

Valorization of Coconut Husk: FeCl₃-activated Biochar for Efficient Nitrate Removal from Simulated Fertilizer Effluent

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Abstract—Nitrate contamination from fertilizer industry effluents poses serious risks to both the environmental and public health. This study investigated the nitrate removal efficiency of coconut husk-derived activated carbon using ferric chloride (FeCl₃) as an activating agent through a batch bioadsorption approach. The effects of adsorbent dosage, contact time, and initial nitrate concentration were evaluated, along with adsorption isotherms and kinetics. Two types of bioadsorbents were tested: Untreated Activated Carbon (UAC) and FeCl₃-treated activated carbon (FeAC), both synthesized from coconut husk. Batch adsorption experiments were conducted using 50 mL of nitrate solution under varying conditions. The average nitrate removal efficiency of FeAC was 86.00%, which was consistently better than UAC. The highest removal of 76.50% was achieved with an optimal dosage of 0.4 g. The maximum removal efficiency for contact time was 92.58% at 120 min, whereas the maximum removal efficiency for initial nitrate concentration was 92.50% at 40 mg/L. Chemisorption was indicated by adsorption kinetics that fit the pseudo-second-order model with R-squared of 0.9926. The Langmuir model, with R-squared of 0.9879, was shown to be the best fit by isotherm analysis, indicating monolayer adsorption behavior.

Keywords—nitrate removal, coconut husk biochar, ferric chloride activation, adsorption, wastewater treatment, sustainable materials

I. INTRODUCTION

Approximately 80% of global wastewater is discharged into the environment without treatment, posing serious risks to ecosystems, public health, and water and food security [1]. This untreated discharge carries harmful contaminants that endanger aquatic biodiversity and undermine climate resilience. In nations such as the Philippines, inadequate sanitation persists due to outdated water management systems, limited infrastructure, and insufficient funding, contributing to widespread waterborne diseases like diarrhea, which claims approximately 505,000 lives annually [2]. Wastewater pollution arises from both point sources, such as direct industrial discharges, and nonpoint sources, including surface runoff carrying fertilizers, oils, and pesticides [3]. Agricultural nutrient runoff, including nitrogen and phosphorus, presents a major threat to water quality and can lead to persistent and multifaceted impacts on ecosystems, environmental stability, and public health [4].

Nitrate is a soluble nitrogen compound formed during nitrification in the nitrogen cycle. Although naturally occurring, excessive nitrate concentrations cause eutrophication, leading to oxygen depletion, aquatic life loss,

and water toxicity. As stated by Ludlow *et al.* [5], high nitrate levels can acutely endanger infants by causing methemoglobinemia or “blue baby syndrome”, a potentially fatal condition characterized by cyanosis, respiratory distress, neurological symptoms, and, in severe cases, coma or death. Despite its health and ecological risks, nitrate remains difficult to remove from water systems due to its high solubility and chemical stability.

Traditional treatment methods such as reverse osmosis, distillation, and ion exchange are effective but often expensive, energy-intensive, and resource-demanding. As a result, adsorption is gaining attention as a simpler and more cost-efficient alternative where contaminants adhere to a solid surface [6]. Activated carbon is one of the most widely used adsorbents for this purpose, owing to its high porosity, large surface area, and effectiveness in removing dissolved organic and inorganic pollutants.

Despite its effectiveness, conventional activated carbon is typically produced from fossil-based sources, making it expensive and less sustainable for large-scale water treatment [7]. Consequently, researchers are investigating agricultural waste materials for activated carbon production, with byproducts such as biochar, lignocellulosic biomass, and coconut husks emerging as promising low-cost and readily available alternatives [8]. In the Philippines, a large amount of coconut husk remains unused. Pogosa *et al.* [9] reported production rates of 0.6 to 1.4 tons per hectare per year, highlighting its potential for reuse. With high lignin and cellulose content, coconut husk is an ideal precursor for producing activated carbon [10]. Repurposing this biomass for water treatment not only provides a sustainable solution to nitrate pollution but also addresses solid waste concerns in the coconut industry.

Panaligan *et al.* [11] pointed out that the properties of activated carbon depend on both the precursor material and the activation method used, whether physical or chemical. The study explains that physical activation typically involves carbonization or pyrolysis, producing activated carbon in forms such as powdered, granular, or pelletized, each with unique adsorption characteristics influenced by the raw material and treatment approach. Ferric chloride, although commonly employed for heavy metal removal, has demonstrated effectiveness in reducing nitrate concentrations through adsorption [12].

In contrast to conventional applications, this study employs ferric chloride to activate coconut husk-based carbon specifically for nitrate adsorption, presenting a novel

approach that extends its utility beyond heavy metal remediation. While ferric chloride has been widely applied in the context of heavy metal removal, there remains a significant research gap in its use for activating biochars aimed at targeting polyatomic anions such as nitrate. Addressing the need for cost-effective and sustainable treatment solutions, the research explores the use of ferric chloride-impregnated activated carbon derived from coconut husks to remove nitrate from simulated fertilizer effluent. The adsorption process investigated in this study is governed by chemisorption, where ferric chloride activation introduces iron-associated surface features that enhance nitrate affinity through strong surface interactions. This biosorbent provides dual benefits by mitigating water pollution and valorizing agricultural waste, aligning with environmental, industrial, and societal priorities.

The study evaluates the effects of adsorbent dosage, contact time, and initial nitrate concentration on removal efficiency and identifies the optimum conditions for nitrate adsorption. It also examines the physicochemical properties of the synthesized activated carbon to assess their influence on the adsorption of polyatomic ions such as nitrates. Supporting the United Nations Sustainable Development Goals, particularly Goal 6 on clean water and sanitation, Goal 12 on responsible consumption and production, and Goal 13 on climate action, this research highlights how renewable agricultural residues can serve as effective adsorbents for sustainable wastewater treatment.

II. LITERATURE REVIEW

Activated carbon is a porous, carbon-rich material extensively utilized in water treatment, wastewater management, air purification, and various industrial applications due to its high surface area and effective adsorptive properties [13]. Beyond industrial use, it also plays a vital role in environmental remediation by enabling the removal and modification of diverse compounds in both liquid and gaseous phases.

The production of activated carbon begins with carbonization, a process that removes volatile components from carbonaceous precursors and initiates the development of a basic pore structure. The choice of raw material significantly influences the resulting microstructure and adsorption performance, as the properties of the precursor directly affect the effectiveness of the final product [14]. During carbonization, thermal decomposition leads to carbon enrichment and the formation of micro- and mesopores essential for adsorption. Ge *et al.* [15] emphasized that carbonization conditions strongly affect volatile release behaviour, which in turn shapes surface morphology and porosity.

Chemical activation, such as using FeCl_3 , is a common method to enhance porosity and surface chemistry in carbonaceous materials, promoting micropore development and controlled pore size distribution [16, 17]. FeCl_3 has recently gained attention as a promising alternative due to its ability to generate well-developed pore structures at relatively low activation temperatures, contributing to a more energy-efficient and sustainable route for producing activated carbons from biomass. FeCl_3 activation is particularly well-suited for cellulose-rich biomass feedstocks such as

coconut husks, wood, rice straw, and corn stover, due to its ability to introduce iron active sites and promote microporous development during pyrolysis. These agricultural residues are renewable, abundant, and low-cost, making them ideal candidates for sustainable activated carbon production.

III. MATERIALS AND METHODS

A. Preparation of Coconut Husk Activated Carbon

Coconut husks were sourced from a local wet market, washed thoroughly with tap water to remove dirt, and sun-dried for two weeks. The dried husks were then cut into smaller pieces using a bolo and scissors. These were subsequently subjected to chemical activation using ferric chloride (FeCl_3) as described by Bedia *et al.* [17]. The chopped coconut husks were placed in a basin, and a 5% FeCl_3 solution was added at an impregnation ratio of 4:1 (w/w), based on the methodology of Abd Rashid *et al.* [18]. The mixture was stirred vigorously for 30 min at room temperature using a ladle, then allowed to soak for 24 hours. After impregnation, the material was stored in resealable plastic bags.

Following impregnation, the material was subjected to pyrolysis. The soaked coconut husk samples were transferred into a crucible and carbonized in a muffle furnace at 700°C for one hour under an inert atmosphere [17]. After carbonization, the resulting activated carbon was ground and sieved to a particle size of 0.063 mm, rendering it suitable for subsequent batch adsorption experiments.

B. Preparation of Simulated Fertilizer Industry Effluent

To simulate fertilizer industry effluent, a nitrate stock solution was prepared using anhydrous potassium nitrate (KNO_3) dissolved in distilled water. KNO_3 of 0.1141 grams were accurately weighed and dissolved in 100 mL of distilled water in a beaker. The solution was then quantitatively transferred into a 1-liter volumetric flask and diluted to the mark with additional distilled water. From this stock, working solutions with concentrations of 40 ppm, 50 ppm, and 60 ppm were subsequently prepared for use in the batch adsorption experiments. All solutions were freshly prepared immediately prior to experimentation to ensure accuracy and consistency.

C. Batch Adsorption Experiments

Batch experiments were first performed using Unmodified Activated Carbon (UAC), followed by ferric chloride-treated activated carbon (FeAC), applying identical procedures and conditions to ensure a reliable analytical comparison of their nitrate adsorption performance. For all trials, 50 mL of nitrate solution was transferred into 150 mL beakers, with initial concentrations verified using a Hanna HI782-25 Marine Nitrate High Range Checker and pH adjusted to 3.0 using 0.1 M HCl or NaOH, as guided by Sadeghi Afjeh *et al.* [19].

In the first set of trials, the adsorbent dosage was varied using 0.2 g, 0.3 g, and 0.4 g of the activated carbon, while keeping the nitrate concentration fixed at 40 mg/L and the contact time constant at 30 min. The solution was stirred at 360 rpm at room temperature, then filtered through 45 nm ashless paper to separate the residual carbon. The resulting filtrate was analyzed using the same nitrate checker, and the used filter paper was discarded in a designated waste

container.

Using the optimal dosage determined from the previous trials (0.4 g), the contact time was then varied to 30, 60, 90, and 120 min, keeping the nitrate concentration at 40 mg/L and the pH at 3.0. This helped identify the contact duration necessary to reach adsorption equilibrium under the same experimental setup and procedure.

Finally, the influence of initial nitrate concentration was examined using 40, 50, 60, and 70 mg/L solutions, while maintaining the previously identified optimal dosage and contact time. The same pH adjustment, stirring conditions, filtration, and measurement protocols were applied. Error bars in the figures represent Standard Error ($\pm$ SE), reflecting variability across replicates and ensuring consistency of results. All tests were conducted in triplicate, and nitrate removal efficiency was calculated using Eq. (1):

$$\text{Removal Efficiency (\%)} = \frac{C_0 - C_e}{C_0} \times 100 \quad (1)$$

where C_0 is the initial and C_e is the final nitrate concentration after treatment.

D. Scanning Electron Microscopy

Scanning Electron Microscopy (SEM) was utilized to examine the surface morphology of the coconut husk- FeCl_3 treated activated carbon before and after the batch experiment. This technique was selected due to its ability to analyze porous surface structures, which are critical for high adsorption capacity. The analysis was conducted by Phenolab of De La Salle University.

IV. RESULT AND DISCUSSION

A. Surface Morphology Analysis

A rough surface with fewer unique pore structures and granulated particles attached to the surface could be observed in the SEM image of the UAC before adsorption (Fig. 1(a)), indicating a lower probability of successful adsorption. In contrast to the pre-adsorption state, the unimpregnated activated carbon showed smoother edges and surfaces during the batch adsorption experiment (Fig. 1(b)). Although the cavities became less rugged, bead-shaped formations that indicate nitrate ion adsorption were still observed. This observation is consistent with the findings of Karthikeyan *et al.* [20], who reported similar bead-like structures on adsorbent surfaces after nitrate sorption.

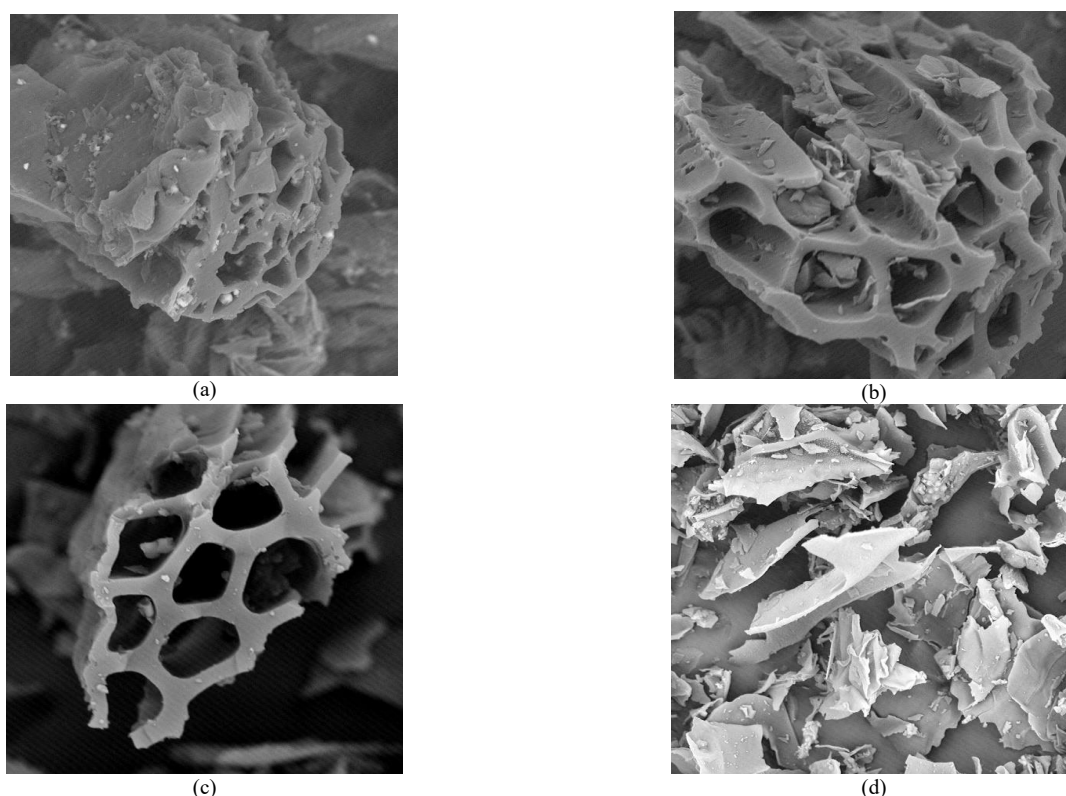


Fig. 1. SEM images of coconut husk activated carbon samples: (a) UAC before batch adsorption experiment; (b) UAC after batch adsorption experiment; (c) FeAC before batch adsorption experiment; (d) FeAC after batch adsorption experiment.

Meanwhile, the FeAC prior to adsorption (Fig. 1(c)) showed a highly porous and hollow surface structure, indicating a high potential for adsorption due to the abundance of accessible pores. The formation of these pores is attributed to the activation process, during which the chemical activator evaporates, leaving an empty framework within the carbon structure [21], consistent with the results observed in this study. After the batch adsorption experiment (Fig. 1(d)), the surface of the FeAC appeared significantly

rougher compared to its pre-adsorption state. This roughening suggests successful adsorption of nitrate ions onto the adsorbent surface. Similar findings were reported by Boujelben *et al.* [22], who observed increased surface roughness in their iron-coated sorbents following phosphorus removal, supporting the current result that associates rougher surfaces with successful ion adsorption. Moreover, the same image shows that nitrate ions have effectively occupied the cavities, pores, and surface structures of the

FeCl_3 -treated activated carbon, corroborating the findings of Kavand *et al.* [23], who similarly reported substantial pore coverage after ion adsorption. Although surface morphology differences were visually confirmed via SEM, we acknowledge that BET surface area analysis would have provided more quantitative insight.

B. Batch Adsorption

1) Effect of adsorbent dosage

The effect of adsorbent dosage on nitrate removal efficiency was first evaluated using UAC. The nitrate removal increased with higher dosages, with the 0.4 g dosage achieving the highest average removal efficiency at 55.75%, followed by 33.08% for 0.3 g and 12.00% for 0.2 g. However, the overall removal efficiency remained modest, suggesting limited availability of active sites due to the lack of chemical activation.

In comparison, FeAC exhibited significantly higher removal efficiencies across all dosages. The highest average nitrate removal was observed at 0.4 g (76.50%), with 66.25% at 0.3 g and 33.08% at 0.2 g.

In line with the findings of Battas *et al.* [24], who noted that higher adsorbent dosages increase the number of active sites for contaminant removal, the increase in removal effectiveness with increased adsorbent dosage is ascribed to the larger number of accessible adsorption sites. Fig. 2 illustrates the trends in nitrate removal efficiency for both UAC and FeAC as a function of adsorbent dosage.

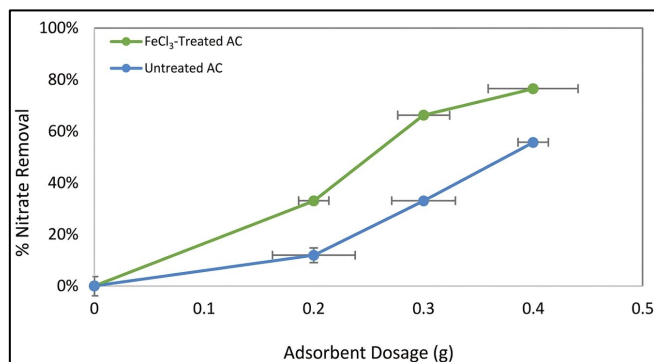


Fig. 2. Effect of adsorbent dosage on nitrate removal efficiency using FeAC and UAC. Conditions: Initial nitrate concentration = 40 mg/L, pH = 3.0, room temperature ($28 \pm 1^\circ\text{C}$), contact time = 30 min, adsorbent dosage = 0.2 g, 0.3 g, 0.4 g.

2) Effect of contact time

As illustrated in Fig. 3, contact time had a significant influence on nitrate removal efficiency for both UAC and FeAC. The removal efficiency for UAC peaked at 68.58% at 120 min after increasing gradually over time but plateauing at 90 min. Limited adsorption capability is suggested by the comparatively low removal rates of 55.75% at 30 min, 64.25% at 60 min, and 68.08% at 90 min. Despite prolonged contact time, this limitation is probably caused by a lack of active sites, which results in limited nitrate removal. In contrast, FeAC demonstrated markedly higher nitrate removal across all contact times. Removal efficiency improved from 76.50% at 30 min to 92.50% at 90 min, eventually reaching 92.58% at 120 min.

Ferric chloride chemical activation, which added more active sites and increased the adsorbent's surface chemistry,

is responsible for the improved performance [25]. The activation of coconut husk biochar with ferric chloride promotes surface functionality and porosity by engaging in both chemical oxidation and structural reconfiguration. As highlighted in the Mössbauer analysis and Fourier Transform Infrared spectroscopy (FTIR) results of Oliveira *et al.* [16], FeCl_3 undergoes partial reduction and hydrolysis during heat treatment, yielding iron oxides and chlorinated iron complexes that participate in carbon matrix disruption and micropore development. These transformations enhance the surface chemistry of the adsorbent by generating iron-bound functional groups that serve as active sites for nitrate adsorption. Under acidic conditions, where the surface becomes positively charged, these sites likely facilitate chemisorption via inner-sphere complexation and electrostatic interactions.

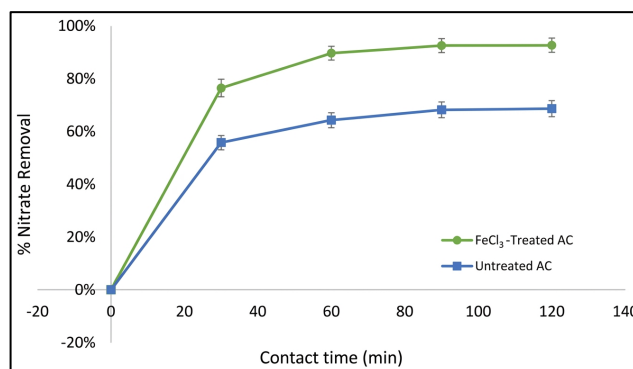


Fig. 3. Effect of contact time on nitrate removal efficiency using FeAC and UAC. Conditions: Initial nitrate concentration = 40 mg/L, pH = 3.0, room temperature ($28 \pm 1^\circ\text{C}$), contact time = 30, 60, 90 min, & 120 min, adsorbent dosage = 0.4 g.

Similar findings were reported by Kuang *et al.* [26], who observed that FeCl_3 activation enhances nitrate uptake through a combination of pore-filling and surface binding mechanisms. Although FTIR validation was not conducted in this study, the observed fit to the pseudo-second-order kinetic model and Langmuir isotherm supports a monolayer chemisorption mechanism, further elaborated in the subsequent sections. To add, findings of Suliestya *et al.* [27], who observed that prolonged contact gives nitrate ions more opportunity to interact with the adsorbent surface, are in line with the increase in adsorption with time. However, the minimal change between 90 and 120 min suggests that equilibrium was achieved at 90 min, with most active sites already saturated. As described by Gupta and Vyas [28], diminishing available sites at longer contact times may lead to adsorption reaching a plateau.

3) Effect of initial nitrate concentration

The effect of initial nitrate concentration was evaluated under the optimized conditions of 0.4 g adsorbent dosage and 90-min contact time. For the UAC, Fig. 4 shows that the highest average removal efficiency was 68.08% at 40 ppm initial concentration. As the nitrate concentration increased, the removal efficiency declined sharply, reaching only 9.95% at 70 ppm. This trend highlights the limited adsorption capacity of the untreated material, especially at higher contaminant loads.

On the other hand, FeAC maintained outstanding nitrate removal efficiency throughout a range of initial

concentrations, as illustrated in the same figure. At 40 ppm, the removal efficiency reached its maximum of 92.50%, which progressively dropped to 88.00% at 50 ppm, 82.83% at 60 ppm, and 75.43% at 70 ppm. According to Ahmadpari *et al.* [29], the saturation of accessible active sites is the cause of the observed drop in removal effectiveness at higher starting concentrations. Even at greater nitrate concentrations, the treated adsorbent showed good performance despite the modest reduction, indicating that it is suitable for treating wastewater of greater intensity.

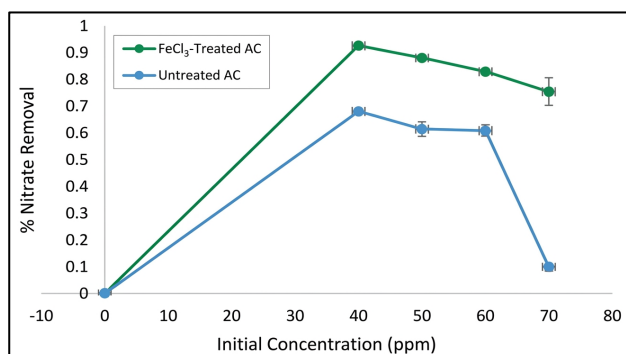


Fig. 4. Effect of adsorbent dosage on nitrate removal using FeAc and UAC. Conditions: Initial nitrate concentration = 40 mg/L, 50 mg/L, 60 mg/L, & 70 mg/L, pH = 3.0, room temperature (28 ± 1 °C), contact time = 120 mins, adsorbent dosage = 0.4 g.

C. Adsorption Kinetics

According to Musah *et al.* [30], linear models are commonly used to study adsorption with the aim of estimating efficiency, rate constants, and diffusion; their selection of models is determined by correlation coefficients. The ideal adsorbent dosage and equilibrium contact time were determined from the batch tests, and a 40 mg/L nitrate concentration at pH 3 was used to evaluate adsorption kinetics. The sequence followed the same procedure as the batch adsorption trials. The kinetic models validated are the Pseudo-First Order (PFO) and the Pseudo-Second-Order (PSO), which were elaborated by Surela *et al.* [31].

The adsorption capabilities were calculated using Eq. (2):

$$q = \frac{(C_0 - C_t) V}{m} \quad (2)$$

where C_0 and C_t are the initial and time t concentrations (mg/L), V is the volume of the solution (L), and m is the mass of the biosorbent (g). This equation quantifies the amount of nitrate removed by the adsorbent at any given time.

The PFO, or the Lagergren model, assumes that the rate of adsorption depends on the number of unoccupied surface sites and is proportional to the difference between equilibrium and current adsorption [32]. It is represented by Eq. (3):

$$\ln(q_e - q_t) = \ln(q_e) - k_1 t \quad (3)$$

This model helps assess whether the adsorption follows first-order kinetics by analyzing the fit between experimental and calculated values of adsorption capacity (q_t).

The PSO Kinetic model assumes adsorption is controlled by chemisorption and is related to the square of the unoccupied sites and is expressed in Eq. (4).

$$\frac{t}{q_t} = \frac{1}{k_2 q_e^2} + \frac{t}{q_e} \quad (4)$$

Table 1. Kinetic parameters of pseudo-first-order and pseudo-second-order models for nitrate adsorption at varying adsorbent dosages

Dosage (g)	Model	$Q_{e,theo}$ (mg/g)	$Q_{e,exp}$ (mg/g)	K (min^{-1})	R^2
0.2	PFO	3.6302	3.1667	-4.42×10^{-5}	0.8841
	PSO	0.3847	3.1667	1.4695	0.9944
0.3	PFO	2.8893	3.2500	-3.42×10^{-5}	0.8279
	PSO	0.3409	3.2500	6.0581	0.9986
0.4	PFO	0.6928	3.0000	0.0007	0.8786
	PSO	0.4862	3.0000	3.10331	0.9848

Different adsorbent dosages were used to assess consistency across varying dosages. The correlation coefficient (R^2) values presented in Table 1 show that the PSO kinetic model is the most consistent ($R^2 > 0.98$), suggesting that it is the most suitable model for the adsorption.

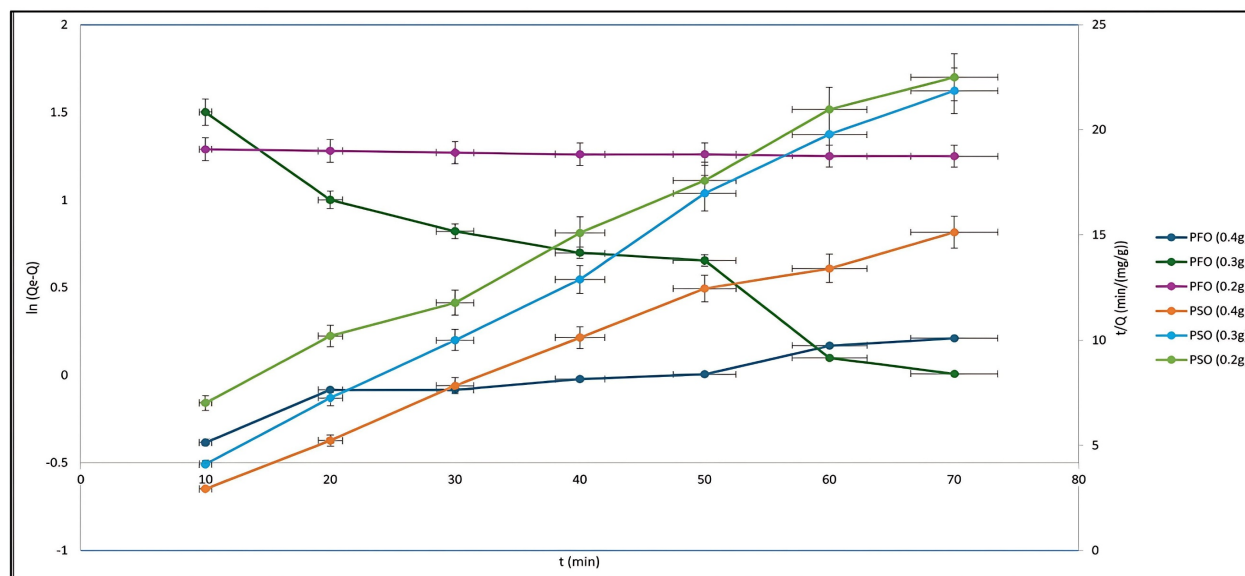


Fig. 5. Linearized PFO and PSO plots for the adsorption of nitrate onto FeAC. Conditions: initial nitrate concentration = 40 mg/L, pH = 3.0, room temperature (28 ± 1 °C), contact time = 10 mins–120 mins (with 10 mins interval), adsorbent dosage = 0.2 g, 0.3 g, & 0.4 g.

The suitability of the PSO kinetic model indicates that adsorption is governed by chemisorption, which is also supported by the study of Yao *et al.* [33] and Trivedi *et al.* [34], where NO_3 adsorption by biochar followed PSO kinetics with high R^2 , indicating a chemical adsorption mechanism. The tabulated values showed that while 0.4 g achieved the highest nitrate removal, the rate constant (K_2) peaked at 0.3 g, possibly due to particle aggregation at higher dosages. Fig. 5 presents the adsorption kinetics data fitted to PSO and PFO models. Fig. 6 presents the trend of nitrate removal efficiency and corresponding adsorption capacity

across varying initial concentrations (40–70 mg/L) using 0.4 g of FeAC, a dosage previously optimized in the experimental series. The right y-axis represents the amount of nitrate removed per unit mass of adsorbent under each tested condition. While the recorded adsorption capacities (ranging from 4.5 to 6.0 mg/g) may appear modest in comparison to advanced engineered materials, this performance is consistent with other low-cost agricultural waste-derived adsorbents that operate efficiently under acidic pH conditions without post-treatment modification.

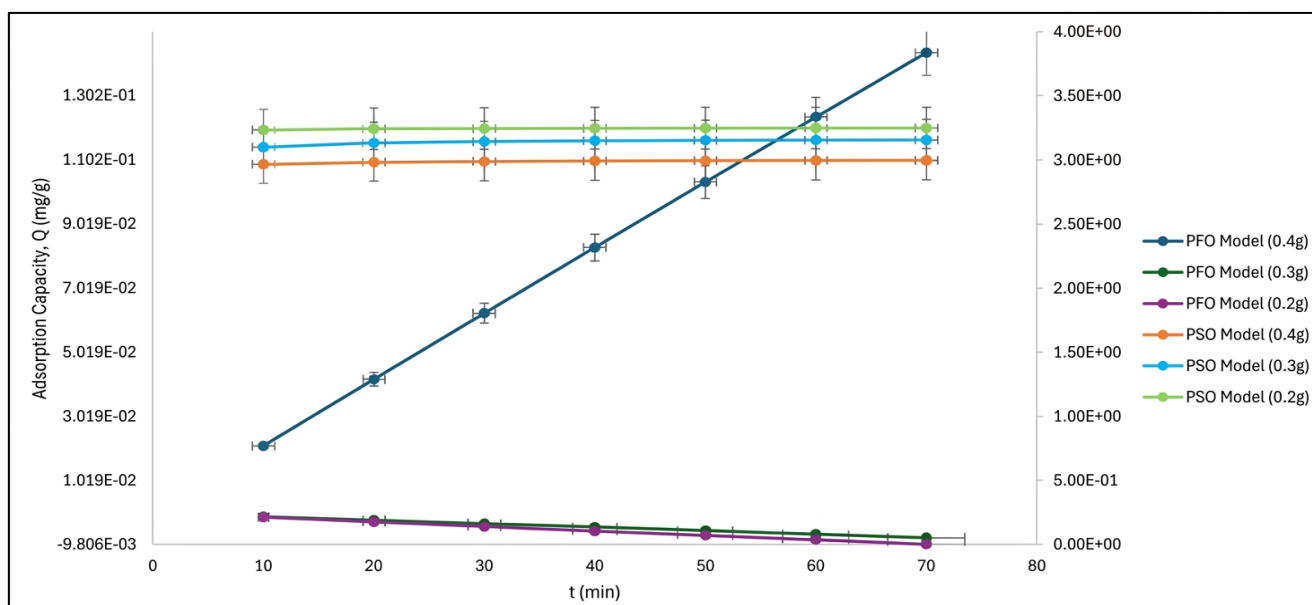


Fig. 6. Adsorption Capacity (Q) vs contact time for nitrate on FeAC, fitted to Pseudo-First-Order (PFO) and Pseudo-Second-Order (PSO). Conditions: initial nitrate concentration = 40 mg/L, pH = 3.0, room temperature ($28 \pm 1^\circ\text{C}$), contact time = 10 mins–120 mins (with 10 mins interval), adsorbent dosage = 0.2 g, 0.3 g, & 0.4 g.

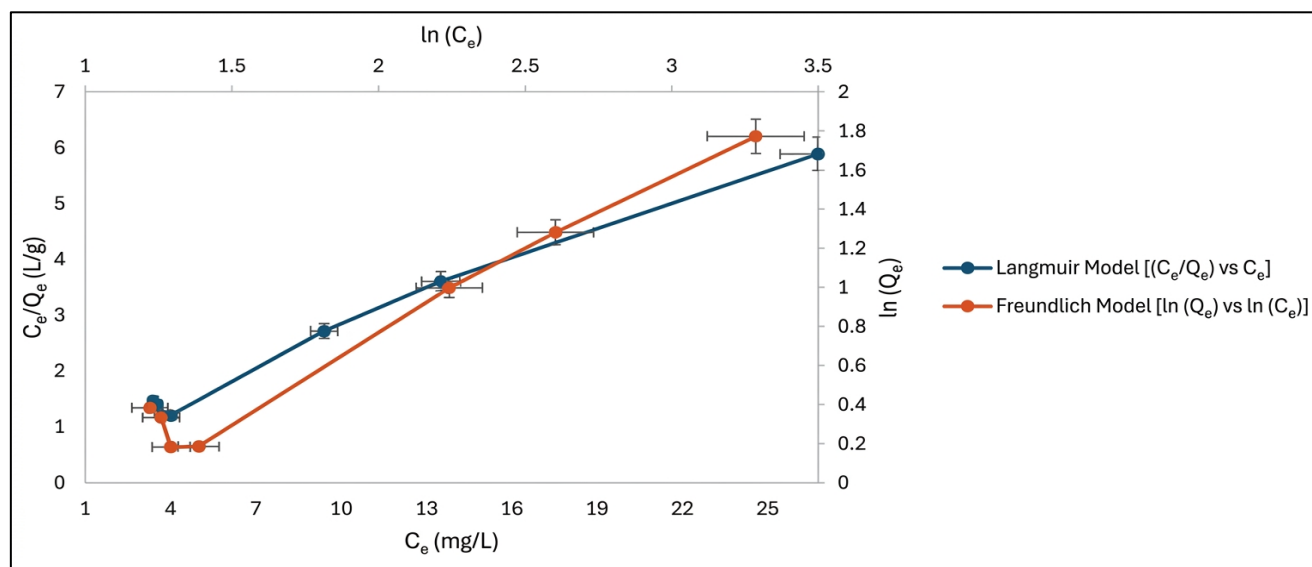


Fig. 7. Comparison of Langmuir and Freundlich linearized plot for adsorption of nitrate ions on FeAC. Conditions: initial nitrate concentration = 40 mg/L, pH = 3.0, room temperature ($28 \pm 1^\circ\text{C}$), contact time = 30 mins, adsorbent dosage = 0.2 g–0.8 g (with 0.1 g interval).

D. Adsorption Isotherms

Adsorption isotherms were evaluated to understand the equilibrium relationship between nitrate ions in the aqueous phase and their corresponding uptake by the FeCl_3 -treated coconut husk activated carbon. The surface characteristics and adsorption performance of the adsorbent were evaluated through equilibrium studies. As noted by Hu *et al.* [35],

adsorption isotherms describe the distribution of solute molecules between the liquid and solid phases at equilibrium. The experimental data were analyzed using both the Freundlich and Langmuir isotherm models. To ensure consistency, the isotherm experiments were conducted under the same optimized conditions for adsorbent dosage and contact time as the adsorption kinetics study. Equilibrium

data were collected by varying the initial nitrate concentrations and measuring the corresponding adsorption capacities. Fig. 7 shows the linearized plots of the Langmuir and Freundlich isotherm models.

The Langmuir model assumes monolayer adsorption onto a homogeneous surface with a finite number of identical sites, while the Freundlich model accounts for heterogeneous surface energies and multilayer adsorption. Non-linear and linearized plots of both models were constructed, and their respective parameters were derived. A summarized comparison of the two models is provided in Table 2. The Langmuir isotherm demonstrated a better fit to the experimental data, as evidenced by a higher correlation coefficient, indicating that nitrate adsorption onto the FeAC approached monolayer coverage on a uniform surface.

Table 2. Adsorption Isotherm parameters for FeCl₃-AC

Parameters	Langmuir	Freundlich
R^2	0.9879	0.9834
Slope	0.3357	0.1039
Q_m (mg/g)	2.9789	-
Y-intercept	1.9557	0.7571
K_L	1.0000	-
R_L	0.0224	-
K_F	-	1.2703

The calculated Langmuir constants suggested a favourable adsorption process, and the maximum adsorption capacity (q_m) obtained from the model confirmed the adsorbent's potential to handle relatively high nitrate concentrations in solution. Additionally, the tabulated values in Table 2 show that the separation factor (R_L) calculated from the Langmuir model lies between 0 and 1, confirming that the adsorption process is favorable. The R_L value of 0.0224 is very close to zero, signifying highly favorable adsorption approaching irreversibility. This result is consistent with the PSO kinetic model, which indicates that the adsorption is governed by chemisorption, a strong and essentially irreversible process.

Meanwhile, the Freundlich constant ($K_F = 1.2703$) also indicates favorable adsorption capacity, although the overall fit is slightly lower than Langmuir. The result is also consistent with the findings of Trivedi *et al.* [34], who identified the Langmuir isotherm as the most appropriate model for a comparable nitrate adsorption system and confirmed the applicability of the PSO kinetic model.

Although the Freundlich model showed a reasonable fit, its lower correlation coefficient compared to the Langmuir model indicated a lesser role of multilayer or heterogeneous adsorption. However, the Freundlich constant ($n > 1$) still reflected favorable adsorption. Overall, the isotherm analysis confirmed that FeCl₃-treated coconut husk activated carbon exhibited strong affinity for nitrate ions, best described by the Langmuir model.

V. CONCLUSION

This study evaluated the nitrate removal performance of coconut husk-based activated carbon, both untreated and chemically treated with ferric chloride using batch adsorption experiments under varying dosages, contact times, and initial nitrate concentrations.

The carbon treated with FeCl₃ performed better than any other tested condition. At a dosage of 0.4 g, it removed 76.50% of the nitrate, compared to 55.75% for the UAC.

Because there were more adsorption sites available, nitrate removal effectiveness improved as adsorbent dosage increased. At 90 min, equilibrium was reached, with UAC at 68.08% and FeAC at 92.50% elimination. In terms of initial concentration, removal was optimal at 40 mg/L; performance deteriorated at higher concentrations, likely as a result of active site saturation.

Kinetic analysis confirmed that the pseudo-second-order model best described the adsorption process ($R^2 = 0.9926$), indicating chemisorption. Monolayer adsorption on a homogeneous surface was implied by the Langmuir model, which was found to have the best fit by isotherm modeling ($R^2 = 0.9879$). At 0.8 g of FeAC, the highest adsorption capacity was recorded, with 91.53% removal.

Ferric chloride-treated coconut husk activated carbon demonstrated significantly enhanced nitrate adsorption capacity compared to its untreated counterpart. Its effectiveness, renewability, and low-cost preparation support its application as a promising bio adsorbent for nitrate-contaminated fertilizer effluents. However, the experiments were performed under single-ion batch conditions without coexisting anions or organic matter that are typically present in real industrial wastewater, which may affect adsorption through competitive interactions and pH variation, especially under neutral or alkaline conditions. Although SEM images confirmed surface morphology differences, BET surface area analysis was not conducted due to financial and instrumentation constraints. Future research is recommended to include BET analysis to better correlate pore characteristics with adsorption performance, assess the material's regeneration and reuse potential for long-term application, and evaluate its behaviour under continuous flow systems and multi-component wastewater conditions to better simulate practical treatment scenarios.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Alexandra Nicole Lusterio, Eina Gem Hyacinth Remo Remo, and Lalaine Tumlos were responsible for conducting the experiments, collecting the initial data, performing early-stage analyses, and preparing the institution's version of the manuscript. Jan Marvin Frias oversaw the research activities and offered direction during the experimental planning and execution stages. Lalaine Tumlos and Tristan Roy Panaligan revised and edited the manuscript, improving its organization, updating technical content, and ensuring compliance with journal editing requirements and publication standards. All authors had approved the final version.

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REFERENCES

- [1] The Nature Conservancy. (2025). Wastewater pollution. [Online]. Available: <https://www.nature.org/en-us/what-we-do/our-priorities/protect-water-and-land/land-and-water-stories/wastewater-pollution/>

- [2] World Health Organization. Drinking-water. (2025). [Online]. Available: <https://www.who.int/news-room/fact-sheets/detail/drinking-water>
- [3] W. Wang *et al.*, "Analysis of nonpoint source pollution and water environmental quality variation trends in the Nansi Lake basin from 2002 to 2012," *J Chem*, vol. 2015, pp. 1–11, 2015. doi: 10.1155/2015/967165
- [4] M. J. Luna Juncal, P. Masino, E. Bertone, and R. A. Stewart, "Towards nutrient neutrality: A review of agricultural runoff mitigation strategies and the development of a decision-making framework," *Science of The Total Environment*, vol. 874, 162408, May 2023. doi: 10.1016/j.scitotenv.2023.162408
- [5] J. T. Ludlow, R. G. Wilkerson, and T. M. Nappe, *Methemoglobinemia*. Treasure Island (FL): StatPearls Publishing, 2023.
- [6] J. Ayach *et al.*, "Comparing conventional and advanced approaches for heavy metal removal in wastewater treatment: An in-depth review emphasizing filter-based strategies," *Polymers (Basel)*, vol. 16, no. 14, Jul. 2024. doi: 10.3390/polym16141959
- [7] A. Ahmad and T. Azam, "Water purification technologies," *Bottled and Packaged Water*, Elsevier, pp. 83–120, 2019. doi: 10.1016/B978-0-12-815272-0.00004-0
- [8] G. L. Dotto and G. McKay, "Current scenario and challenges in adsorption for water treatment," *J. Environ. Chem. Eng.*, vol. 8, no. 4, Aug. 2020. doi: 10.1016/j.jece.2020.103988
- [9] J. O. Pogosa, V. B. Asio, M. M. Bande, S. Bianchi, J. Grenz, and F. Pichelin, "Productivity and sustainability of coconut production and husk utilization in the Philippines: Coconut husk availability and utilization," *International Journal of Environmental and Rural Development*, vol. 9, no. 1, pp. 31–38, 2018.
- [10] Yuliusman, S. P. Sipangkar, M. Fatkhurrahman, F. Al Farouq, and S. A. Putri, "Utilization of coconut husk waste in the preparation of activated carbon by using chemical activators of KOH and NaOH," in *Proc. AIP Conference Proceedings*, 2020, 060026. doi: 10.1063/5.0014990
- [11] T. R. Panaligan, J. Aquino, D. Centeno, K. M. Pedrosa, and J. Tumamao, "Adsorption of iron (II) ions from simulated industrial wastewater utilizing activated carbon from cogon grass (*Imperata cylindrica*)," *International Journal of Environmental Science and Development*, 2024. doi: 10.18178/ijesd.2024.15.5.1497
- [12] A. A. Aghapour, S. Nemati, A. Mohammadi, H. Nourmoradi, and S. Karimzadeh, "Nitrate removal from water using alum and ferric chloride: A comparative study of alum and ferric chloride efficiency," *Environmental Health Engineering and Management*, vol. 3, no. 2, pp. 69–73, Mar. 2016. doi: 10.15171/EHEM.2016.03
- [13] Z. Heidarinejad, M. H. Dehghani, M. Heidari, G. Javedan, I. Ali, and M. Sillanpää, "Methods for preparation and activation of activated carbon: a review," *Environ. Chem. Lett.*, vol. 18, no. 2, pp. 393–415, Mar. 2020. doi: 10.1007/s10311-019-00955-0
- [14] N. A. Bakar *et al.*, "An insight review of lignocellulosic materials as activated carbon precursor for textile wastewater treatment," *Environ Technol Innov*, vol. 22, May 2021. doi: 10.1016/j.eti.2021.101445
- [15] L. Ge *et al.*, "An analysis of the carbonization process and volatile-release characteristics of coal-based activated carbon," *Energy*, vol. 257, Oct. 2022. doi: 10.1016/j.energy.2022.124779
- [16] L. C. A. Oliveira *et al.*, "Preparation of activated carbons from coffee husks utilizing FeCl₃ and ZnCl₂ as activating agents," *J Hazard Mater*, vol. 165, no. 1–3, pp. 87–94, Jun. 2009. doi: 10.1016/j.jhazmat.2008.09.064
- [17] J. Bedia, M. Peñas-Garzón, A. Gómez-Avilés, J. J. Rodriguez, and C. Belver, "Review on activated carbons by chemical activation with FeCl₃," *C (Basel)*, vol. 6, no. 2, Apr. 2020. doi: 10.3390/c6020021
- [18] R. Abd Rashid, A. H. Jawad, M. A. Mohd Ishak, and N. N. Kasim, "FeCl₃-Activated Carbon Developed from Coconut Leaves: Characterization and Application for Methylene Blue Removal," *Sains Malays.*, vol. 47, no. 3, pp. 603–610, Mar. 2018. doi: 10.17576/jsm-2018-4703-22
- [19] M. Sadeghi Afjeh, G. Bagheri Marandi, and M. J. Zohuriaan-Mehr, "Nitrate removal from aqueous solutions by adsorption onto hydrogel-rice husk biochar composite," *Water Environment Research*, vol. 92, no. 6, pp. 934–947, Jun. 2020. doi: 10.1002/wer.1288
- [20] P. Karthikeyan, H. A. T. Banu, and S. Meenakshi, "Synthesis and characterization of metal loaded chitosan-alginate biopolymeric hybrid beads for the efficient removal of phosphate and nitrate ions from aqueous solution," *Int. J. Biol. Macromol.*, vol. 130, pp. 407–418, Jun. 2019. doi: 10.1016/j.ijbiomac.2019.02.059
- [21] N. A. Rashidi and S. Yusup, "A review on recent technological advancement in the activated carbon production from oil palm wastes," *Chemical Engineering Journal*, vol. 314, pp. 277–290, Apr. 2017. doi: 10.1016/j.cej.2016.11.059
- [22] N. Boujelben, J. Bouzid, Z. Eloucar, M. Feki, F. Jamoussi, and A. Montiel, "Phosphorus removal from aqueous solution using iron coated natural and engineered sorbents," *J. Hazard. Mater.*, vol. 151, no. 1, pp. 103–110, Feb. 2008. doi: 10.1016/j.jhazmat.2007.05.057
- [23] M. Kavand, N. Asasian, M. Soleimani, T. Kaghazchi, and R. Bardestani, "Film-Pore-[Concentration-Dependent] Surface Diffusion model for heavy metal ions adsorption: Single and multi-component systems," *Process Safety and Environmental Protection*, vol. 107, pp. 486–497, Apr. 2017. doi: 10.1016/j.psep.2017.03.017
- [24] A. Battas, A. El Gaidoumi, A. Ksakas, and A. Kherbeche, "Adsorption Study for the Removal of Nitrate from Water Using Local Clay," *The Scientific World Journal*, vol. 2019, no. 1, 9529618, Feb. 2019. doi: 10.1155/2019/9529618
- [25] A. Azhdarpoor, L. Khosrozadeh, and M. Shirdarreh, "Nitrate removal from water using complex of activated carbon with Fe³⁺," *Water Supply*, vol. 19, no. 4, pp. 1097–1102, Jun. 2019. doi: 10.2166/ws.2018.157
- [26] P. Kuang *et al.*, "Increasing Surface Functionalities of FeCl₃-Modified Reed Waste Biochar for Enhanced Nitrate Adsorption Property," *Processes*, vol. 11, no. 6, 1740, Jun. 2023. doi: 10.3390/pr11061740
- [27] Suliestyah, P. N. Hartami, and E. J. Tuheteru, "Effect of weight and contact time adsorption of activated carbon from coal as adsorbent of Cu(II) and Fe(II) in liquid solutions," in *AIP Conference Proceedings*, 2020, vol. 2245, no. 1, 070025. doi: 10.1063/5.0007891
- [28] A. Gupta and R. K. Vyas, "Evaluation of acyclovir adsorption on granular activated carbon from aqueous solutions: batch and fixed-bed parametric studies," *Chemical Papers*, vol. 77, no. 8, pp. 4599–4612, Aug. 2023. doi: 10.1007/s11696-023-02810-7
- [29] H. Ahmadpari *et al.*, "Preliminary Study of the Process of Nitrate Removal Optimization from Aqueous Solutions Using Taguchi Method," *Revista INGENIERÍA UC*, vol. 26, no. 2, pp. 154–162, 2019.
- [30] M. Musah, Y. Azeh, J. Mathew, M. Umar, Z. Abdulhamid, and A. Muhammad, "Adsorption Kinetics and Isotherm Models: A Review," *Caliphate Journal of Science and Technology*, vol. 4, no. 1, pp. 20–26, Feb. 2022. doi: 10.4314/cajost.v4i1.3
- [31] A. K. Surela, L. K. Chhachhia, V. K. Surela, and P. L. Meena, "Polypyrrole-Based Composites for Dyes Removal From Contaminated Water," in *Reference Module in Materials Science and Materials Engineering*, Elsevier, 2024. doi: 10.1016/B978-0-323-95486-0.00019-3
- [32] M. A. Hubbe, S. Azizian, and S. Douven, "Implications of apparent pseudo-second-order adsorption kinetics onto cellulosic materials: A review," *Bioresources*, vol. 14, no. 3, pp. 7582–7626, Aug. 2019. doi: 10.15376/biores.14.3.7582-7626
- [33] J. Yao, Z. Wang, M. Liu, B. Bai, and C. Zhang, "Nitrate-Nitrogen Adsorption Characteristics and Mechanisms of Various Garden Waste Biochars," *Materials*, vol. 16, no. 16, 5726, Aug. 2023. doi: 10.3390/ma16165726
- [34] Y. Trivedi *et al.*, "Mechanistic assessment of functionalised biochar derived from customised pyrolyzer for nitrate removal," *Results in Engineering*, vol. 26, 104672, Jun. 2025. doi: 10.1016/j.rineng.2025.104672
- [35] Q. Hu, R. Lan, L. He, H. Liu, and X. Pei, "A critical review of adsorption isotherm models for aqueous contaminants: Curve characteristics, site energy distribution and common controversies," *J. Environ. Manage.*, vol. 329, 117104, Mar. 2023. doi: 10.1016/j.jenvman.2022.117104

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