UNIZIK JOURNAL OF ENGINEERING AND APPLIED SCIENCES (UJEAS)

Research Article

Kinetic Analysis and Adsorptive Efficiency in Ciprofloxacin Removal from Pharmaceutical Waste-water using an Effective Adsorbent

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Special Issue

A Themed Issue in Honour of Professor Onukwuli Okechukwu Dominic (FAS).

This special issue is dedicated to Professor Onukwuli Okechukwu Dominic (FAS), marking his retirement and celebrating a remarkable career. His legacy of exemplary scholarship, mentorship, and commitment to advancing knowledge is commemorated in this collection of works.

Edited by
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UNIZIK JOURNAL OF ENGINEERING AND APPLIED SCIENCES

UNIZIK Journal of Engineering and Applied Sciences 4(1), March (2025), 1474-1485
Journal homepage: https://journals.unizik.edu.ng/index.php/ujeas
PRINT ISSN: 2992-4383 || ONLINE ISSN: 2992-4391

Kinetic Analysis and Adsorptive Efficiency in Ciprofloxacin Removal from Pharmaceutical Waste-water using an Effective Adsorbent

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ABSTRACT

This work exploits palm tree trunk (PTT), an agricultural byproduct, as an efficient adsorbent to remove Ciprofloxacin (CIP) chemicals from pharmaceutical wastewater. The batch adsorption procedure was used to examine the effects of parameters on the adsorption rate, including contact duration, adsorbent dosage, temperature, concentration, and pH. The sorption potential of palm tree trunks was investigated further using studies on adsorption kinetics, thermodynamics, and isotherms. At an ideal pH of 4, the percentage of CIP removed by PTT was 90.94 %. Ciprofloxacin adsorption on the same adsorbent improved as the concentration of ciprofloxacin in wastewater reduced, the solution pH increased to 7, and the solution temperature rose to 50° C. The Freundlich, Temkin, and Langmuir isotherm models examined the equilibrium data. The maximum adsorption capacity value for PTT was 3.571 mg/g, according to the result of R^2 values, which showed a strong fit for the Langmuir model. The pseudo-second-order kinetic model provided the best explanation for the adsorption process. The results of the calculations of thermodynamic variables, such as ΔH, ΔG, and ΔS, at the ideal temperature of 40 ^{0}C were -6.022 KJ/mol, -2617.64 KJ/mol, and 3.495206 J/molK, respectively, confirming the adsorptive process's feasibility and exothermicity. Enthalpy was less than 84 KJ/mol. According to the results, PTT was an efficient adsorbent for eliminating CIP, and its adsorption capacity rose with temperature.

Keywords: Palm tree trunk; Adsorption; Ciprofloxacin; Kinetics models; Isotherms models

1. Introduction

One of the most important sectors of the world economy, the pharmaceutical manufacturing business, is frequently linked to environmental pollution. There are serious environmental dangers due to the increasing industrial pollution in Nigeria (Edo et al., 2024). Because of the inappropriate treatment and disposal of industrial waste, the pharmaceutical industry is one of the main causes of water contamination. The demise of numerous plant and animal species may result from this contamination's disruption of the ecosystem's delicate balance. (Bashir et al., 2020).

Particularly significant pollutants in wastewater from pharmaceutical businesses include antibiotics like ciprofloxacin, which are widely utilized in a variety of industries, including medicine and agriculture. (Mithuna and others, 2024). Antibiotics destroy or stop the growth of germs by interfering with vital biological functions. Antibiotic-resistant bacteria are a serious hazard to public health because of the extensive use of antibiotics. (Hossain et al., 2022)

The persistence and extensive effects of ciprofloxacin in aquatic habitats make it a dangerous pollutant (Barathe et al., 2024). Pharmaceutical wastewater has been shown to contain a number of antibiotics, including tetracycline, erythromycin, fluoroquinolones (such as ciprofloxacin), and others that are harmful to aquatic ecosystems and human health (Chu et al., 2020 and Zhang et al., 2019).

Because they are improperly disposed of, fluoroquinolones (FQs), a family of antibiotics commonly used to treat urinary infections, have been found in the natural environment, contributing to water pollution and bacterial resistance. A typical FQ used to treat a variety of illnesses and to encourage animal growth is ciprofloxacin (CIP). (Chen et al., 2024). The longevity of CIP and its resistance to microbial degradation make its release into water sources potentially harmful to ecosystems (Xiang et al., 2020a; Yang et al., 2020).

Wastewater polluted with antibiotics can be treated using a variety of techniques, such as advanced oxidation processes, membrane filtration, adsorption, chemical oxidation, biological treatment, and ozonation. Adsorption has become a popular and effective technique among these because of its high efficacy in getting rid of antibiotics, cost-effectiveness, ease of use, and effectiveness in removing contaminants (Wang et al., 2020; Zhao and Zhou, 2019).

Because of its aromatic structure and oxygen-containing functional groups, lignin, a naturally occurring polymer found in large quantities in plant cell walls, has demonstrated potential as an adsorbent for organic pollutants (Supanchaiyamat et al., 2019). While lignin-based adsorbents have shown promise, more study is needed to better understand their selective adsorption ability and the underlying mechanisms linked with their structural characteristics. (Fattahi et al., 2024)

One of the main agricultural wastes produced by palm trees is the palm tree trunk (PTT). It's economic worth and contributions are still undervalued despite its many uses (Yang et al., 2020). With about 2,600 species and a propensity to flourish in hot regions, PTT output is significant worldwide. The physical composition of the palm tree at the time of fall yields an impressive 41.07% of the dry trunk (Da Silva et al., 2020).

To use lignin as an adsorbent to remove ciprofloxacin from pharmaceutical Wastewater, lignin was isolated from palm tree trunks using a lignin extraction process. The impacts of several variables, such as pH, adsorbent dosage, starting ciprofloxacin concentration, and adsorption temperature, were assessed by batch studies. The best adsorption conditions were identified, and thermodynamic analyses were carried out to learn more about the adsorption procedure. To find the models that best explained the experimental data and the interactions between the adsorbent and the adsorbate, a variety of kinetic models (pseudo-first-order, pseudo-second-order, and Elovich) and adsorption isotherms (Langmuir, Temkin, and Freundlich) were also examined.

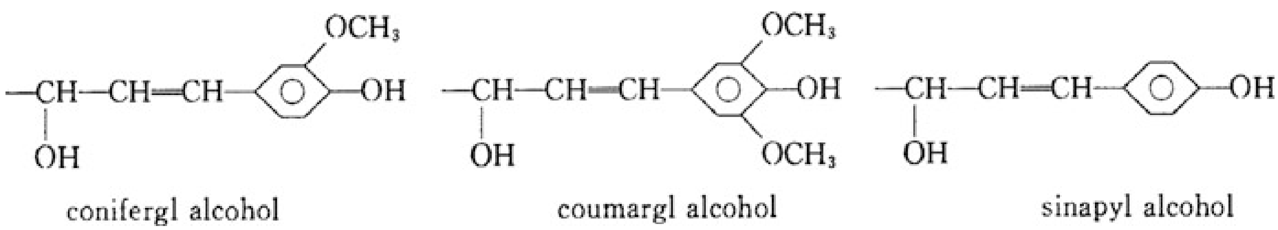

Fig. 1. Basic structural unit of lignin

2.0 Materials and Methods

2.1 Adsorbent

The trunks of palm trees were sourced from a farm located in Eziowelle, Anambra state Idemili North Local Government Area. Using a cutlass, the raw material was cut to about 1 cm in length. It was then cleaned with deionized water to get rid of any remaining dirt, and it was sun-dried for 30 days until its dry weight was constant. The primary purpose of this initial reduction in particle size is to make the sun-drying process easier. To get the dried biomass to pass through the BS 40-mesh (425 μm) sieve and stay on the BS 60-mesh (250 μm) screen, it was next ground into a powder using a mechanical grinder. Following lignin extraction, the ground palm tree trunk biomass (PTTB) samples were kept apart in an airtight polyethylene bag.

2.1.1 Lignin Extraction Protocol

2.2.2. Formic Acid/Acetic Acid Treatment

The initial step in the process of extracting lignin from palm tree trunk biomass was pulping, which involved chopping the biomass into tiny pieces and putting them in a conical flask. The biomass in the flask was mixed with 85% organic acid (the ratio of formic acid to acetic acid was 70:30 by volume) at a fiber-to-liquor ratio of 1:8 (w/v), and it was then brought to a boil on a hot plate for two hours. The flask and its contents were let to cool to room temperature after two hours. After being filtered through a muslin cloth, the fibers were cleaned with hot distilled water and 80% formic acid

2.2.3. Peroxyformic Acid/Peroxyacetic Acid (PFA/PAA) Treatment

Following pulping, pulps treated with formic acid/acetic acid (FA/AA) were further de-lignified by subjecting them to a PFA/PAA solution mixture for two hours at 80°C in a hot water bath. 8ml of 35% H2O2 was added to an 85% formic acid/acetic acid mixture to create the PFA/PAA solution mixture. The de-lignified fibers were then rinsed with hot water after being filtered to remove cooking liquor, which is a mixture of lignin and hemicellulose with formic acid, from cellulose.

2.2.4. Bleaching

The de-lignified fibers were bleached by immersing them in a hot water bath at 8 °C for two hours with 14 ml of a 35% H_2O_2 solution (pH 11–12). To get rid of any remaining lignin, the pulp was lastly cleaned with distilled water. To get rid of all the lignin, this procedure was repeated.

2.2.5. Isolation of Lignin

We separated lignin by using the method recommended by (Nuruddin et al., 2019). 105°C was used to heat the spent liquor following the pulping and de-lignification procedure. By adding distilled water five times the volume of concentrated liquor, the lignin dissolved in formic acid was precipitated, and the resulting mixture was filtered through a muslin cloth. Following the precipitation, distilled water was used to wash the lignin. After being oven-dried, the lignin is crushed with a machine. The adsorbents' particle sizes were determined by sieving them using a Particle Size Distribution Analyzer (Model 117.08, MALVERN Instrument, USA). To investigate the effects of adsorbent dosage, contact time, pH, starting concentration, temperature, and other variables on ciprofloxacin uptake from pharmaceutical wastewater, several batch tests were carried out. The wastewater used in these investigations was made from a stock solution with varying doses of ciprofloxacin, labeled, and kept apart in glass-stoppered conical flasks. An adsorbent with a consistent particle size of 150 µm was then added to the wastewater in the proper dosages. The system was set up on a hot plate and, using a magnetic stirrer, it was continually and steadily stirred at different temperatures and contact times. After allowing the suspension to cool, filter paper was used to filter it. The content of ciprofloxacin in the treated wastewater was ascertained by analyzing the filtrate with a UV spectrophotometer. Utilizing a UV-VIS spectrophotometer set at 270 nm, the absorbance of the liquid samples was determined. Equations 1 and 2 were utilized to determine the amount of ciprofloxacin adsorbed at equilibrium and at a particular period. Equation 3 was utilized to ascertain the proportion of ciprofloxacin that was eliminated from the pharmaceutical wastewater.

$$q_e = \frac{(c_o - c_e)v}{w} \quad (1)$$

$$q_t = \frac{(c_o - c_t)v}{w} \quad (2)$$

$$RE\ (\%) = \frac{(c_o - c_t)v}{c_0} \times 100 \quad (3)$$

where qe is the adsorbent's equilibrium adsorption capability, expressed in mg/g: The adsorption capacity at time, t (mg/g), is denoted by qt: C0 represents the initial concentration of ciprofloxacin in the solution (mg/l); Ce represents the final or equilibrium concentration of ciprofloxacin in the solution (mg/l); Ct represents the quantity of ciprofloxacin adsorbed at time t (mg/l); V represents the solution's volume (1); and W represents the adsorbent's weight (g).

3.0 Results and Discussion

The findings from the aforementioned research have been examined and supported by the following reliable explanations:

Table 1: Characterization result of Palm tree trunk (PTT)

Parameters	Palm tree trunk (PTT)
Moisture Content (%)	4.0
Ash Content (%)	6.9
Cellulose Content (%)	1.02
Hemi-Cellulose (%)	12.74
Lignin Content (%)	86.24

3.1 Batch Adsorption

3.1.2 Effect of dosage of adsorbent

At a pH of 7 and a temperature of 40°C, the impact of adsorbent dosage on the elimination of ciprofloxacin (CIP) was investigated; the findings are shown in Fig. 2. As shown in Fig. 2, the removal effectiveness of CIP from the solution increased in proportion to the dose of locally generated lignin (PTT) being increased from 1.0g to 2.5 g. For 1.0 g, 1.5 g, 2.0 g, and 2.5 g dosages, the clearance efficiencies at 10 minutes were 16%, 16.9%, 18.3%, and 18.3%, respectively. The elimination efficiencies increased further to 60%, 63%, 67%, and 69% for the same doses at the 60 min equilibrium period.

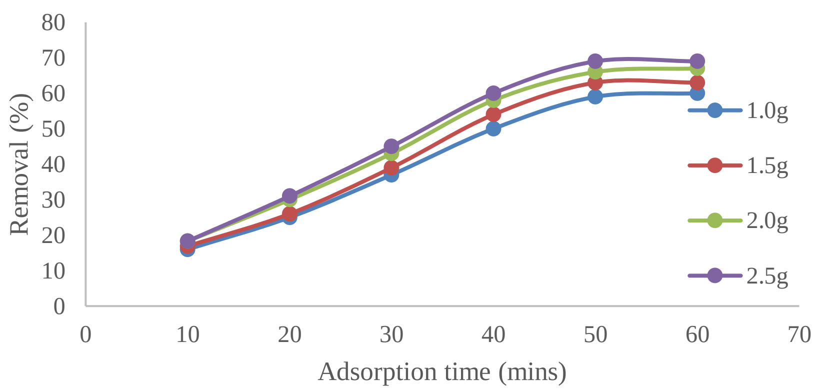

Fig. 2: Effect of dosage of PTT on the adsorption of CIP

3.1.3 Effect of pH on the Adsorption of CIP

As illustrated in Fig. 3, the impact of pH on the adsorbents' adsorptive ability was investigated at a temperature of 40 °C and a dosage of 2.5 g. For CIP utilizing palm tree trunk (PTT), the removal efficiencies at 10 minutes were 16%, 17%, 18%, and 18% for pH values of 4.0, 5.0, 7.0, and 9.0, respectively, as shown in Fig. 3. For the same pH values, the removal efficiencies rose to 48%, 76%, 68%, and 64% at 60 min.

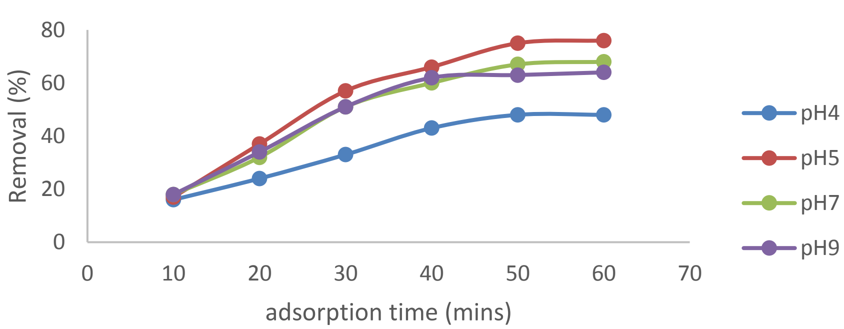

Fig.3: Effect of pH of solution on the adsorption of CIP by PTT

3.1.4 Effect of Temperature on the Adsorption of CIP

Using the palm tree trunk (PTT), the impact of temperature on the adsorptive removal of ciprofloxacin (CIP) from aqueous solution was assessed. For temperatures of 30 °C, 40 °C, 50 °C, and 60 °C, the removal efficiencies at 10 minutes were 16%, 20%, 22%, and 23%, respectively, as shown in Fig. 4. For the same temperatures, the efficiencies climbed to 58%, 70%, 76%, and 68% with an extended adsorption time of 60 minutes. Up until 50 °C, this suggests a considerable increase in removal efficiency; after that, the efficiency decreased.

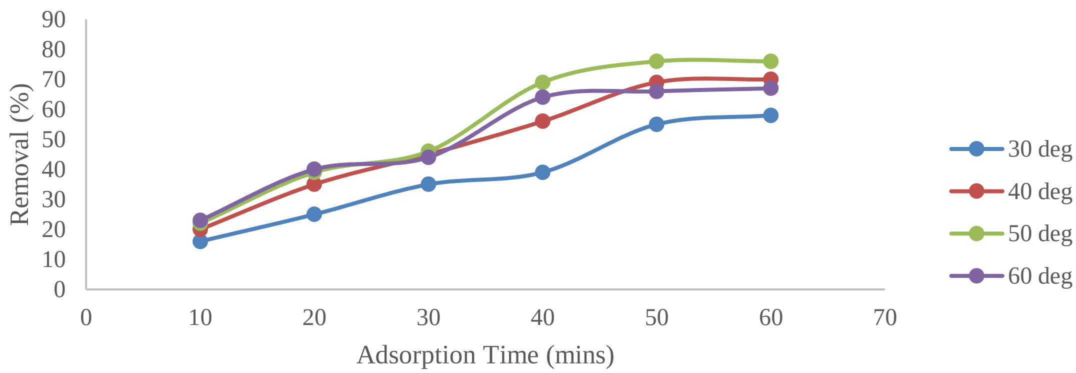

Fig. 4: Effect of temperature of solution on the adsorption of CIP by PTT

3.2 Equilibrium Isotherm Studies

The study investigated the linear versions of the Temkin, Freundlich, and Langmuir isotherm models, offering details on the properties of the adsorption process as well as their applicability. The dimensionless equilibrium parameter, R_L, which represents important characteristics of the Langmuir isotherm, was used to investigate the Langmuir isotherm model. The isotherm's shape is indicated by R_L values, which range from 0 to 1. R_L values in this range indicate advantageous adsorption; values over 1 indicate unfavorable adsorption, 0 indicates irreversible adsorption, and 1 indicates linear adsorption (Singh et al., 2023). The outcome showed that PTT had good adsorption with a R_L value of 0.991. In addition, the study based on R^2 values showed that the Freundlich isotherm 0.994 and Langmuir 0.978 for PTT models fit the experimental data well, which is in line with results published by Brasil et al. (2020). According to Alotaibi et al. (2024), the parameter 1/n in the framework of the Freundlich isotherm model represents the process's heterogeneity and adsorption strength. The parameter 'n' specifies the kind of adsorption, whereas lower 1/n values suggest greater anticipated variability. Indicating adsorption capacity, the Freundlich constant (k_f) showed values for CIP adsorption on PTT in (Table 2). Notably, the PTT adsorbent showed 'n' values greater than 1, indicating that adsorption is physical.

In terms of the Temkin isotherm model, the maximal binding energy (L mg/l) is represented by the binding constant (A_T). The correlation coefficient (R^2) values were used to assess the applicability of isotherm equations. Among all the models examined, the Langmuir and Freundlich isotherm models had the highest correlation coefficient, proving to be the most effective for explaining CIP adsorption onto PTT. According to this finding, the majority of the adsorption took place as a monolayer of CIP adsorbed onto a uniform adsorbent surface (Lu et al., 2020; El-Aswar et al., 2024).

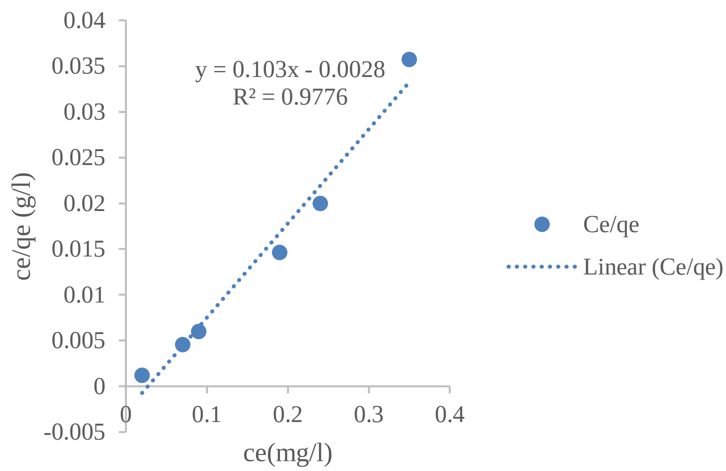

Fig.5: Linearized isotherm plot for adsorption of CIP on PTT

Table 2. Equilibrium Isotherm Parameters of CIP Adsorption

Model	**Parameter**	**Value**
	q_m	3.571
	K_L	0.0272
	R_L	0.991
Langmuir	R^2	0.978
	N	1.484
	K_f	3.438
Freundlich	R^2	0.994
	b_T	6360.904
	a_T	2948.23
Tempkin	R^2	0.855

4.4 Kinetic Studies of CIP Adsorption

It is essential to comprehend the chemical kinetics of an adsorption system to calculate reaction rate constants and gauge the rate of the reaction. We can describe adsorption mechanisms by using kinetic models. Three kinetic models were used in this investigation to examine the sorption kinetics of CIP on PTT and interpret experimental data: pseudo-first-order, pseudo-second-order, and the Elovich model. The Elovich model makes a distinction between chemisorption and physical adsorption, (Singh et al., 2024) whereas the pseudo-first and pseudo-second-order models presume that the adsorption process is pseudo-chemical (Grassi et al., 2024).

The pseudo-first-order, pseudo-second-order and Elovich kinetic models' results are shown in Table 3 after R^2 analysis and a summary of the constants and R^2 values derived from the linear plots. It is noteworthy that the pseudo-second-order kinetic model has a comparatively better R^2 value than the Elovich and pseudo-first-order models. The pseudo-second-order model's high R^2 value suggests that it accurately describes the adsorption process of CIP uptake on EMIB, CMC, and NHC. This discovery demonstrates how well the pseudo-second-order kinetic model captures the kinetics of CIP adsorption onto the corresponding adsorbents.

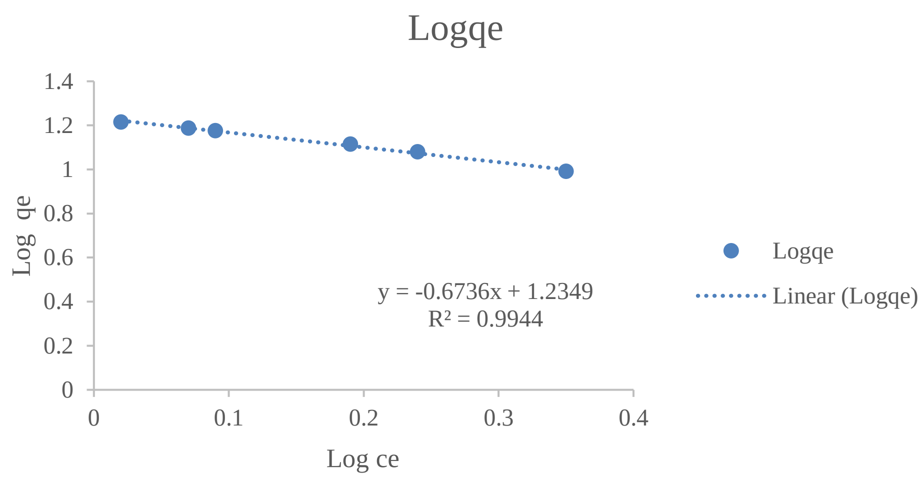

Fig: 6 Linearized kinetic plots for adsorption of CIP on PTT

Table 3: Kinetic Parameters of CIP Adsorption

Kinetic Model	**Parameter**		**PTT**
PFO		K_1	172.865
		q_e	5.018
	R^2		0.57
PSO		K_2	0.0019
		q_e	0.838
	R^2		0.731
Elovich		α	7.272
		β	2.34E 11
	R^2		0.827

4.5 Thermodynamics of CIP Adsorption

Standard enthalpy (ΔH), standard entropy (ΔS), and standard free energy (ΔG) are essential thermodynamic characteristics that are used to evaluate the spontaneity and viability of adsorption processes (Yap et al., 2024) (Toghan et al., 2023). An examination of the data in Table 4.4 shows that for all adsorbents, the ΔG values become more negative as the temperature rises. This pattern indicates the feasibility and spontaneity of the adsorption processes (Zhou et al., 2020). Additionally, the uniformity in ΔG values for all adsorbents at a certain temperature suggests that the adsorption process' spontaneity is constant at various temperatures (El-Bindary et al., 2022). In addition, Table 4 shows that the ΔS values were always positive and did not change with temperature. This positive entropy change indicates weak interactions between CIP and the adsorbent (PTT) and an increase in the randomness or degree of freedom of the adsorbed species. Additionally, the constant positive ΔS values show that the system tends toward greater disorder, suggesting that entropy is probably driving the adsorption process. The adsorption process is exothermic, as indicated by the negative values of the enthalpy change (ΔH). Physical adsorption processes are characterized by ΔH values below 84 kJ/mol, which the adsorbent exhibited (Wei et al., 2022). Instead of stronger chemical bonds, this lower range of ΔH indicates that weak van der Waals forces are involved in the adsorption of CIP onto PTT. The thermodynamic analysis thus indicates the efficiency and spontaneity of CIP adsorption on PTT. The exothermic nature of the process, as displayed by negative ΔH values, further supports the physical interaction between CIP and the adsorbent. The results present important insights into the thermodynamic mechanisms governing CIP adsorption and highlight the potential of PTT as an efficient adsorbent in wastewater treatment applications. The negative ΔG values confirm the feasibility and spontaneity of the process, while the positive ΔS values indicate an increase in disorder at the solid-liquid interface, indicating physical adsorption. The entire adsorption process was therefore exothermic. The results made in this investigation were supported by similar findings published by Ali et al. (2022), Sellaoui et al. (2023), and M et al. (2018).

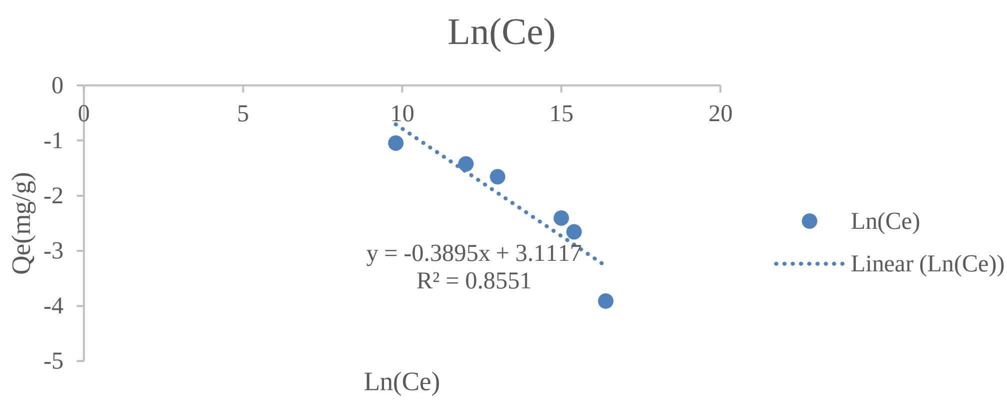

Fig: 7 Linearized thermodynamics plot for adsorption of CIP on PTT

Table 4: Thermodynamic Parameters of CIP adsorption

Adsorbent	Temp. (K)	ΔG (KJ/mol)	ΔH(KJ/mol)	ΔS(J/molK)
	303	-2591.31		
PTT	313	-2617.64	-6.022	3.495206
	323	-2675.29		
	333	-2677.82		

4.6 Practical Application and Potential Scalability

4.6.1 Practical Applications

Pharmaceutical Industry: Wastewater Treatment: Pharmaceutical manufacturing generates significant volumes of wastewater containing various chemicals, including antibiotics like ciprofloxacin. Implementing PTT-based adsorption systems within existing wastewater treatment plants can significantly enhance the removal efficiency of these contaminants. This not only minimizes environmental pollution but also ensures compliance with increasingly stringent environmental regulations.

Process Optimization: By integrating PTT-based adsorption into specific stages of the pharmaceutical manufacturing process, such as intermediate cleaning or final product purification, the release of antibiotic residues can be minimized at the source.

Sustainable Production: Adopting PTT-based technology aligns with the growing emphasis on sustainable manufacturing practices within the pharmaceutical industry. It demonstrates a commitment to environmental responsibility and can enhance the company's environmental image.

Agricultural Sector: Livestock Waste Management: In intensive livestock farming, antibiotics are often used for disease prevention and growth promotion. This leads to the release of antibiotics into animal waste, which can contaminate surrounding soils and water bodies. PTT-based adsorption systems can be integrated into livestock waste management systems to effectively remove antibiotics from manure and wastewater before it enters the environment.

Protecting Water Resources: By preventing antibiotic contamination of agricultural runoff, PTT-based technology can help protect vital water resources such as rivers, lakes, and groundwater. This is crucial for maintaining the

ecological health of aquatic ecosystems and ensuring the availability of clean water for human consumption and agricultural use.
Improving Food Safety: Reducing antibiotic contamination in agricultural environments can help mitigate the risk of antibiotic-resistant bacteria entering the food chain. This is essential for ensuring food safety and protecting public health.
Domestic Wastewater Treatment:
On-site Treatment: In rural areas and developing countries, access to centralized wastewater treatment plants may be limited. PTT-based adsorption systems can be implemented as on-site treatment units for individual households or communities. These systems can be designed to be compact, easy to operate, and affordable, making them accessible to a wide range of users.
Decentralized Treatment: This decentralized approach can improve wastewater treatment efficiency and reduce the environmental impact of domestic wastewater in areas where centralized infrastructure is lacking.
Community-Based Solutions: PTT-based technology can empower local communities to take ownership of their wastewater treatment and contribute to environmental protection.
Remediation of Contaminated Sites:
Soil and Sediment Remediation: PTT-based adsorbents can be applied to contaminated soils and sediments to effectively remove ciprofloxacin and other pollutants. This can be particularly useful in remediating sites impacted by historical discharges from pharmaceutical manufacturing plants or accidental spills.
Groundwater Remediation: In cases where groundwater has been contaminated with antibiotics, PTT-based adsorbents can be used in in-situ or ex-situ remediation techniques to remove contaminants from the groundwater.
Environmental Restoration: The remediation of contaminated sites using PTT-based technology can contribute to environmental restoration efforts and help to restore the ecological integrity of impacted areas.

4.6.2 Potential Scalability

Abundant and Renewable Resources.
Sustainable Sourcing: By establishing sustainable sourcing practices for PTT, such as utilizing waste from palm oil processing industries, the environmental impact of adsorbent production can be minimized.
Local Availability: The widespread cultivation of palm trees in many tropical and subtropical regions ensures the availability of PTT as a readily accessible and cost-effective raw material for adsorbent production.

Simple and Cost-Effective Production:
Modular Design: PTT-based adsorbents can be produced using simple and scalable processes, such as drying, grinding, and activation. This allows for the development of modular production units that can be easily adapted to different production scales and locations.
Low-Cost Materials: The use of readily available and inexpensive materials for adsorbent production can significantly reduce the overall cost of the technology.

Modular Design and Flexibility:
Customizable Systems: Adsorption systems can be designed in a modular fashion, allowing for easy customization to suit specific treatment needs and site conditions. This flexibility ensures that the technology can be adapted to a wide range of applications, from small-scale domestic systems to large-scale industrial installations.
Scalability and Adaptability: The modular design allows for easy scaling up or down of the treatment capacity to meet changing demands. This adaptability is crucial for ensuring the long-term sustainability and effectiveness of the technology.

Integration with Existing Infrastructure:
Retrofit Applications: PTT-based adsorption systems can be easily integrated into existing wastewater treatment plants with minimal modifications to existing infrastructure. This minimizes disruption to existing operations and facilitates the rapid adoption of the technology.
Retrofitting Existing Plants: Existing wastewater treatment plants can be retrofitted with PTT-based adsorption units to enhance their treatment capabilities and improve overall treatment efficiency.

Further Research and Development

Optimization of Adsorption Conditions:

Process Variables: Further research should focus on optimizing various process variables, such as pH, temperature, contact time, and adsorbent dosage, to maximize adsorption efficiency and minimize treatment costs.
Influence of Water Quality. The impact of different water quality parameters, such as the presence of other contaminants or dissolved organic matter, on the adsorption performance of PTT should be investigated.

Modification of PTT Biomass:

Chemical Modification. Chemical modifications, such as surface functionalization with various chemical groups, can enhance the adsorption capacity and selectivity of PTT for ciprofloxacin.
Physical Modification: Physical modifications, such as carbonization or activation, can increase the surface area and porosity of PTT, thereby improving its adsorption properties.

Pilot-Scale Studies:

Real-World Performance. Conducting pilot-scale studies in real-world settings, such as pharmaceutical manufacturing plants or wastewater treatment plants, will provide valuable data on the performance, reliability, and cost-effectiveness of PTT-based adsorption systems under actual operating conditions.
*Data Collection and Analysis***.** These studies will allow for the collection of data on key performance indicators, such as treatment efficiency, operating costs, and environmental impact, which can be used to refine the design and optimize the operation of full-scale systems.

Life Cycle Assessment:

Environmental and Economic Sustainability. Conducting a comprehensive life cycle assessment (LCA) of PTT-based adsorption technology will help to evaluate its overall environmental and economic sustainability.
Comparison with Other Technologies. The LCA can be used to compare the environmental and economic impacts of PTT-based adsorption with other conventional wastewater treatment methods, such as activated sludge or membrane filtration.
By addressing these areas through continued research and development, PTT-based adsorption technology can be further refined and optimized, paving the way for its widespread application in addressing the challenge of antibiotic contamination in water bodies.

Conclusion

This study investigated the adsorption potential of palm tree trunk (PTT) biomass as a low-cost and eco-friendly adsorbent for removing ciprofloxacin (CIP) from pharmaceutical wastewater. [1] The results demonstrated that PTT exhibits significant adsorption capacity for CIP, with the optimal removal efficiency achieved at pH 7 and a temperature of 50°C. The maximum adsorption capacity (qmax) of PTT for CIP was determined to be 3.571 mg/g, as calculated from the Langmuir isotherm model, which best fits the experimental data.
Kinetic studies revealed that the adsorption process followed pseudo-second-order kinetics, indicating that chemisorption might be the rate-limiting step. Thermodynamic parameters, including ΔG, ΔH, and ΔS, were calculated, confirming the feasibility, spontaneity, and exothermic nature of the adsorption process. The negative value of ΔG indicated the thermodynamic feasibility of the adsorption process, while the negative value of ΔH confirmed its exothermic nature.
The study demonstrates the potential of PTT as an effective and sustainable adsorbent for the removal of ciprofloxacin from pharmaceutical wastewater. Its availability, low cost, and environmental friendliness make it an attractive alternative to conventional adsorbents. Further research could focus on optimizing the adsorption process by modifying the PTT biomass through chemical or physical treatments to enhance its adsorption capacity and selectivity for ciprofloxacin.

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