

Thiamethoxam is a highly toxic, systemic, second-generation neonicotinoid insecticide that belongs to the thianiotinyl subclass (Kayser et al., 2016). Thiamethoxam is used primarily in Agriculture because of its wide range of effectiveness and ability to be absorbed by plant tissues for protection against sucking and chewing pests like Aphids (Jiang, Zhang, Lin, Liu, & Mu, 2019). However, its high water solubility makes it highly mobile, leading to considerable leaching into groundwater and surface water bodies, negatively affecting the environment and aquatic organisms, and threatening human health (de Carvalho, Silva, Pereira, Cavallini, & Pereira, 2024). This creates an urgent need for effective remediation strategies for contaminated water. Finding an efficient and affordable method to eliminate pesticide residues has become a critical need for our surrounding environment

2.2 Chemical structure of TMX

Structurally TMX contains a 1, 3-thiazole ring, which incorporates sulphur and nitrogen atoms. The molecule also contains a chlorothiazolyl group, a nitro guanidine functional group and several heteroatoms, including Nitrogen, Oxygen, Sulphur, and Chlorine. These functional groups contribute to the chemical and physiochemical properties of Thiamethoxam, including its polarity and ability to interact with surfaces through different intermolecular forces. The presence of heteroatoms and polar functional groups is important in adsorption studies because they can participate in interactions such as hydrogen bonding, electrostatic interactions and other surface molecule interactions with functional groups present on Activated Carbon.



Chemical structure of thiamethoxam

Figure 2 shows Chemical structure of TMX

2.3 Review of wastewater technologies for pollutant removal from water

Wastewater treatment has become a global concern due to the increasing release of organic pollutants, including synthetic dyes, pharmaceuticals, and pesticides, into the environment. Removing these pollutants involves various physical, chemical, and biological methods. The physical methods include sedimentation, degasification, and filtration; chemical methods include flocculation, disinfection, adsorption, ion exchange, and chemical precipitation; while the biological methods include Techniques such as membrane technology, aerobic treatment, anaerobic treatment, and activated sludge. Biological treatment, among other methods, has been employed to remove organic pollutants from contaminated water. However, many of these methods are limited by high operational costs, incomplete removal of organic pollutants and generation of secondary waste products. Biological methods, while sustainable, are limited by low biodegradability and pesticide toxicity (Rashid, Shafiq, Akhter, Iqbal, & Hussain, 2021).

Among the available wastewater treatment options, adsorption shows promise as one of the most efficient methods for removing pesticides such as TMX from wastewater. Adsorption is advantageous over other methods because of its simple design, lower initial costs, environmental friendliness, and ability to remove low-concentration pollutants. Unlike chemical oxidation and biological degradation, adsorption does not rely on complex reaction pathways, making it suitable for compounds that are resistant to biodegradation(Mutegoa, 2024).

2.3.1 Sedimentation

Sedimentation involves allowing suspended particles in a liquid to settle under gravity, forming a sediment layer at the bottom of the container. This technique is based on the density difference between the liquid and the particles. Though this method has proven effective at removing suspended particles, it is not effective at removing some pesticides, such as TMX, that dissolve in water.

2.3.2 Degasification

This technique works on the principle of mass transfer, in which dissolved gases move from the liquid phase to the gaseous phase. In general, TMX particles have a higher proportion in the liquid state than in the gaseous state. This limits their removal from waste water systems using degasification technology.

2.3.3 Flocculation and coagulation

These processes work by attracting smaller particles, such as dirt and sediment, into larger floc clusters that are easier to remove from water. Though this technique is effective, it is limited in developing communities due to its upfront costs and the accumulation of residual chemicals generated during purification.

2.3.4 Disinfection

Disinfection involves adding chemicals to wastewater, such as chlorine, chloramines, ozone, and UV light, to kill pathogens in water sources. This technique, however, is not effective at removing pesticides such as TMX from water because they are inorganic.

2.3.5 Chemical precipitation

This involves adding coagulants and flocculants to wastewater to destabilise suspended particles. The destabilised suspended particles are then removed by sedimentation or filtration. Although this technique is effective, the chemicals used can increase costs, environmental impacts, and sludge generation.

2.3.6 Advanced oxidation processes

Advanced Oxidation Processes generate highly reactive radicals, such as hydroxyl radicals (.OH), that break down organic contaminants into simpler, less harmful compounds. Common AOPs for pesticide removal include UV/H2O2 oxidation, Fenton and photo-Fenton processes, ozonation, and TiO2 photocatalysis for TMX. While AOPs are very effective in degrading pesticides, their use is often limited by high operational costs, the need for specialised

equipment, high energy requirements, and the formation of intermediate byproducts. As a result AOP are often combined with other treatment methods like adsorption to improve efficiency

2.3.7 Biological degradation

This involves using microorganisms, such as bacteria and fungi, to break down pesticide molecules. Some microbial strains can metabolise TMX through enzymatic reactions that convert the insecticide into simpler metabolites. Biodegradation methods generally include oxidation reactions, hydrolysis, and enzymatic breakdown of functional groups. Although biological processes are environmentally friendly and low-cost, they suffer from slow degradation rates and sensitivity to environmental factors such as pH, temperature, and microbial population stability. Additionally, high pesticide levels may hinder microbial activity, reducing treatment efficiency.

2.3.8 Membrane filtration

Membrane filtration techniques like nanofiltration, reverse osmosis, and ultrafiltration for removing pesticides from water rely on size exclusion and electrostatic interactions between the membrane surface and contaminant molecules. Membrane filtration systems offer several advantages, including high separation efficiency and the ability to remove multiple contaminants. However, membrane processes often face challenges such as high operational costs and the necessity of regular maintenance.

2.3.9 Photo degradation

Photo degradation refers to the breakdown of pesticide molecules when exposed to ultraviolet or solar radiation. TMX molecules absorb light energy, resulting in molecular excitation and subsequent degradation. This process occurs naturally in surface waters exposed to sunlight but natural photolysis is usually slow and incomplete. Artificial UV systems can speed up degradation rates but require continuous energy input and may produce intermediate compounds with unknown toxicity.

2.3.10 Adsorption

Adsorption has proven to be one of the most effective ways to remove pesticides from water due to its simplicity, effectiveness and cost. Adsorption takes place because the particles on the surface and in the bulk of the adsorbent are not in the same environment, that is to say, the net force acting on them is not the same. If any species comes into contact with the surface molecules, the surface molecules hold that species and balance their unbalanced forces. In adsorption, contaminants stick to the surface of a solid adsorbent through physical or chemical

interactions. Several studies report effective TMX adsorption using various adsorbents, including AC, biochar, carbon nanotubes, and materials derived from agricultural biomass. AC is used because of its high surface area, well-developed pore structure and numerous surface functional groups that interact with the pesticide molecules. The adsorption of TMX onto AC involves π-π interactions between aromatic rings, hydrogen bonding between surface functional groups and TMX molecules and electrostatic interactions. Adsorption is a leading method for pesticide removal due to its effectiveness and adaptability to various water treatment systems.

2.4 TMX adsorption and isotherms

The need to design low-cost adsorbents for the removal of organic pollutants has become a growing concern for many researchers. So modelling of experimental data from adsorption processes is a very useful way to determine the mechanisms of various adsorption systems. The extent at which the organic pollutant adsorbs onto AC is analysed using adsorption isotherms. Adsorption isotherms describe the relationship between the adsorbate and the adsorbent at equilibrium and provide insights into whether molecules are adsorbed on monolayer or multilayer surfaces. They show the adsorbent's adsorption capacity and indicate the intensity of the adsorption process. Several adsorption isotherms have been used to fit data from static adsorption tests, including the Langmuir, Freundlich, and Temkin isotherms.

2.4.1 Langmuir adsorption isotherm

Langmuir adsorption isotherm describes monolayer adsorptions. It assumes that adsorption takes place at finite number of definite localizes states, requires identical adsorption sites where only one molecule will be adsorbed at each site. The linear model of Langmuir isotherm model can be illustrated as;

$$\frac{C_e}{q_e} = \frac{1}{K_L q_m} + \frac{C_e}{q_m} \quad \textbf{.....Equation 1}$$

Where $q_e$the corresponding adsorption capacity of the adsorption process at equilibrium (amount of adsorbate adsorbed per unit mass of adsorbent at equilibrium), q_m is the maximum adsorption capacity for monolayer adsorption, C_e is the equilibrium concentration of the adsorbate in solution (mg/L) and K_L is Langmuir adsorption constant related to the affinity of binding sites.

A plot of $\frac{C_e}{q_e}$ versus C_e gives a straight line with a slope $\frac{1}{q_m}$ and intercept $\frac{1}{K_L q_m}$ from which constants; K_L and q_m can be calculated.

2.4.2 Freundlich adsorption isotherm

Freundlich Adsorption isotherm applies to multilayer adsorption on heterogeneous sites

The adsorption of organic pollutants onto Activated Carbon often follows the empirically derived Freundlich Equation

$$q_e = \mathrm{K}_f C_e^{\frac{1}{n}} \text{.....Equation 2}$$

Where, K is the adsorption capacity in L/mg, $\frac{1}{n}$ is the adsorption intensity or surface heterogeneity, w mass of the adsorbed solute(mg/g), C is the concentration of the solute at equilibrium(mg/L) and K and n are fitting constants. The adsorption is favoured only when $0<\frac{1}{n}<1$. The linearized form can be expressed as;

$$\mathrm{In}\, q_e = \mathrm{lnK}_f + \frac{1}{n} InC_e \text{....Equation 3}$$

Where; K_f is the Freundlich adsorption capacity and n is the adsorption intensity, q_e is the amount of adsorbate adsorbed per unit weight of adsorbent and C_e is the equilibrium adsorbate concentration in solution.

A plot of In q_e against InC_e produces a straight line with slope $\frac{1}{n}$ and intercept lnK_f

On the other hand the adsorption on of TMX on AC happens through several mechanisms including, hydrophobic interactions, organic pesticide molecules cling to hydrophobic Carbon surfaces in water. Hydrogen bonding, functional groups present on AC like hydroxyl, carboxyl, and carbonyl groups can form hydrogen bonds with TMX molecules. π-π interactions, the aromatic structures in AC interact with the aromatic rings of TMX molecules. Pore-filling, TMX molecules move into the micro pores and meso-pores of AC where they are trapped through physical adsorption. The adsorption mechanism is a combination of physical adsorption and chemical adsorption interactions.

2.5 Kinetic models of adsorption of TMX on AC

Adsorption kinetics refers to how quickly a solute is removed from solution and attaches to the surface of an adsorbent. Adsorption kinetic studies give insights into the adsorption mechanism, factors affecting the adsorption rate and adsorption efficiency. Understanding

these kinetics helps to understand whether the process is dominated by surface reactions, diffusion or chemical interactions between the adsorbent and adsorbate. Several kinetic models have been applied to determine the rate of adsorption and how TMX molecules interact with the adsorbent surfaces including; Pseudo first order kinetic model; pseudo second order kinetic model and Elovich kinetic model among others. These models help analyse the adsorption data got after conducting the Batch Adsorption experiments. Kinetics studies show that TMX adsorption typically occurs in two stages; that is Rapid initial adsorption and slow approach to equilibrium. The rapid initial phase happens because many adsorption sites are available on the adsorbent surface. As these sites fill up, the adsorption rate slows down until equilibrium is reached.

2.5.1 Pseudo first order kinetic model (PFO)

The pseudo first order kinetic model, which was brought up by Lagergren is among the first models to describe the kinetics of adsorption. This model takes on an assumption that the occupation rate of adsorption sites is proportional to the number of unoccupied sites on the adsorbent surface. The mathematical expression for the linearized pseudo first order form is;

$$\frac{dqt}{dt} = K_1(q_o - q_t) \text{ ... ...Equation 4}$$

Upon integration, it follows that,

$$log(q_o - q_t) = \log q_e - \frac{K_1}{2.303} t \text{ ... ... Equation 5}$$

Where qe=adsorption capacity at equilibrium (mg/g), qt is the adsorption capacity at time t, k1 is the pseudo first order rate constant (per minute), t is the contact time in minutes

A plot of log $(q_e - q_t)$ against time gives a straight line if the adsorption follows pseudo first order kinetics. However, in cases where chemisorption of pesticides is involved, this model may not fit the experimental data very well.

2.5.2 Pseudo second order kinetic model (PSO)

The pseudo second order takes on an assumption that the rate-limiting step involves chemical adsorption (chemisorption) through electron sharing between the adsorbent and adsorbate. Several studies show that the pseudo second order kinetic model is best fit to explain the adsorption of TMX. This shows that the chemical interactions are significant in the adsorption process. For instance, the research on pesticide adsorption found correlational coefficients greater than 0.9 for the pseudo-second order model indicating that it accurately describes TMX adsorption.

The mathematical expression of the pseudo second order kinetic model in linear for is given by

$\frac{dqt}{dt} = K_2(q_o - q_t)^2$ … … …. **Equation 6**

Upon integration the pseudo second order rate equation is;

$$\frac{1}{q_o - q_t} = \frac{1}{q_o} + K_2 t \text{ … … … Equation 7}$$

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;

$\frac{t}{qt} = \frac{1}{K_2 q_o^2} + \frac{t}{q_o}$ … … … … .. **Equation 8**

Where K2 is the pseudo second order rate constant, (g/mg/min), qe is the adsorption capacity at equilibrium and qt is the adsorption capacity at time t

2.5.3 Elovich kinetic Model

The Elovich kinetic model describes adsorption on heterogeneous surfaces, where the adsorption energy changes. This model is essential for chemisorption processes involving surface heterogeneity.

2.5.4 Intraparticle diffusion model

The intraparticle diffusion model helps determine if diffusion model helps determine if diffusion inside the adsorbent's pores controls the adsorption process.

A plot of $\frac{t}{qt}$ against time will yield a straight line if the model applies.

2.6 Activated carbon from biomass: Precursor and Activation

Different agricultural residue have been used as precursors for AC including, maize cobs, rice husks, rice straws, coffee husks, sugar cane bagasse, wood saw dust among others because of their high carbon content, low cost and local availability of these precursors. Rice stalks are ideal precursors for activated carbon (AC) production because of their high lignocellulose content and abundance as Agricultural waste. The lignocellulose composition influences the carbon yield, pore development and surface functionality after carbonisation and activation(Iwanow, Gärtner, Sieber, & König, 2020).

Transformation of this biomass into a high surface area adsorbent typically involves carbonization then followed by chemical activation. Physical activation involves two phases.

The first phase involves carbonization of the raw materials at elevated temperatures. In the second phase, the Carbonized sample is activated thoroughly in the presence of gases such as air, carbon dioxide and steam to improve porosity. Chemical activation involves the use of dehydrating or activating agents such as phosphoric acid, potassium hydroxide or zinc chloride and potassium carbonate. Chemical activation involves the impregnation of the raw material with a chemical activating agent such as phosphoric acid, sulphuric acid, sodium hydroxide, potassium hydroxide and zinc chloride followed with heating of the mixture in an inert atmosphere(Wazir, Wazir, & Wazir, 2024).

Phosphoric acid promotes formation of meso pores and oxygen containing surface groups, this is effective at moderate temperatures and widely used for lignocellulosic precursors. Potassium hydroxide, potassium carbonate and other alkali agents produce highly microporous structures with very high BET surface areas. Zinc chloride produces well-developed porosity and aromatic condensation but raises environmental and post treatment concerns due to zinc residues(Alcañiz-Monge, Román-Martínez, & Lillo-Ródenas, 2022).

2.7 Existing TMX adsorption Performance and identification of the research gap

Recent studies have explored the use of various materials for Thiamethoxam removal including waste derived Nano- particles, clay; TiO2 based composites, bio char and magnetic nanocomposite(El-Kammah, Elkhatib, Gouveia, Cameselle, & Aboukila, 2022). For instance the research on Iraqi date seed derived AC showed moderate removal efficiencies, with a maximum adsorption dose of 0.05g/l, typically following pseudo-second order kinetics(Fadel, 2024). These studies explain TMX uptake through electrostatic attraction, hydrogen bonding, π-π interactions and surface complexation and fit equilibrium data to Langmuir and Freundlich adsorption Isotherms(El-Kammah et al., 2022). These studies indicate that surface modification increases porosity and introduces specific binding sites /functional groups that enhances TMX removal. Despite the encouraging studies on TMX adsorption, a significant research gap exists in the specific application of chemically activated rice straws for Thiamethoxam removal. Most recent studies focus on other precursors or different kinds of pesticides(Rashid et al., 2021). There is limited detailed data on how the high silica content found in rice stalks affects the adsorption of neonicotinoids specifically TMX and how varying PH levels specifically interact with TMX on a rice straw carbon surface. This study will fill the gap by providing a local low cost adsorbent for TMX removal from wastewater.

CHAPTER THREE: METHODOLOGY

3. Materials and Reagents

Rice straws were obtained from local rice farms in Nagongera. A TMX formulation was purchased. All chemical reagents used for activation and PH adjustment, including phosphoric acid, sodium hydroxide, and Hydrochloric acid, were of laboratory reagent grade.

3.1 Activated Carbon synthesis and pre-treatment protocol

3.1.1 Precursor preparation

Rice straws were cut into small pieces and washed thoroughly with tap water and rinsed with distilled water to remove dirt and other contaminants. The straws were then oven dried at 110^0C for 48 hours to eliminate the moisture content. After drying, the straws were crushed using a grinder and sieved to obtain a uniform particle size of 1.0 mm(Heidarinejad et al., 2020).

3.1.2 Chemical Activation

The ground straws were mixed with a 85% solution of H_3PO_4 .This mixture was stirred and left to soak for 24 hours at room temperature to allow the acid to penetrate the lignocellulose, matrix the impregnated sample placed in a crucible and heated in a muffle furnace at 600^0C. The resulting Activated Carbon was cooled and washed with 0.1 M HCl to remove residual activating agents and mineral ash, followed by repeated heating with hot distilled water until the filtrate reaches a neutral PH of 7.0. Finally, the AC dried at 110^0C and stored in an airtight container.

Figure 3 shows Synthesized Rice Straw Activated Carbon

3.2 AC characterization

The prepared RSAC was characterized to determine its physiochemical properties using different techniques. FTIR was used to identify the functional groups on the AC surface, and SEM for surface pores(Kigozi et al., 2020).

3.2.1 FTIR Characterization

FTIR analysis was carried out to identify the surface functional groups present on RSAC responsible for Thiamethoxam adsorption. The FTIR spectrum was recorded with in the range of 4000-400 cm^{-1} using an ATR-FTIR spectrophotometer. A broad and weak absorption band was observed around 3200-3500 cm^{-1} was attributed to OH stretching vibrations of hydroxyl groups originating from alcohols, phenols, and absorbed moisture. The presence of hydroxyl groups suggested that the RSAC surface has oxygen-containing functionalities capable of participating in hydrogen-bonding interactions during adsorption. A small absorption peak observed near 2900 cm^{-1} corresponding to aliphatic C-H stretching vibrations indicating the presence of residual organic structures inherited from the lignocellulosic nature of RS biomass. The band appearing around1600-1700cm was assigned to C=O stretching vibrations of carbonyl groups and aromatic C=C skeletal vibrations. These functional groups are important because they increase the polarity and chemical reactivity of RSAC surface thereby enhancing adsorption affinity towards TMX molecules. The most prominent absorption band was observed around 1000-1100 cm^{-1}. This peak was attributed to C-O stretching vibrations and Si-0-Si stretching associated with silica compounds naturally present in RS. The strong intensity of this peak indicates the abundance of oxygen containing groups and siliceous materials on the RSAC surface. Additional absorption peaks appearing within the region of 700-500 cm-1 were associated with Si-O bending vibrations and mineral components remaining after carbonization and activation.

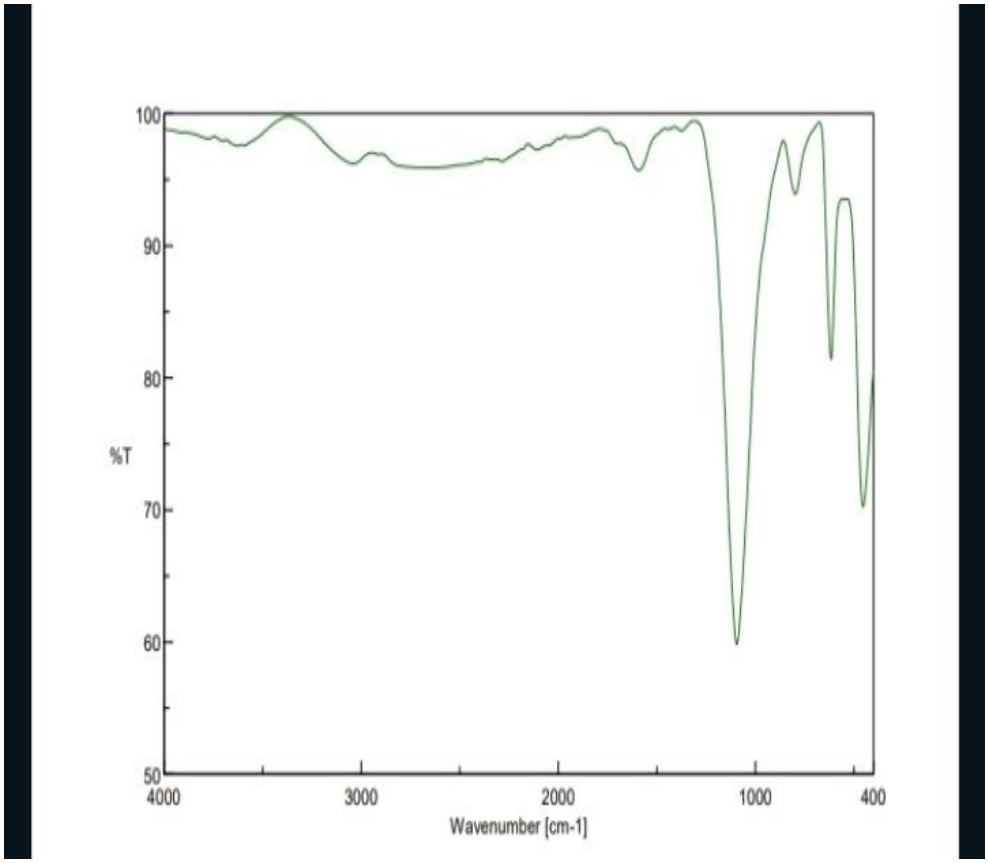
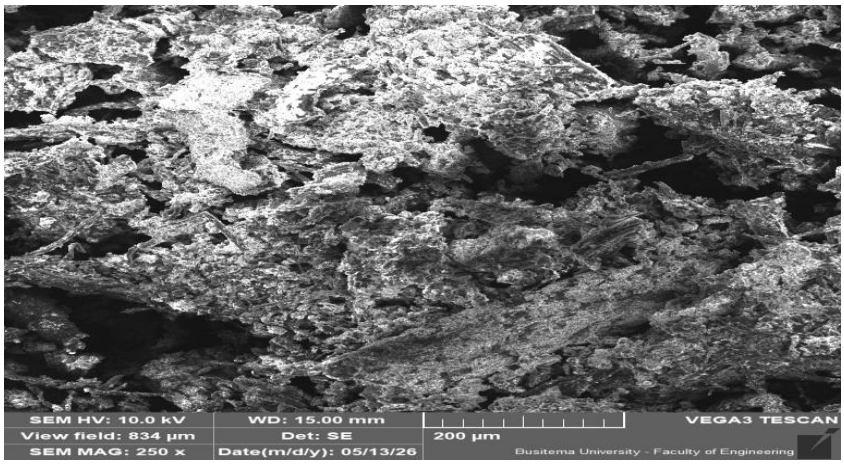


Figure 4 shows FTIR Spectra of RSAC showing the functional groups present on the RSAC

3.2.2 SEM Characterization of RSAC

The SEM images of the RSAC showed that the material had a rough and irregular surface with many pores and cavities indicating that the activation process successfully developed a porous structure. These pores provide more active sites for adsorption of TMX molecules from water



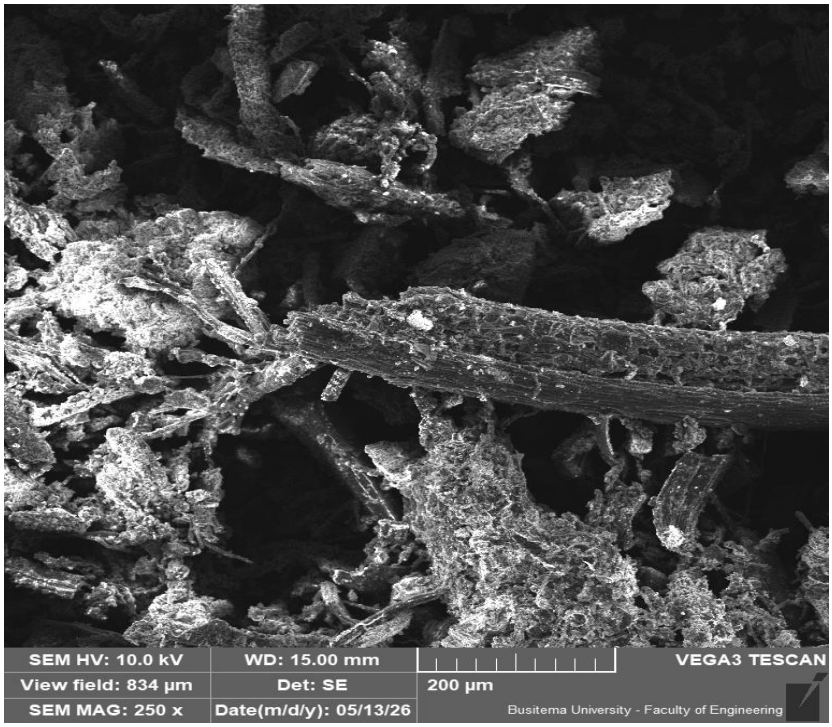


Figure 5 shows SEM Images for RSAC

3.2.3 EDX Analysis

The EDX analysis showed a high oxygen content (30.6 wt. %), moderate carbon (37.8 wt. %), and significant sodium and silicon. The high O/C ratio indicates abundant oxygen containing functional groups.

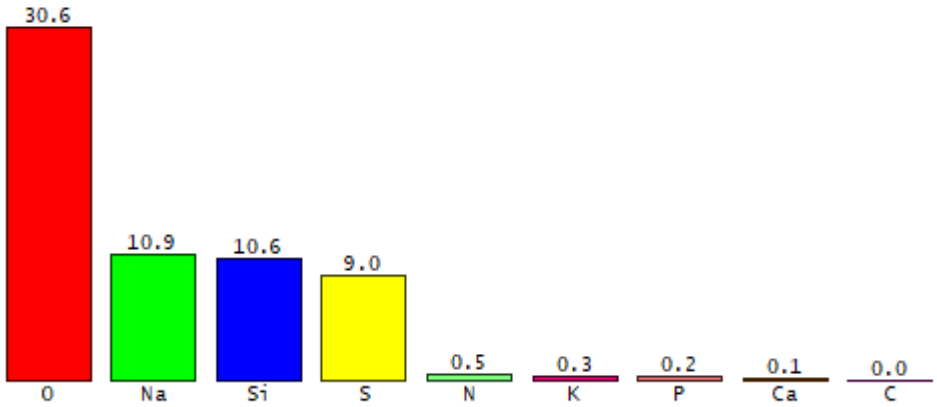


Figure 6 shows EDX graph showing elemental composition

Element	Weight %
Carbon (C)	37.8
Oxygen (O)	30.6
Sodium (Na)	10.9
Silicon (Si)	10.6
Sulphur (S)	9.0
Nitrogen (N)	0.5
Potassium (K)	0.3
Phosphorous (P)	0.2
Calcium (Ca)	0.1

Table 1 shows EDX percentage Elemental Composition of RSAC

3.2.4 Determination of Iodine Number (IN)

The determination of is a simple test performed to indicate the internal surface area of RSAC. The iodine number is the number of milligrams of Iodine adsorbed from an aqueous solution by 1g of AC when the iodine concentration of the residual filtrate is 0.02N

Procedure,

1.0g of RSAC was measured using a weighing scale and transferred into a 250ml conical flask.

10 ml of 5% HCl was pipetted into the flask and swirl until the RSAC was completely soaked. The contents were boiled for 30 seconds, and cooled. 100mls of 0.10N Iodine solution was added to the contents in the conical flask, stoppered immediately and shaken vigorously for 30s after which they were immediately filtered. 20mls of the initial filtrate was discarded and

the remainder was collected in a clean conical flask. The filtrate was stirred using a glass rod. 50 ml of the filtrate were pipetted into a 250 ml conical flask and titrated with 0.10 N sodium thiosulphate solution until the yellow colour almost disappeared. 1 ml of starch solution was added and titration continued until the blue colour disappeared. The volume of sodium thiosulphate solution used was recorded.

Standardization of sodium thiosulphate solution

Results

Standardization of sodium thiosulphate solution

Titre	1	2	3
Initial Burette Reading	0.00	0.00	0.00
Final Burette Reading	25.00	24.90	24.90
Volume Used	25.00	24.90	24.90

Standardization of Iodine solution prepared

Titre	1	2	3
Initial Burette Reading	0.00	0.00	0.00
Final Burette Reading	50.00	49.90	49.90
Volume Used	50.00	49.90	49.90

Iodine Number Test

Titre	1	2	3
Initial Burette Reading	0.00	0.00	0.00
Final Burette Reading	14.20	14.10	14.10
Volume Used	14.20	14.10	14.10

Table 2 shows results for Iodine number determination data

3.3 Preparation of stock solution and working solutions of TMX

The stock solution of TMX was prepared from a commercial pesticide formulation, striker pesticide containing 141g/L Thiamethoxam due to the limited availability of the analytical grade. A stock solution of Thiamethoxam with a concentration of 1000mg/L was prepared by dilution of the commercial formulation using distilled water using the dilution formula,$C_1V_1=C_2V_2$ where C_1 is the concentration of Thiamethoxam in the pesticide formulation(141000mg/L), C_2 is the desired concentration(1000mg/L), and V_2=1000mL. The desired volume of the pesticide formulation, $v_1 = \frac{C_2 V_2}{C_1} = \frac{1000X1000}{14100} \simeq 7.1mL$. 7.1mL of the pesticide formulation was measured using a pipette and transferred into a 1000mL volumetric flask, Distilled water was added to the calibration mark. The solution was thoroughly mixed to obtain a 1000mg/L stock solution. An intermediate solution of 100mg/L was prepared from the stock solution to improve accuracy in the subsequent dilutions, using the dilution formula by transferring 10mL of the stock solution into a 100mL volumetric flask and diluted to the mark with distilled water to obtain the intermediate solution. Working solutions of 5,10,15,20,25 and 30 mg/L respectively were prepared from the 100 mg/L intermediate solution using serial dilution from dilution formula $C_1V_1=C_2V_2$, where C_1=100mg/L,V_2 =100 mL and required volumes V_1 for each concentration calculated to obtain 5,10,15,20,25 and 30 mL respectively. These respective volumes was pipetted from the intermediate solution transferred into separate 100mL volumetric flasks and diluted to the mark with distilled water. The solutions were mixed thoroughly to ensure homogeneity.

3.4 Thiamethoxam Characterization and determination

Standard solutions of 5, 10,15,20,25, and 30mg/L were prepared and filtered before analysis. Spectrophotometric measurements were performed over the range of 200-250nm to determine the maximum wavelength of the 25 mg/L TMX formulation using a JENWAY 6705 UV/VIS spectrophotometer. Full scan spectrum was obtained with λ max at 220 nm.

3.5 Thiamethoxam Characterization and determination

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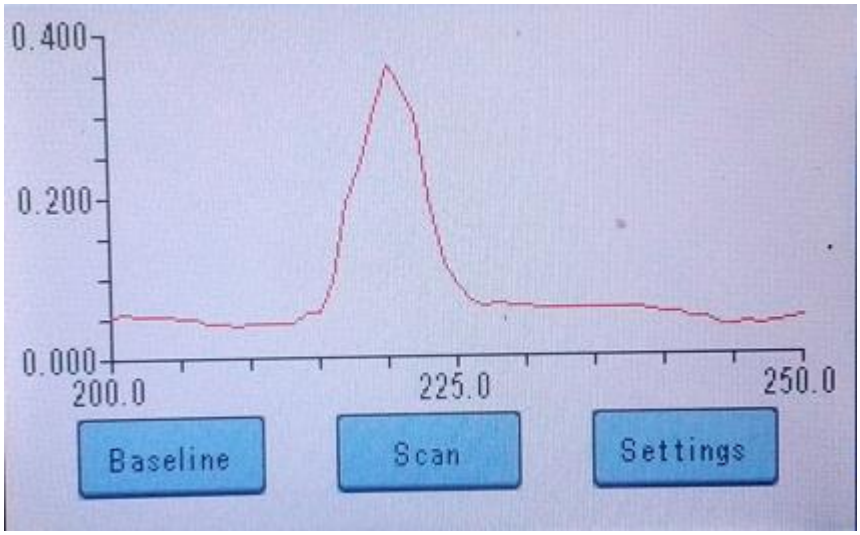

Figure 7 shows Spectrum for maximum Absorbance peak and wavelength for a TMX solution

The absorbance of each standard solution was measured at 220 nm wavelength (λmax) using the UV-Visible spectrophotometer. A calibration curve of absorbance versus concentration was plotted. To determine the concentration of Thiamethoxam, the absorbance of the samples obtained after adsorption experiments was measured at 220 nm (λmax). The concentrations of Thiamethoxam was got by referencing the absorbance values to the calibration curve..

3.6 Batch Adsorption Experiments

Batch adsorption experiments were carried out to evaluate the removal efficiency of TMX from aqueous solutions using Rice Straw Activated Carbon (RSAC).

3.6.1 Effect of Adsorbent Dosage on TMX removal

Varying masses of Rice Straw Activated Carbon (RSAC) that is 0.1, 0.2, 0.3, 0.4, and 0.5 were added to different conical flasks containing 50-mLof 25mg/L Thiamethoxam solution. The mixtures were shaken at 150rpm for 150 minutes at room temperature, after which the mixtures were filtered, the resulting filtrate was centrifuged at a speed of 3500 for 30 minutes using an Omega 6 centrifuge Machine and residual concentrations measured using UV-Visible spectrophotometer.

3.6.2 Effect of Contact time

0.50g of RSAC was be added to 50-mL of 25 mg/L TMX solution in different conical flasks, the mixtures and shaken at 150rpm and samples withdrawn at predetermined intervals of 10,30,40,60,90,120 and 150 minutes respectively. Each sample was filtered, centrifuged at 3500 speed for 30 minutes and analysed for residual concentration using UV-Visible spectrophotometry.

3.6.3 Effect of pH on TMX Removal

The pH **of** 50-mL of 25 mg/L TMX solutions in different conical flasks was adjusted to the desired pH values of 2,3,5,7,9 and 11 using 0.1M HCl and 0.1M NaOH. A fixed mass of 0.10g of RSAC was be added to each solution and mixture shaken at 150rpm for 150 minutes. After filtration, the residual concentrations was determined using UV-Visible spectrophotometry.

3.6.4 Effect of initial Thiamethoxam Concentration

Five samples of 5, 10.0, 15.0, 20.0, 25.0 and 30 mg/L of TMX were prepared. Each solution of 50-mL was placed in different conical flasks. To each flask, 0.1g of RSAC was added and the mixture shaken constantly at 150 rpm using an orbital shaker 150 minutes. After filtration, the equilibrium concentration of TMX was determined using a UV-Visible spectrophotometer. The percentage removal of TMX will be calculated from, percentage Removal $=\frac{C_0-C_e}{C_0}x100$ the adsorption capacity (q_e) was calculated from $q_e = \frac{(C_0-C_e)v}{m}$ where C_o =initial concentration (mg/L),C_e = equilibrium concentration (mg/L) and V= volume of solution (L), m=mass of adsorbent (g).

CHAPTER FOUR: RESULTS AND DISCUSSION

4. Introduction

This chapter presents and discusses the results obtained from the adsorption of Thiamethoxam onto rice straw activated carbon (RSAC). The adsorption performance was evaluated through contact time, adsorbent dosage, initial concentration, pH, SEM, FTIR, adsorption isotherms and kinetic studies. Removal of organic pollutants such as TMX by adsorption, is influenced by many factors for example, PH, temperature, time, initial solution concentration, and adsorbent dosage. The best way to study the influence of these adsorption parameters and optimize them is by studying the response against one factor while maintaining the rest at constant values.

4.1 Presentation of results

4.1.1 Determination of Iodine Number

The iodine number was calculated and found to be 913 mg/g, which means that 1g of RSAC can adsorb approximately 913 mg of Iodine from a standard solution under the test conditions. Thus, the activation process of RSAC successfully created numerous microspores, making the adsorbent suitable for TMX removal.

4.1.2 SEM Characterization of RSAC

SEM micrographs revealed a rough, heterogeneous and porous surface containing cracks, cavities and channels. These structural features indicate successful activation of rice straw and provide numerous adsorption sites for Thiamethoxam uptake.

4.1.3 FTIR characterization of RSAC

FTIR analysis indicated the presence of hydroxyl (O–H), carbonyl (C=O), C–H and C–O functional groups. These oxygen-containing groups contribute to adsorption through hydrogen bonding and surface interactions.

4.1.4 Calibration Curve

A calibration curve was developed using standard TMX solutions of 0 to 30mg/L. The plotted scatter of the calibration curve was linear with a high correlation coefficient (R^2 =0.996), absorbance values increased proportionally with concentration demonstrating compliance with the Beer lamberts law.

Concentration(mg/l)	Absorbance
0	0
5	0.214
10	0.331
15	0.481
20	0.686
25	0.807
30	0.991

Table 3. TMX Calibration data

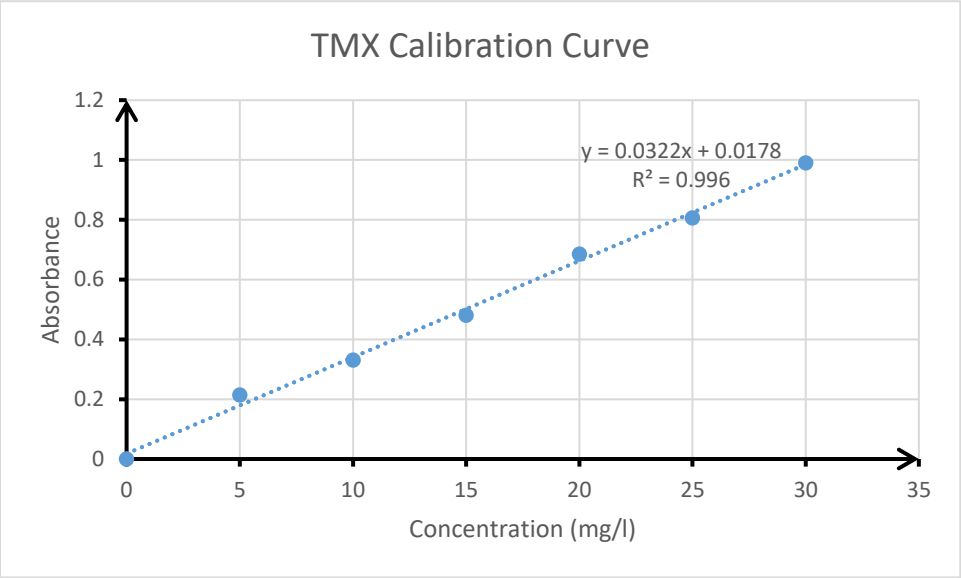

Figure 8. shows TMX Calibration Curve

4.1.5 TMX Adsorption process

The adsorption equilibrium data were applied to two adsorption isotherms models to recognize the best model that describes TMX adsorption

4.1.6 Effect of contact time on TMX adsorption

The influence of exposure time 0 to 150 minutes was carried out using a solution of 25mg/L solution at normal pH. The results in fig. 9 show that increasing agitations time increases TMX removal onto RSAC. Adsorption efficiency increased rapidly during the initial stages and gradually approached equilibrium at approximately 120 minutes. Increasing agitation time beyond 120 minutes did not significantly affect TMX Removal. Similar findings as obtained in this study were reported by (El-Kammah et al., 2022) who also observed that increasing contact time increases TMX adsorption.

Time(mins)	abs	ct	% R	qt	t/qt	Qe	ln(qe-qt)
0	0.807	25.000	0.0	0.000	0.000	8.770	8.770
10	0.615	18.547	25.8	3.227	3.099	8.77	5.543
30	0.51	15.286	38.9	4.857	6.176	8.77	3.913
40	0.473	14.137	43.5	5.432	7.364	8.77	3.338
60	0.38	11.248	55.0	6.876	8.726	8.77	1.894
90	0.264	7.646	69.4	8.677	10.372	8.77	0.093
120	0.258	7.460	70.2	8.770	13.683	8.77	0.000
150	0.254	7.335	70.7	8.832	16.983	8.77	-0.062

Table 4 Effect of Contact time on TMX Removal

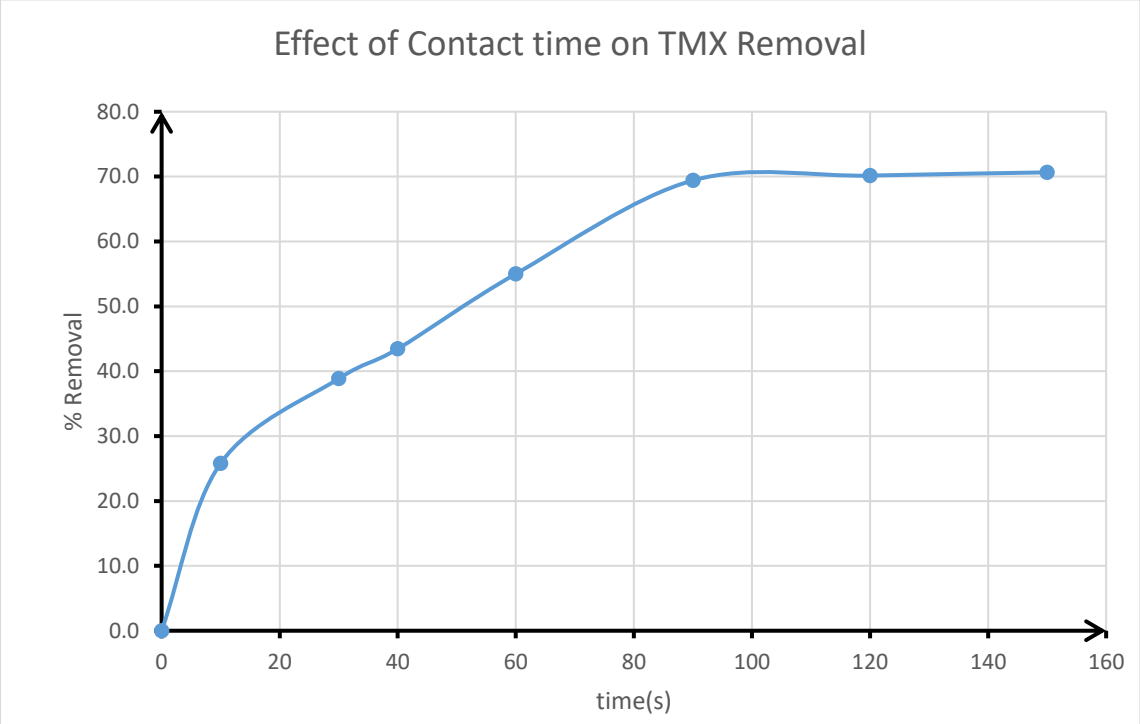

Figure 9 Effect of contact time on TMX Removal

The rapid adsorption during the initial stages can be attributed to abundance of vacant adsorption sites available on the RSAC surface. As adsorption continued, these sites became increasingly occupied leading to a reduction in the adsorption rate until equilibrium was reached.

4.1.7 Adsorbent dosage

The impact of adsorbent dosage 0.1g to 0.5g was carried out using an initial 25mg/L TMX solution and agitation time 150minutes. Increasing the dosage of the adsorbent increased the

removal efficiency of TMX by providing more active binding sites. The adsorption capacity decreased due to underutilization of these sites and particle agglomeration of adsorbent molecules at higher doses, which may lead to decreasing number of sorption sites. Similar studies were reported by (El-Kammah et al., 2022).

Mass	Dosage(g/L)	Abs	Ce	Removal	qe
0.1	2	0.435	12.95652	48.17391	0.301087
0.2	4	0.372	11	56	0.175
0.3	6	0.269	7.801242	68.79503	0.143323
0.4	8	0.183	5.130435	79.47826	0.124185
0.5	10	0.142	3.857143	84.57143	0.105714

Table 5 Effect of adsorbent dosage on TMX adsorption

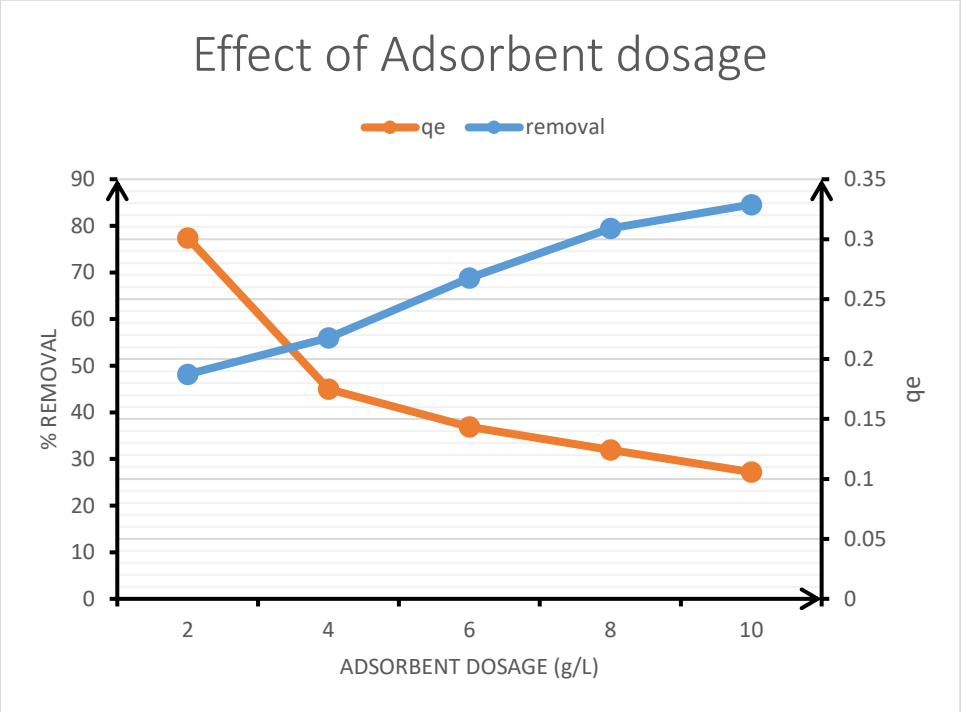

Figure 10 Effect of adsorbent dosage on TMX removal

4.1.8 Solution pH

Optimizing the pH of the adsorbate is relevant in adsorption studies due to its effect on the adsorbent surface charge. Fig 5 below shows that increasing pH from 2 to about 7 increases percentage TMX removal, after which further increase results into a significant decline in percentage removal of TMX. The maximum adsorption capacity (9.5 mg/g) and highest percentage TMX removal (76.1%) was achieved at a pH of 6. The findings obtained in this study are consistent with those reported by (El-Kammah et al., 2022).

initial pH	Absorbance	ce	removal	pH final	Qt
2	0.32	9.385093	62.5	3.7	7.807453
4	0.28	8.142857	67.4	4.5	8.428571
6	0.21	5.968944	76.1	6.3	9.515528
7	0.24	6.900621	72.4	7.2	9.049689
9	0.33	9.695652	61.2	8.4	7.652174
11	0.54	16.21739	35.1	10.2	4.391304

Table 6 Effect of initial pH on TMX adsorption

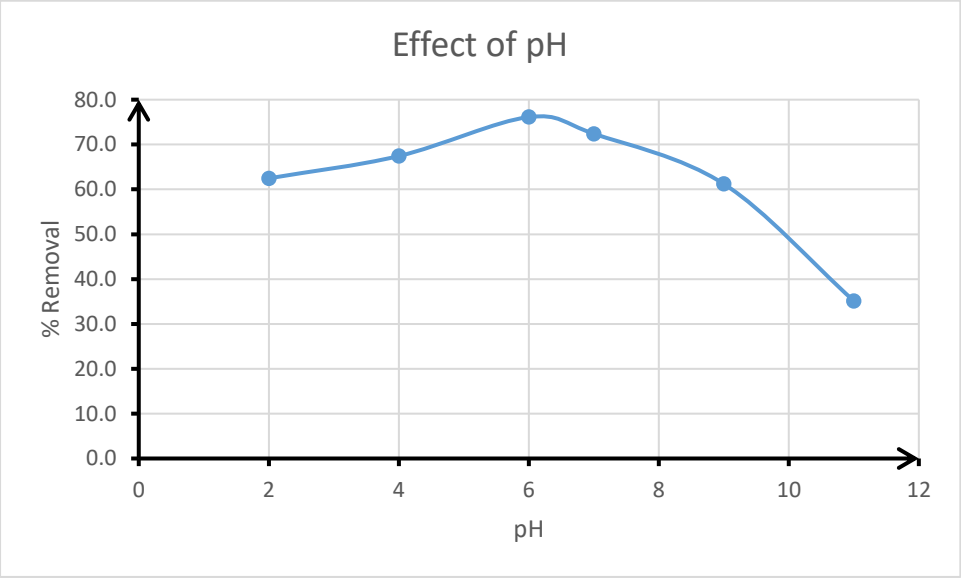

Figure 11 Effect of solution pH on TMX removal

4.1.9 Initial TMX Concentration effect

The effect of initial TMX concentration in aqueous solution in the range 5 to 30 mg/L was studied at room temperature using 0.1g of RSAC and optimising other conditions. Fig 6 below shows that increasing the initial TMX concentration from 5 to 30 mg/L reduces percentage TMX removal from 74.97% to 40% and increases the adsorption capacity from 0.37mg/g to 1.20 mg/g. This is because increasing the TMX concentration initially increases the adsorption capacity (qe), but as the process progresses, the excess amount of adsorbate is faced with a limited number of active sites available on the sorbent surface. Percentage removal decreased as initial Thiamethoxam concentration increased because adsorption sites became progressively saturated. Similar studies were reported by (El-Kammah et al., 2022).

initial concentration	abs	ce	removal	qe	ce/qe	log ce	log qe	ln qe	ln Ce
5	0.058	1.2516	74.9689	1.874224	0.667771	0.097449	0.272821	0.628194	0.224385
10	0.13	3.4845	65.1553	3.257764	1.06959	0.542137	0.51292	1.181041	1.248317
15	0.211	6	60	4.5	1.333333	0.778151	0.653213	1.504077	1.791759
20	0.326	9.5714	52.1429	5.214286	1.835616	0.980977	0.717195	1.651402	2.258782
25	0.453	13.5	46	5.75	2.347826	1.130334	0.759668	1.7492	2.60269
30	0.597	18	40	6	3	1.255273	0.778151	1.791759	2.890372

Table 7 Effect of initial TMX concentration

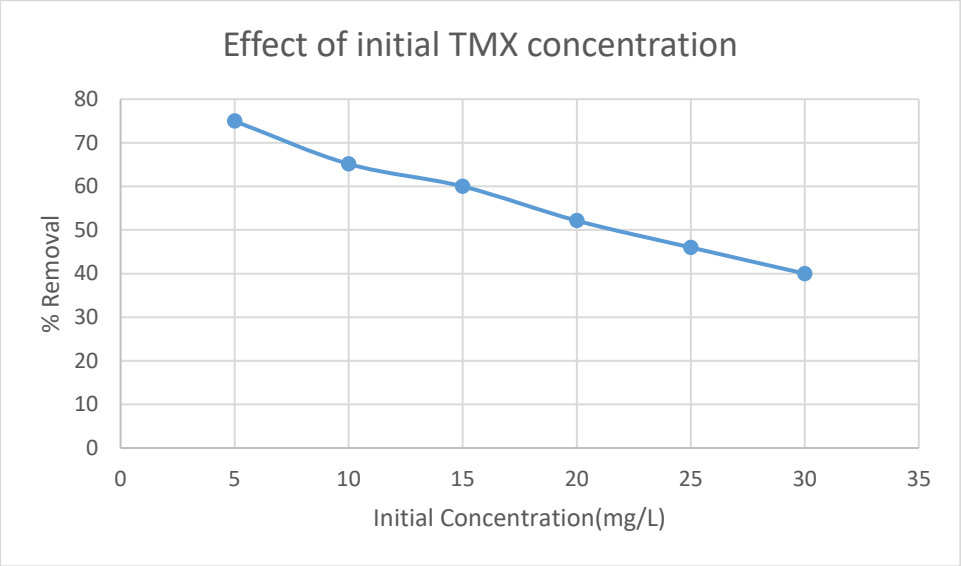

Figure 12 Effect of initial TMX Concentration on TMX Removal

4.2 Kinetic Models

4.2.1 Pseudo First Order Kinetic Model

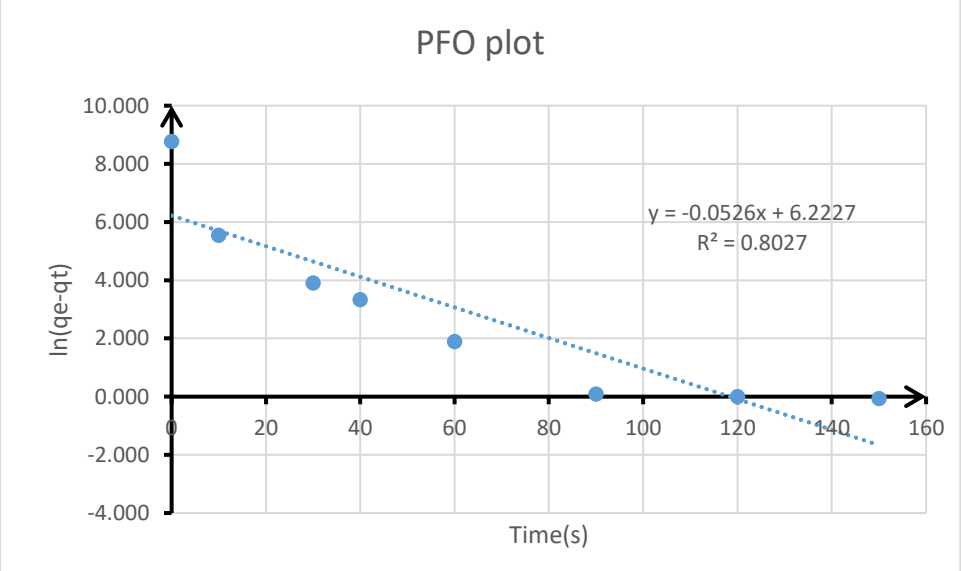

Figure 13 Pseudo First Order plot

4.2.2 Pseudo Second Order Kinetic Model

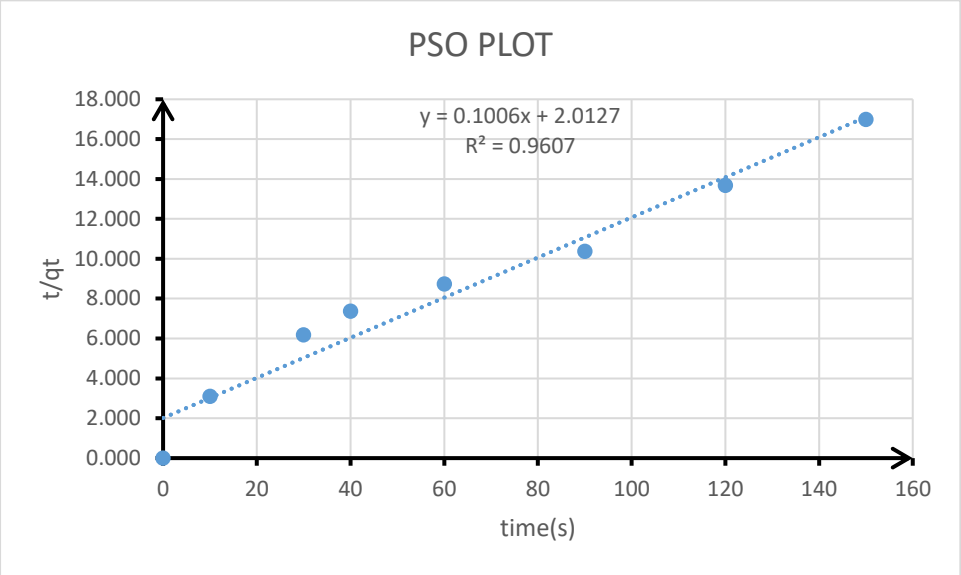

Figure 14 Pseudo Second order plot

4.3 Adsorption isotherms

The adsorption behaviour of TMX on RSAC was examined using the Freundlich and Langmuir isotherm models. The Langmuir adsorption isotherm model provided a best fit (R^2=0.9983) compared to Freundlich model (R^2=0.9714).This indicates that adsorption of TMX on RSAC predominantly occurs as a monolayer on a relatively homogeneous surface. The maximum monolayer adsorption capacity (qm) was determined to be 7.337 mg/g, with a Langmuir constant (KL) of 0.2561 L/mg suggesting favourable adsorption. The Freundlich constant Kf was 1.8172 mL/g, and the heterogeneity factor (1/n) was 0.4468, and n was 2.2381 which is greater than one, thus the adsorption process was favourable that is there were more sites available for the adsorption.

Adsorption Isotherm	Description	Parameters	RSAC
Freundlich, $q_e = \mathrm{K}_f C_e^{\frac{1}{n}}$	K_f = Freundlich constant n=constant(intensity of analyte sorption) qe=equilibrium constant	K_f (mL/g) 1/n(slope) n R^2	1.817189 0.4468 2.238138 0.9714
Langmuir $\frac{C_e}{q_e} = \frac{1}{K_L q_m} + \frac{C_e}{q_m}$	q_m = maximum adsorption capacity K_L = Langmuir Constant(free energy of adsorption)	q_m (mg/g) K_L (L/mg) R^2	7.337 0.2561 0.9983

Table 8 Adsorption isotherm models and parameters for TMX Adsorption onto RSAC

4.3.1 Freundlich Adsorption Isotherm

The Freundlich model assumes a heterogeneous surface with varying energy sites indicating multilayer adsorption.

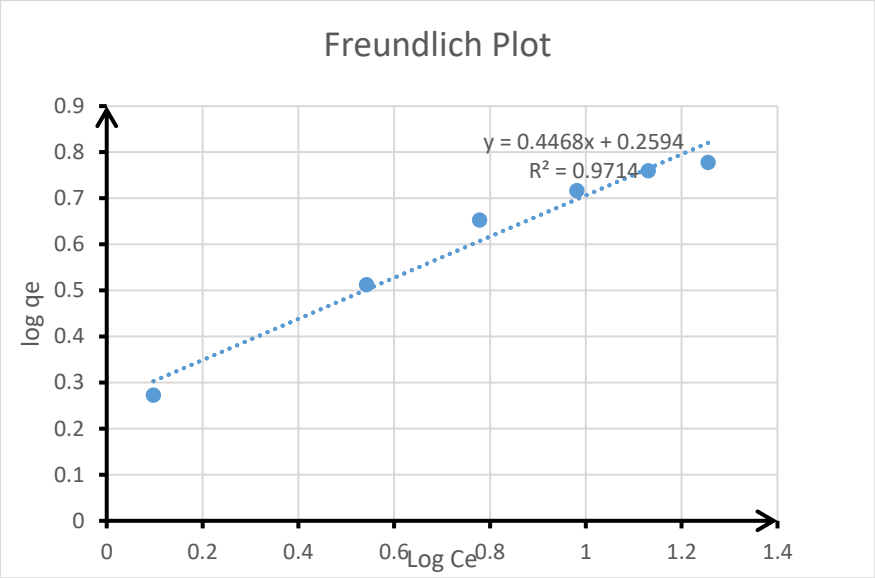

Figure 15 Freundlich Adsorption Isotherm plot

4.3.2 Langmuir Adsorption Isotherm

The Langmuir adsorption isotherm indicates that the adsorption of TMX on RSAC is primarily monolayer, occurring on a homogenous surface where each active site is occupied by a single analyte molecule.

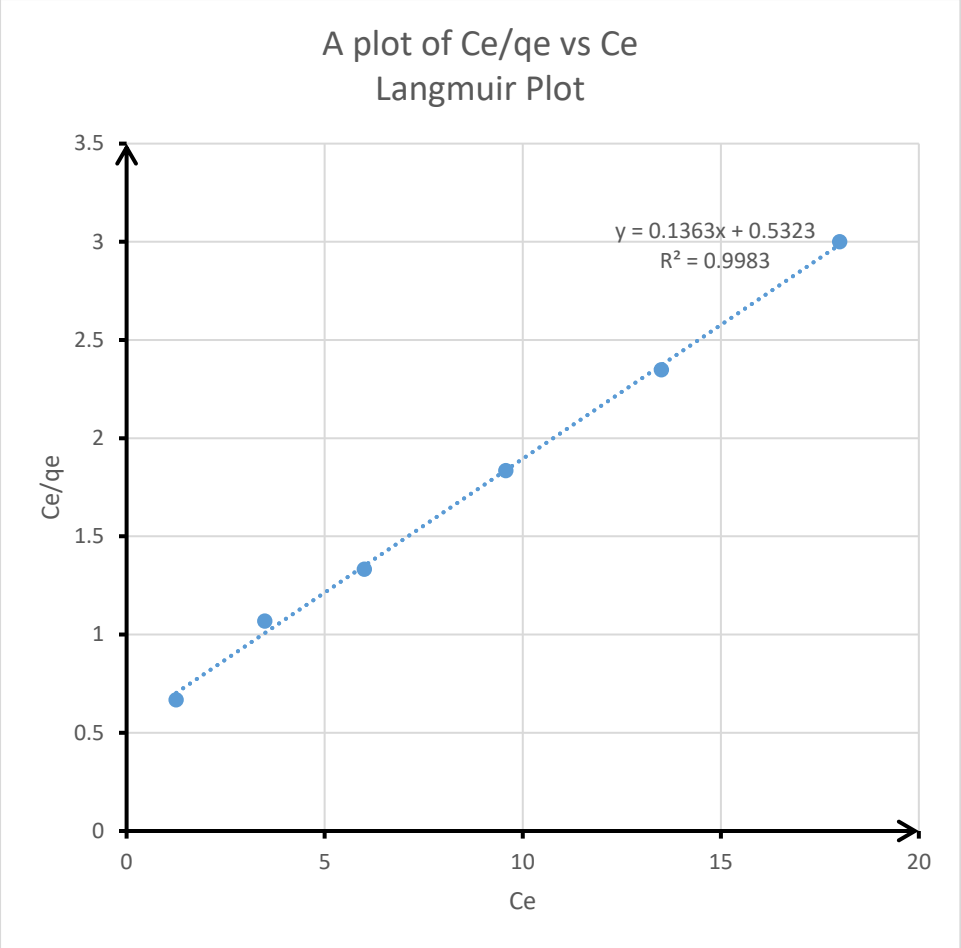

Figure 16 Langmuir Adsorption Isotherm plot

4.4 Discussion of Results

4.4.1 Proposed Mechanism for TMX adsorption on RSAC

The FTIR characterization of RSAC showed presence of O-H, C-O, C=S functional groups that might have facilitated the reactivity of TMX with RSAC. The O-H groups on RSAC may act as H acceptor and the strongly electronegative Nitrogen or oxygen atoms possessing lone pairs of electrons of TMX pesticide act as hydrogen donor forming Hydrogen bonds. Electrostatic interactions, the pH of the surrounding solution played a significant role in the electrostatic interactions. At acidic pH, there is protonation of the OH groups on the RSAC surface.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATION

5. Conclusion

RSAC was produced and evaluated for TMX removal from aqueous solutions. The RSAC showed significant potential for the removal of TMX from aqueous solutions. The optimum conditions for adsorption were a pH of 6, a contact time of 120 minutes and adsorbent dosage of 0.5 g of RSAC. Removal efficiency increased with increasing adsorbent dosage due to increased surface area and availability of adsorption sites.

Langmuir adsorption isotherm was the best isotherm model to fit TMX adsorption process with a maximum adsorption capacity qmax of 7.337 mg/g. The PSO was a best fit for TMX removal. The efficiency of RSAC for TMX removal from aqueous solutions can is attributed to hydrogen bonding and strong electrostatic interactions. This study shows the potential of RSAC for effective remediation of TMX from wastewater.

5.1 Recommendations

5.1.1 Utilization of RSAC for water treatment

RSAC demonstrated a good potential for the removal of TMX from aqueous solutions, therefore its recommended as a low cost environment friendly adsorbent for treatment of pesticide contaminated water particularly in Eastern Uganda where Rice Straws are readily available.

5.1.2 Thiamethoxam Removal from Real water Effluent

Since this was a laboratory model, further research should be carried out in real wastewater effluents.

5.1.3 Optimization of operating conditions

Water treatment systems should employ RSAC in water treatment and operate under the optimum conditions established in this study to maximize pesticide removal efficiency.

5.1.4 Integration with other wastewater treatment methods

Adsorption of organic pollutants like TMX on RSAC should be combined with other water treatment methods such as Advanced Oxidation Process, membrane filtration to enhance overall pesticide removal efficiency.

5.2 Areas for further research

5.2.1 Regeneration and Reusability of RSAC on TMX removal

Future studies should assess the regeneration potential and reuse cycles of RSAC to determine its long term economic and practical viability in water treatment applications.

5.2.2 Adsorption of other pesticides on RSAC

Further studies should evaluate the effectiveness of RSAC in removing other class of pesticides from water sources.

5.2.3 Column Adsorption Studies

Since this study was conducted using Batch Adsorption experiments, future studies should focus on continuous flow column systems that more closely resemble real world water treatment processes.

5.2.4 Effect of Co-existing pollutants

Additional studies should examine how the presence of competing pollutants such as heavy metals, organic matter and other agrochemicals influence the adsorption performance of RSAC.

5.2.5 Advanced Surface Characterization

Further Characterization using advanced analytical techniques such as BET surface area analysis, X-ray diffraction (XRD) to provide a deeper understanding of the adsorption mechanism.

5.2.6 Investigation of Thermodynamic parameters

Detailed thermodynamic studies should be carried out over a wide range of temperatures to determine whether adsorption of TMX on RSAC is a spontaneous or Non Spontaneous process.

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