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Utilization of Rubber Shell-Derived Activated Carbon for Ammonia Reduction in Synthetic Wastewater: An Adsorption Isotherm Study

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ABSTRACT: Indonesia is one of the largest rubber-producing countries, where ammonia is used as an anticoagulant in rubber processing. Ammonia contributes to industrial wastewater contamination, with a maximum allowable concentration of 5 mg/L, requiring treatment methods such as adsorption using activated carbon. This study evaluated the potential of activated carbon derived from rubber shells to reduce ammonia levels in synthetic wastewater by varying adsorbent mass and determining the most suitable adsorption isotherm model. The activated carbon was prepared through carbonization at 500°C for 1 h and activated using 40% phosphoric acid (H_3PO_4) at a 1:4 (w:v) ratio for 24 h. BET analysis showed a surface area of 324.26 m²/g. Optimum adsorption was achieved with 2.5 g of adsorbent, resulting in a final ammonia concentration of 4.788 mg/L, 88% adsorption efficiency, an adsorption capacity of 1.409 mg/g, and an equilibrium time of 60 min. The Freundlich isotherm model best described the adsorption process (R^2 = 0.9632, RMSE = 0.0111, MSE = 0.0001, SSE = 0.0006), indicating multilayer adsorption on a heterogeneous surface. These findings support Sustainable Development Goal (SDG) 6: Clean Water and Sanitation through improved wastewater treatment.
Keywords: adsorption; ammonia; clean water and sanitation; isotherm; rubber shell

1. Introduction

Ammonia is used in rubber processing as an anticoagulant to prevent the pre-coagulation of latex during storage and processing (Anggraini et al., 2023). However, the use of ammonia in this process can produce wastewater with high ammonia concentrations. The concentration of ammonia in rubber factory wastewater can reach 30.3 mg/L (Abrori et al., 2022), which exceeds the permissible limit of 5 mg/L as stipulated in the Regulation of the Minister of Environment of the Republic of Indonesia Number 5 of 2014. When concentrations exceed the permissible limit, ammonia can be toxic and disrupt the balance of aquatic ecosystems and harm aquatic organisms (Zhang et al., 2023). For humans, exposure to ammonia-contaminated water can cause eye and skin irritation, respiratory problems, and if swallowed, can cause digestive disorders such as nausea or vomiting (Helwandi, 2025). In addition to producing liquid waste, the rubber industry also produces solid waste in the form of rubber shells. This solid waste has the potential to pollute the environment and has low economic value if not utilized properly (Hadijah et al., 2020). Therefore, effective treatment methods are needed to reduce ammonia levels in wastewater while utilizing solid waste from the rubber industry to minimize negative impacts on the environment. One method that can be applied to reduce ammonia concentration in wastewater is adsorption, which is considered an economical treatment method due to its relatively low operational costs (Siswanti et al., 2023).

Adsorption is a process in which a solid surface binds molecules from the gas or liquid phase (Utami et al., 2024). In this process, ammonia molecules adhere to the surface and pores of the adsorbent, thereby reducing the ammonia concentration in wastewater. Rubber shells, as a solid waste with high cellulose content, have the potential to be processed into activated carbon that can be utilized in this adsorption process (Aminin et al., 2021). Several studies have explored the application of biomass materials with high cellulose content to produce activated carbon for ammonia adsorption. A study using coffee grounds activated with 4% HCl achieved an adsorption efficiency of 84.64% (Septiani et al., 2021). Activated carbon derived from durian peel activated with 20% H_3PO_4 showed an efficiency of 62.81% (Tien et al., 2025). In addition, coconut shells activated through a physical activation method resulted in an efficiency of 67.59% (Ningrum et al., 2025), while almond kernel activated with 10% KOH achieved an adsorption efficiency of 59.6% (Vamvuka et al., 2024).

Variations in adsorption efficiency indicate that the characteristics of activated carbon produced from different biomass types and activation methods significantly affect ammonia adsorption performance. The activation method can influence the development of pore structure and surface area, which play important roles in the adsorption process. Therefore, the selection of biomass and activation method becomes important in producing activated carbon with good adsorption performance.

Rubber shell is one type of lignocellulosic biomass with the potential to be utilized as activated carbon. Previous studies have shown that activated carbon derived from rubber shells has good adsorption performance for several contaminants, particularly heavy metal ions. Activated carbon from rubber shells activated using HCl showed Cr(VI) adsorption efficiency 96.67% (Zulfadhli & Iriany, 2017). In another study, rubber shell activated carbon activated with NaOH demonstrated Fe(III) adsorption efficiency 96.37% (Robenita et al., 2024). Activated carbon prepared using H_3PO_4 activation also exhibited Pb(II) adsorption efficiency 80% (Rahayu et al., 2024), while KOH-activated rubber shell carbon showed Fe(II) adsorption efficiency greater than 67.49% (Abdullah et al., 2025). According to Abdullah (2025), activated carbon from rubber shells has a surface area of 346.92 m^2/g. However, previous studies have mainly focused on heavy metal adsorption, while the application of rubber shell activated carbon for ammonia adsorption remains underexplored. Therefore, it is necessary to conduct research to evaluate the potential of rubber shell activated carbon as an adsorbent in reducing ammonia levels in wastewater through variations in the mass of activated carbon and to determine the most appropriate adsorption isotherm model based on the ammonia adsorption capacity of the adsorbent. This study contributes to the achievement of Sustainable Development Goal (SDG) 6, particularly Target 6.3, which aims to improve water quality by reducing pollution, minimizing the release of hazardous substances, and increasing wastewater treatment and safe reuse practices. The utilization of rubber shell activated carbon for ammonia removal offers a sustainable approach to wastewater treatment, supporting access to cleaner water and improved environmental sanitation.

2. Materials and Methods

2.1. Materials

The materials used in this study were rubber shells, 40% phosphoric acid (H_3PO_4), ammonium chloride (NH_4Cl), distilled water, phenol solution (C_6H_5OH), 0.5% sodium nitroprusside solution ($C_5FeN_6Na_2O$), alkaline citrate solution ($C_6H_5Na_3O_7$), and 5% sodium hypochlorite solution (NaClO).

2.2. Preparation of Activated Carbon from Rubber Shells

The rubber shells were cleaned of impurities and dried under sunlight. Subsequently, the carbonization process was carried out by placing the rubber shells in a furnace at a temperature of 500 °C for 1 hour to produce rubber shell carbon. The resulting carbon was cooled in a desiccator, ground using a blender, and sieved to obtain particle sizes of −100 +200 mesh. Furthermore, the carbon was soaked in 40% H_3PO_4 solution for 24 hours with a ratio of 1:4 (m/v). The activated carbon obtained was washed repeatedly with water until the pH was neutral, then dried using an oven at 110 °C until the weight was constant.

2.3. Determination of Wavelength at Maximum Adsorption and Standard Curve

The wavelength range of 630–655 nm was used to determine the maximum ammonia absorption. Prior to the observation, hypochlorite and phenol were reacted to form indophenol (Utomo et al., 2023). The absorbance of indophenol was observed over the wavelength range used. Then, the wavelength with maximum absorption was determined.

Ammonia solutions with various concentrations of 0.1–0.7 mg/L, each as much as 25 mL were put into Erlenmeyer flasks, added with 1 mL of phenol solution, 1 mL of sodium nitroprusside solution, and 2.5 mL of oxidizing solution. The Erlenmeyer flasks were covered with aluminum foil and allowed to react for 1 hour. Then, the absorbance was measured using a UV-Vis spectrophotometer at the wavelength that has maximum absorption. This experiment was done in duplicates.

2.4. Ammonia Adsorption and Adsorption Efficiency

A 100 mL ammonia solution with a concentration of 40.01 mg/L was added with 0.5 g of activated carbon, stirred using a magnetic stirrer (CMAG HS-4) at a scale speed of 2. Every 15 minutes, the concentration was observed until the equilibrium concentration was reached. This experiment was repeated for other mass variations (1, 1.5, 2, and 2.5 g).

The solution was then filtered using filter paper. A 25 mL filtrate was taken and mixed with 1 mL of phenol solution, 1 mL of sodium nitroprusside solution, and 2.5 mL of oxidizing solution. The Erlenmeyer flask was covered with aluminum foil and allowed to react for 1 hour. Each experiment was done in duplicate.

The ammonia adsorption efficiency is calculated based on the comparison between the adsorbed ammonia concentration and the initial concentration in the solution. The adsorption efficiency of ammonia at each contact time is determined as follows in Eq 1 and 2.

$$E_t = \frac{C_o - C_t}{C_o} x100\ \% \quad (1)$$

The adsorption efficiency at equilibrium is calculated using Eq 2.

$$E_e = \frac{C_o - C_e}{C_o} x100 \quad (2)$$

2.5. Adsorption Isotherm Models

The adsorption capacity at equilibrium is calculated using Eq 3.

$$q_e = \frac{(C_o - C_e) * V}{m} \quad (3)$$

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The equilibrium adsorption isotherm was analyzed using the Langmuir, Freundlich, Halsey, and Jovanovic models (Nandiyanto et al., 2023) (Eq 4 to 8).

1) Isotherm Langmuir

$$\frac{1}{q_e} = \frac{1}{K_L.Q_m}\frac{1}{C_e} + \frac{1}{q_m} \tag{4}$$

$$RL = \frac{1}{1+K_L.C_o} \tag{5}$$

2) Isotherm Freundlich

$$log\ q_e = log\ K_F + \frac{1}{n} log\ C_e \tag{6}$$

3) Isotherm Halsey

$$ln\ q_e = \frac{1}{nH} ln\ K_H - \frac{1}{nH} lnC_e \tag{7}$$

4) Isotherm Jovanic

$$\ln qe = \ln qm - Kj.Ce \tag{8}$$

2.6. BET Analysis

The activated carbon was synthesized via carbonization of the precursor material at 500 °C for 1 h. Following carbonization, the carbonized sample was chemically activated by immersion in a 40% phosphoric acid (H_3PO_4) solution at a solid-to-liquid ratio of 1:4 (w:v) for 24 h. The surface area and pore characteristics of the resulting activated carbon were evaluated using nitrogen (N_2) adsorption-desorption measurements at 77.35 K, conducted on a Quantachrome Nova 1200e analyzer. The sample was degassed at 300 °C for 18 h to remove moisture and any pre-adsorbed gases from the porous network.

3. Results and Discussion

3.1. The Effect of Adsorbent Mass and Adsorption Time on Concentration

The effect of variations in adsorbent mass and contact time on ammonia concentration is shown in Figure 1. Based on Figure 1, in the experiment with an adsorbent mass of 0.5 g, the longer the contact time, the lower the ammonia concentration. The change in concentration occurs rapidly in the initial stage, this phenomenon occurs because there are still many active sites on the surface of the adsorbent available, thus allowing a faster transfer of the mass of the adsorbate molecules from the liquid phase to the adsorbent (Siswanti et al., 2025). However, with increasing contact time, the availability of active surface area gradually decreases, so that the mass transfer rate becomes slower until it reaches equilibrium (Siswanti et al., 2023). This trend also applies to other adsorbent masses.

At 2.5 g of adsorbent, the concentration decreased more significantly than at other adsorbent masses. This is because the larger the adsorbent mass, the larger the active surface area and the more active sites available to adsorb ammonia molecules from the solution. As the number of active sites increases, the probability of adsorbate binding to the adsorbent surface also increases. These findings are consistent with the study by Dardiri et al. (2024), which shows that increasing the mass of the adsorbent increases the adsorption of the substance.

The mass of the adsorbent influences the time required to reach adsorption equilibrium. At an adsorbent mass of 0.5 g, adsorption equilibrium was reached at 135 minutes. However, increasing the contact time allows better interaction between the adsorbate molecules and the adsorbent surface, thereby enabling a more effective adsorption process (Dardiri et al., 2024). This indicates that a larger adsorbent mass, the faster equilibrium is achieved due to the greater availability of surface area (Desfitri et al., 2024). In this experiment, the fastest equilibrium time occurred when the adsorbent mass was 2.5 g.

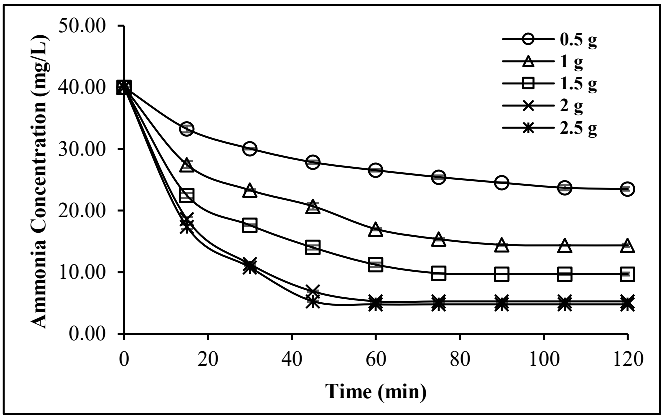

Figure 1. The effect of variations in adsorbent mass on ammonia concentration at times t. Average values are shown (n =2). Standard deviations are shown in vertical lines

3.2. The Effect of Adsorbent Mass and Contact Time on Adsorption Capacity

Adsorption capacity is the ability of activated carbon to absorb ammonia per mass of adsorbent, and is expressed in milligrams of adsorbate per gram of adsorbent. The effect of variations in adsorbent mass and adsorption time on adsorption capacity can be seen in Figure 2.

The effect between contact time and adsorption capacity is directly proportional until equilibrium is reached. In experiments with an adsorbent mass of 0.5 g, the longer the contact time, the greater the adsorption capacity. At equilibrium, the ammonia concentration is constant, so the adsorption capacity is also constant. This also applies to experiments with other adsorbent masses.

Under equilibrium conditions, the effect of adsorbent mass on adsorption capacity is inversely proportional. For the 0.5 g experiment, the adsorption capacity was 3.301 mg/g, but if the adsorbent mass was increased, the adsorption capacity decreased. From this experiment, the smallest adsorption capacity of 1.409 mg/g was obtained at an adsorbent mass of 2.5 g. The decrease in adsorption capacity due to the addition of adsorbent mass was caused by an increase in the number of active sites available on the adsorbent. However, not all of these active sites were filled because the amount of ammonia in the solution remained constant, so some adsorption sites remained empty or not all of them were bound to the adsorbate during the adsorption process (Lisha et al., 2024).

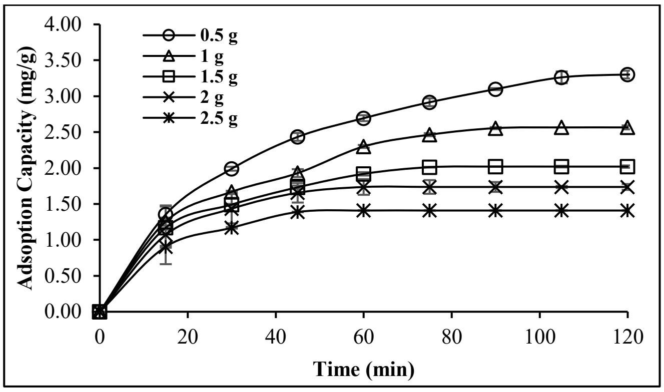

Figure *2*. Effect of adsorbent mass from rubber shell and contact time on ammonia adsorption capacity. Average values are shown (n =2). Standard deviations are shown in vertical lines

3.3. The Effect of Adsorbent Mass and Adsorption Time on Adsorption Efficiency

The effect of variations in adsorbent mass and adsorption time on adsorption efficiency is shown in Figure 3. For experiments using a fixed initial concentration of ammonia solution of 40.01 mg/L, the correlation between contact time and adsorption efficiency is directly proportional, where the adsorption efficiency increases over time until it reaches equilibrium. At a mass of 0.5 grams, the adsorption efficiency increases gradually from 16.94% at 15 minutes to 41.25% at an equilibrium time of 120 minutes.

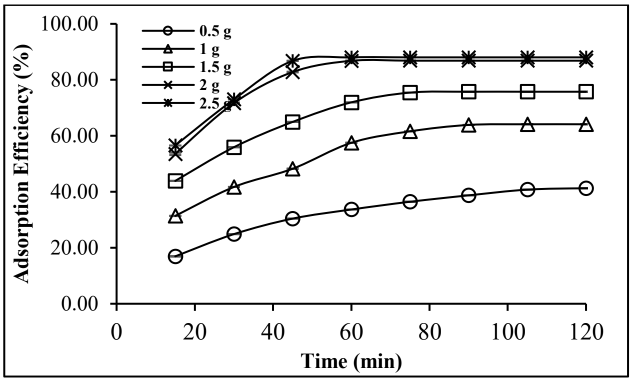

Figure 3. Effect of adsorbent mass from rubber shell and contact time on ammonia adsorption efficiency. Average values are shown (n =2). Standard deviations are shown in vertical lines

This occurs because the longer the contact time, the more opportunities for interaction between activated carbon particles to come into contact or collide with ammonia until the contact time reaches equilibrium (Octiani et al., 2023). The trend of increasing efficiency over time also occurs for other variations in adsorbent mass.

By increasing the amount of adsorbent and the initial concentration of ammonia solution remained at 40.01 mg/L, the adsorption efficiency increased significantly, so that the highest efficiency of 88% was achieved at an adsorbent mass of 2.5 g at 60 minutes. This is due to the increase in the number of active sites in the form of pores on the surface of activated carbon along with the increase in the adsorbent mass. The greater the mass of adsorbent used, the greater the surface area available for ammonia adsorption, resulting in greater ammonia adsorption efficiency (Octiani et al., 2023).

3.4. Adsorption Isotherm Model

Figure 4. shows the relationship between equilibrium concentration (C_e) and adsorption capacity (q_e) at different adsorbent masses, which was used as the basis for the adsorption isotherm evaluation. At a constant adsorbate concentration, increasing the adsorbent mass provides more available active sites. However, because the amount of adsorbate is limited, not all active sites are filled at equilibrium, causing the adsorption capacity at higher adsorbent masses to decrease (Ifa et al., 2021).

To determine the relationship between adsorbate concentration (C_e) and adsorption capacity (q_e) under equilibrium conditions, adsorption isotherm models can be used. The adsorption isotherm model describes the relationship between the equilibrium concentration of adsorbate in the liquid phase and the amount of adsorbate adsorbed on the solid phase at a constant temperature. The adsorption isotherm analysis was conducted using Langmuir, Freundlich, Jovanovic, and Halsey isotherm models. The isotherm parameters were determined using linear regression based on the linearized form of each isotherm equation. This model is important for understanding the adsorption behavior of ammonia and for developing effective adsorption systems (Wang & Guo, 2020). In this study, four isotherm models were evaluated using equilibrium data obtained from experiments conducted with various adsorbent masses, namely 0.5 g, 1.0 g, 1.5 g, 2.0 g, and 2.5 g.

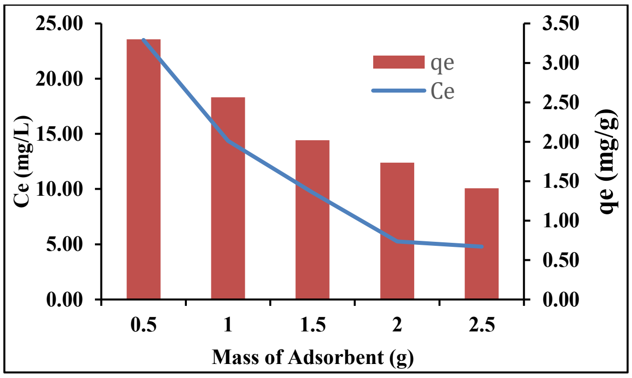

Figure 4. Effect of adsorbent mass on equilibrium concentration and adsorption capacity

The Langmuir isotherm model describes adsorption behavior in which the adsorption capacity reaches a

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maximum when the adsorbate molecules form a monolayer on the adsorbent surface. This model assumes monolayer adsorption on the adsorbent surface, where all adsorption sites have a uniform adsorption energy. The model treats the adsorbed substance as ideal, indicating no interaction between adsorbate molecules or between the adsorbate and the adsorbent (Jabbari & Ghasemi, 2024). The Langmuir constant (K_L) is related to the adsorption capacity (mg/g), which can be correlated with the appropriate surface area and porosity of the adsorbent, so that a large surface area and pore volume will result in a higher adsorption capacity (Al-Ghouti & Da'ana, 2020). The relationship between concentration and adsorption capacity at equilibrium, modeled using the Langmuir isotherm, is presented in Figure 5 (a), which presents the linear plot of $1/C_e$ versus $1/q_e$. The calculated separation factor (R_L) value of 0.179 indicates that the adsorption process in this study is favorable. Adsorption is considered favorable if $R_L < 1$, linear if R_L=1, and unfavorable if $R_L > 1$ (Ismadji et al., 2021).

The Freundlich isotherm is a model based on the adsorption process that occurs on heterogeneous surfaces and forming multilayer adsorption. Multilayer adsorption allows interactions between adsorbed molecules. Thus, this model implies that the adsorption energy is not the same at all surface location (Nandiyanto et al., 2023). This model using the parameters n, which reflects the degree of non-linearity, and 1/n, which indicates the intensity or strength of adsorption.

The relationship between concentration and adsorption capacity at equilibrium based on Freundlich isotherm is presented in Figure 5(b), which shows the linear plot of $\log C_e$ versus $\log q_e$. The calculated n value = 2.062 indicates that n>1 and 0<1/n<1, indicating that the adsorption process in this study occurs through physisorption on heterogeneous surfaces (Mabuza et al., 2022). The Halsey isotherm model is used to describe the multilayer adsorption process of adsorbates on heterogeneous adsorbent surfaces.

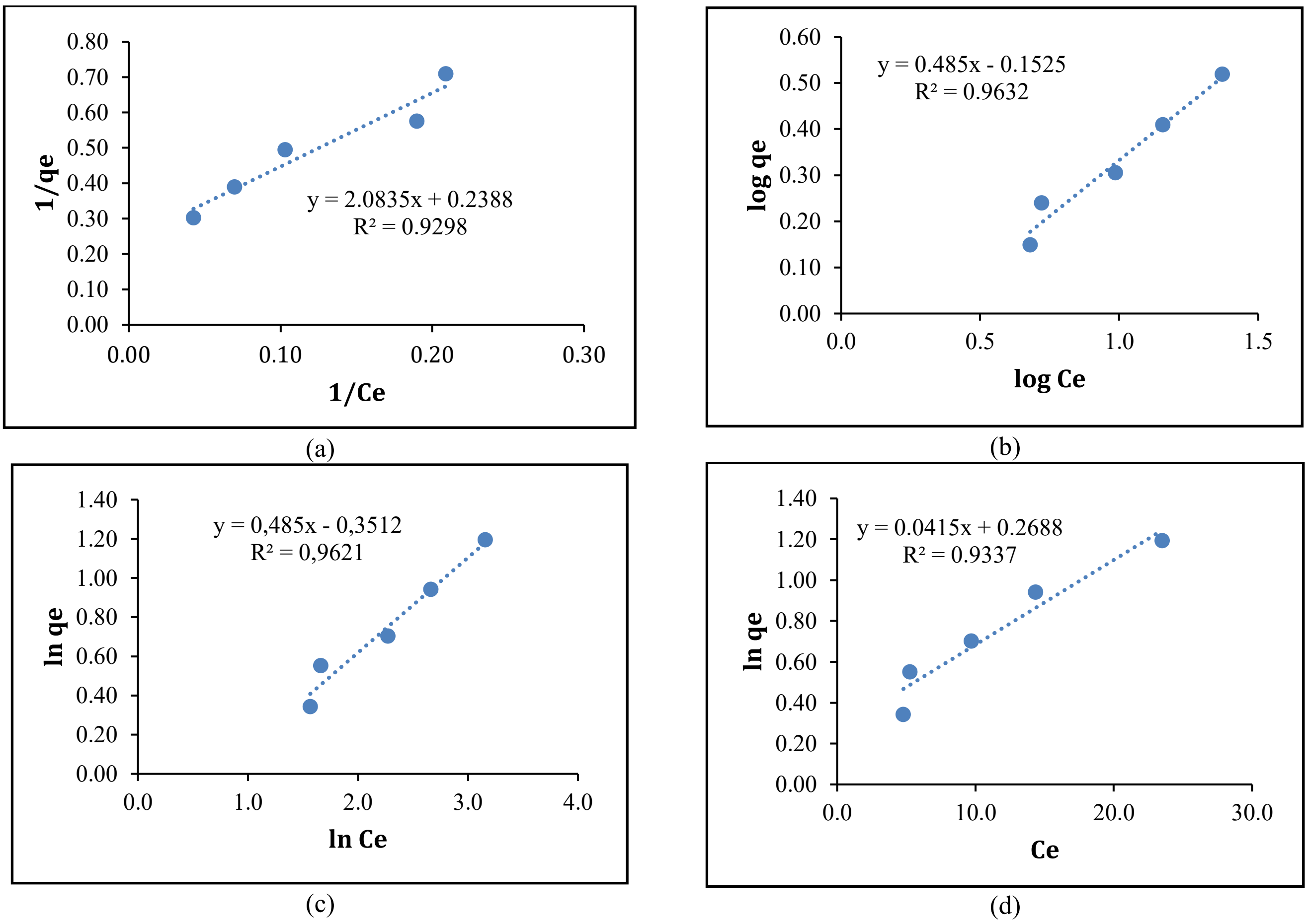

Figure 5. Isotherm curves: (a). Langmuir, (b). Freundlich, (c). Halsey, (d). Jovanovic

Table 2. Results of the adsorption isotherm model and its parameters

Isoterm Model	Parameter	Result
Langmuir	q_m (mg/g)	4.1870
	K_L (L/mg)	0.1150
	R_L	0.1790
	R^2	0.9298
	SSE	0.0071
	RMSE	0.0376
	MSE	0.0014
Freundlich	K_F	0.7040
	n	2.0620
	R^2	0.9632
	SSE	0.0006
	RMSE	0.0111
	MSE	0.0001
Halsey	K_H	2.0630
	n_H	-2.062
	R^2	0.9621
	SSE	0.0163
	RMSE	0.0570
	MSE	0.0114
Javanovic	q_m (mg/g)	1.3080
	K_j (L/mg)	-0.0410
	R^2	0.9337
	SSE	0.0293
	RMSE	0.0765
	MSE	0.0153

This model is a development of the Langmuir isotherm concept and assumes that the adsorption process occurs at a relatively large distance from the adsorbent surface (Jabbari & Ghasemi, 2024). The relationship between concentration and adsorption capacity at equilibrium, modeled using the Halsey isotherm, is illustrated in Figure 5(c), which shows the linear plot of $\ln C_e$versus $\ln q_e$.

The Jovanovic isotherm is a modification of the Langmuir isotherm, where adsorption is assumed to occur on a surface with specific active sites and forms a monolayer. The main difference lies in the consideration of physical contact between adsorbate and adsorbent molecules, as well as the assumption that there is no interaction between the adsorbed molecules. Therefore, the Jovanovic model is able to explain the adsorption phenomenon under actual conditions compared to the Langmuir model (Jabbari & Ghasemi, 2024; Suwannahong et al., 2024). The relationship between concentration and adsorption capacity at equilibrium modeled using the Jovanovic isotherm is presented in Figure 5(d), which shows the linear plot of $C_e$versus $\ln q_e$.

The results of the adsorption isotherm model analysis are presented in Table 2, which compares the data from each isotherm model. The Freundlich isotherm model proved to be the most suitable to describe the ammonia adsorption process, as indicated by the highest coefficient of determination ($R^2 = 0.9632$) and the lowest error values (SSE = 0.0006, RMSE = 0.0111, and MSE = 0.0001). In addition, the Freundlich constant ($n = 2.062$), which is indicates favorable adsorption. The suitability of the Freundlich model implies that the adsorption process occurs on a heterogeneous surface with non-uniform adsorption energies and multilayer adsorption. This result is in line with the research of Tien (2025) who also reported that the Freundlich isotherm model provided the best results in ammonia adsorption with an ($R^2 = 0.970$).

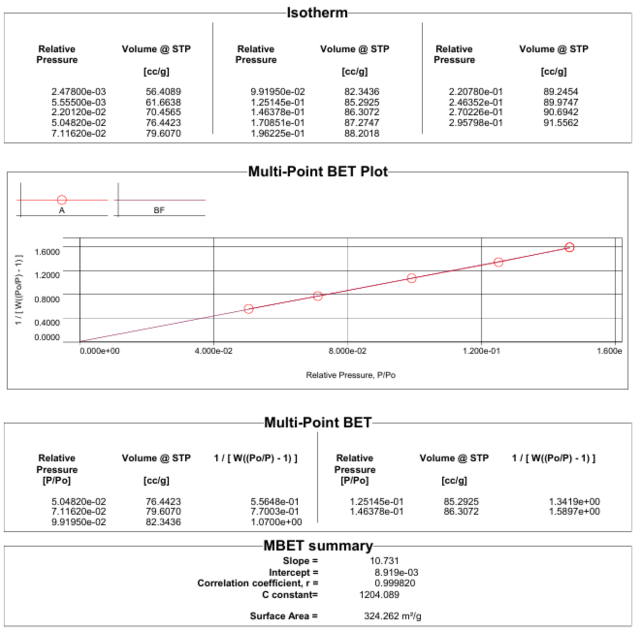

Figure 6. BET result of on rubber shell activated carbon carbonized at a temperature of 500 °C and activated using H_3PO_4 with a concentration of 40% for 1 hour

The Langmuir model also showed relatively good agreement with the experimental data, with an ($R^2 = 0.9298$) and an ($R_L = 0.179$), indicating favorable adsorption. However, the model produced higher SSE, RMSE, and MSE values compared to the Freundlich

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model, suggesting that the assumption of monolayer adsorption on a homogeneous surface was less suitable for describing the adsorption behavior in this study.

3.5. BET Surface Area

Brunauer-Emmett-Teller (BET) analysis is a method for measuring the surface area of a material (Rustanto et al., 2022). The adsorption capacity of activated carbon depends on its surface area. The larger the surface area of activated carbon, the more adsorbate molecules are adsorbed due to the larger contact area (Zou et al., 2021).

Based on the results of the BET test on rubber shell activated carbon carbonized at a temperature of 500 °C and activated using H_3PO_4 with a concentration of 40% for 1 hour, the surface area is 324.26 m^2/g (Figure 6).

3.6. Comparison to previous studies

Based on Table 3, ammonia adsorption has been widely studied using adsorbents from various types of biomass, such as bagasse, coffee grounds, durian peel, coconut shell, and almond seeds, with varying efficiencies depending on the type of adsorbent, activation method, and carbonization conditions (Ningrum et al., 2025; Prasetia et al., 2024; Septiani et al., 2021; Tien et al., 2025; Vamvuka et al., 2024). From these studies, ammonia adsorption efficiencies ranged from 59.6% to 98.2%, indicating that adsorption capacity is influenced by several factors, including the type of biomass, activation method, carbonization conditions, and the characteristics of the adsorbent.

In this study, activated carbon derived from rubber shells and activated with 40% H_3PO_4 showed an adsorption efficiency of 88% and a BET surface area of 324.26 m^2/g. The use of H_3PO_4 as a chemical activating agent is known to increase pores and the surface area of activated carbon, thereby improving its adsorption performance. This result indicates that rubber shells have the potential to be an effective raw material for activated carbon in reducing ammonia levels.

Table 3. Results of ammonia adsorption using various adsorbents

Adsorbent	Carbonization	Activation (Chemical/Physics)	Adsorbate (mg/L)	BET Surface Area (m^2/g)	Adsorption Efficiency (%)	References
Sugarcan bagasse	heated on the stove, 15 min	HCL 0,1 N	232.08	-	98.2	Prasetia et al., (2024)
Coffee grounds	400 ºC, 3.5 h	HCL 4%	10	-	84.64	Septiani et al., (2021)
Coconut shell	400ºC, 1.5 h	800 ºC	0.5	-	67.59	Ningrum et al., (2025)
Durian peel	600 ºC, 1 h	H_3PO_4 20%	40	485.447	62.81	Tien et al., (2025)
Almond kernel	750ºC, 2 h	KOH 10%	50	656	59.6	Vamvuka et al., (2024)
Purple corn cob	650ºC, 2 h	Na_2CO_3 6%	1	-	82	Hamid et al., (2024)
Rubber Shell	500 ºC, 1 h	H_3PO_4 40%	40.01	324.26	88	This Study

4. Conclusions

The results of this study showed that activated carbon prepared from rubber shell, carbonized at 500 °C and activated using 40% phosphoric acid (H_3PO_4), can reduce ammonia concentration in synthetic wastewater. The optimum adsorption conditions were obtained using an adsorbent mass of 2.5 g and a contact time of 60 minutes, resulting in an ammonia removal efficiency of 88% and a final ammonia concentration of 4.788 mg/L, which complies with the wastewater quality standard. Based on the adsorption isotherm analysis, the Freundlich model provided the best fit to the experimental data with an R^2 value of 0.9632. These results indicate that the adsorption process occurred on a heterogeneous surface through multilayer adsorption. These results suggest that rubber shell activated carbon has potential as an alternative, environmentally friendly, and low-cost adsorbent for ammonia removal and wastewater treatment.

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Statement

During the preparation of this manuscript, the authors used ChatGPT-Plus to assist with language improvement, grammar correction, and translation of several sections. All scientific content, data analysis, results, and conclusions were developed and verified by the authors. The authors reviewed and edited all AI-generated output and take full responsibility for the final content of the manuscript.

CRediT authorship contribution statement

Siswanti: Coordinated manuscript revisions within the team, Writing – review & editing, Corresponding author.
Nabilla Diandra Putri: Formal analysis, Data calculation, Literature search and citation collection.
Novia Aliya Devi: Writing – original draft, Manuscript preparation in accordance with relevant theories and scientific principles.
Dwi Amalia: Visualization, Manuscript formatting and layout preparation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

Data availability

All data generated and analyzed during this study, including experimental results for the determination of ammonia concentration in synthetic wastewater using the phenate spectrophotometric method and the measurement of adsorbent surface area using BET analysis included in this published article are available upon request.

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Notation Description

qe = Adsorption capacity at equilibrium (mg/g)
Ct = Adsorbate concentration at the time (mg/L)
Ce = Adsorbate concentration at equilibrium time (mg/L)
Co = Initial adsorbate concentration (mg/L)
qm = Maximum adsorption capacity (mg/g)
KL = Langmuir isotherm constant (L/mg)
RL = Langmuir separation factor
KF = Freundlich isotherm constant (L/mg)
n = Adsorption intensity parameter
KH = Halsey isotherm constant
nH = Heterogeneity of the adsorption surface
KJ = Jovanovic isotherm constant (L/mg)