

Removal of Organic Pollutants from Industrial Rubber Wastewater Using Pineapple Crown Bio-Adsorbents

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Abstract

Industrial rubber wastewater contains high levels of organic substances (proteins, carotenoids, organic salts, and lipids in residual latex) that can be observed in high concentrations of BOD₅ (Biochemical Oxygen Demand) and COD (Chemical Oxygen Demand). Pineapple waste is an organic waste that can be utilized as a bio-adsorbent to remove pollutants from wastewater. This study aims to investigate the effectiveness of pineapple crown waste activated with KOH in removing BOD₅ and COD in rubber industry wastewater. The effectiveness of the adsorbent was tested in batches at varying adsorbent dosages of 0.5 g, 1.0 g, and 1.5 g at stirring speeds of 50 rpm, 100 rpm, and 150 rpm. The adsorption isotherm model was analyzed using the Langmuir and the Freundlich models. The results showed that the optimum BOD₅ removal rate in rubber industry wastewater using pineapple crown adsorbent was achieved at an adsorbent dosage of 0.5 g with a stirring speed of 100 rpm, resulting in an adsorption capacity of 62.78 mg/g and a removal efficiency of 94.35%. The optimum COD removal was achieved at an adsorbent dosage of 0.5 g, with a stirring speed of 100 rpm, resulting in an adsorption capacity of 199.816 mg/g and a removal efficiency of 95.15%. The adsorption isotherm model most suitable for both BOD₅ and COD is the Freundlich model. Increasing the adsorbent dosage does not significantly enhance removal efficiency.

Keywords

Adsorption, Agricultural Waste, Pineapple Waste, Rubber Industry

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1. INTRODUCTION

Industrial rubber wastewater contains pollutants that are harmful when discharged into the environment, especially into waterways. Industrial rubber wastewater contains suspended solids and high organic content (proteins, carotenoids, organic salts, and lipids in residual latex), nitrogen containing organic pollutants, and foul odors that pollute the air in the vicinity of the factory (Maryani et al., 2023). In the rubber industry, chemicals are used as coagulants for the rubber, and a large amount of water is used for the washing process. This results in the rubber industry generating a substantial amount of wastewater. Wastewater from the rubber industry contains rubber components (proteins, carotenoids, and inorganic salts) and chemicals added during processing. These contents can cause damage to aquatic ecosystems if released directly into the environment without prior treatment (Nasir et al., 2019; Sinaga et al., 2023).

Wastewater from the rubber industry contains relatively high levels of organic compounds. This results in high BOD₅

and COD values in rubber industry wastewater (Naswir et al., 2020). According to (Detho et al., 2022). The rubber industry produces wastewater with a Biochemical Oxygen Demand (BOD₅) of 566 mg/L and a Chemical Oxygen Demand (COD) of 1403 mg/L. These data indicate that both parameters exceed the maximum levels specified in Regulation of the Minister of Environment No. 5 of 2014 concerning wastewater quality standards for the rubber industry. Adsorption is one of the strategies used to reduce the concentration of contaminants in wastewater. Adsorption has several advantages, including simple operation, low cost, high efficiency, and the absence of hazardous waste production. The adsorption method is an analytical technique that utilizes an adsorbent to capture adsorbates, which are considered pollutants, from a sample. This method is capable of adsorbing solution molecules and attaching them to the adsorbent through chemical and physical reactions (Dehghani et al., 2023; Mu et al., 2024).

Effective adsorbent materials are often obtained from

high-carbon biomass waste, such as agricultural waste. Pineapple waste is agricultural waste that contains cellulose (69.5-71.5%), pentosan (17-17.8%), lignin (4.4-4.7%), and other carbon components (0.71-0.87%), which can be converted into carbon (Cano et al., 2025). The usefulness of pineapple crowns as bio-adsorbents can be enhanced through chemical activation with potassium hydroxide. Activation increases the surface area of adsorbent pores and improves the efficiency of pollutant adsorption in wastewater. Although many studies have examined the use of pineapple waste as an adsorbent, only a few have specifically examined the ability of pineapple crowns to remove BOD₅ and COD from industrial rubber wastewater (Mu et al., 2024; Saghier et al., 2025).

Previous studies have extensively discussed the use of pineapple waste as an adsorbent, but most of them still use synthetic wastewater and have not been directly applied to rubber industry wastewater. In addition, studies on the use of KOH activated pineapple crowns and the effect of variations in adsorbent mass and stirring speed on BOD₅ and COD removal are still limited. Therefore, the novelty of this study is in its use of KOH activated pineapple crowns as adsorbents for the actual treatment of rubber industry wastewater.

The effectiveness of adsorption is enhanced by activating the adsorbent using KOH. Previous studies have shown that KOH can increase the surface area of the adsorbent, thereby increasing its adsorption capacity (Putra et al., 2025). This study aims to analyze pineapple crown adsorbents activated with KOH for BOD₅ and COD removal, as well as to assess the effect of adsorbent dosage and stirring speed in the adsorption process.

2. EXPERIMENTAL SECTION

2.1 Materials

The pineapple crown was collected from a pineapple plantation in Tangkit Baru village, Jambi Province. Pineapple crowns are dried in the sun until completely dry to reduce their moisture content, and then dried in an oven at 105°C for 48 hours. The sample was then carbonized at 400°C for 2 hours and cooled in a desiccator. The resulting carbon was sieved through a 40 mesh screen to obtain a uniform size. The sieved material is activated with 0.1 M KOH for 24 hours, then filtered with Whatman 42 paper and washed with distilled water until the solution is neutral. It is dried in an oven at 100°C for 1 hour and is ready for use. Characterization includes moisture, ash, and volatile content, as specified in SNI 06-3730-1995.

2.2 Methods

Rubber wastewater was collected from the rubber industry in Jambi City. The experiment was conducted in batches according to the ASTM D3860 standard method (Naswir et al., 2020), using 200 mL of wastewater. The variations in adsorbent dosage used were 0.5, 1.0, and 1.5 g at stirring

speeds of 50, 100, and 150 rpm. The contact time was 30 minutes, and the pH was neutral. The solution was then filtered using Whatman 42 filter paper to separate the solids. The wastewater parameters tested were BOD₅ and COD, using the Baird et al. (2017), which is based on the Standard Methods for the Examination of Water and Wastewater. The test was conducted in triplicate and the results are presented as averages. Removal efficiency was calculated using Equation (1), and adsorption capacity (q_e) using Equation (2) (Riyanti et al., 2024a).

$$\text{Efficiency (\%)} = \frac{C_1 - C_2}{C_1} \times 100\% \quad (1)$$

$$q_e = \frac{C_o - C_e}{m} \times V \quad (2)$$

where C_1 is the initial concentration (mg/L), C_2 is the final concentration (mg/L), V is the volume of the solution, and m is the mass/dose of adsorbent used.

2.2.1 Adsorption Isotherms

Adsorption isotherms were analyzed using two general models, namely the Freundlich and Langmuir models. Freundlich adsorption isotherm provides an equation for adsorption with the concentration of substances in solution (which have not yet attached to the surface) (Murphy et al., 2023). Freundlich detects a heterogeneous surface, suitable for multilayer adsorption. Freundlich isotherm as follows in Equations (3) and (4).

$$\frac{x}{m} = K \times C^{1/n} \quad (3)$$

$$\log q_e = \log K_f + \left(\frac{1}{n}\right) \log C_f \quad (4)$$

Where q_e is the amount of BOD₅ and COD adsorbed per g of adsorbent (mg/g), K_f and n are the Freundlich constants, and C_f is the concentration of adsorbate at equilibrium. The Langmuir isotherm detects a homogeneous surface, suitable for monolayer adsorption. The evaluation used a simple line graph between the balanced substance amount and the stuck substance using Langmuir's method (Murphy et al., 2023) In Equation (5).

$$\frac{C_e}{q_e} = \frac{1}{q_m} \times C_e + \frac{1}{K_L \times q_m} \quad (5)$$

Where K_L is the equilibrium constant, C_e is the concentration of adsorbate at equilibrium, and q_m is the maximum adsorption capacity. This study used first order and second order pseudo kinetic models to determine the adsorption mechanism of solutes by adsorbents and adsorption constants.

3. RESULTS AND DISCUSSION

3.1 Characterization of Adsorbent

The characteristics of pineapple crown adsorbents were examined to determine the best adsorbent quality before testing on industrial rubber wastewater in terms of BOD₅ and COD adsorption in wastewater. The characteristics of activated pineapple crown adsorbents were evaluated through tests for water content, ash content, and volatile content.

Table 1 presents the results of adsorbent characteristic tests from pineapple crowns, referencing the SNI-06-3730-1995 standard. The adsorbent exhibited a moisture content of 10.4%, which is below the 15% maximum, meeting the requirements. The ash content was 4.6%, which is lower than the 10% limit, indicating a relatively low inorganic mineral content. The volatile content was 6.7%, well under the 25% maximum, demonstrating good thermal stability.

Table 1. Pineapple Crown Adsorbent Characteristic Tests

Parameters	Test Results	SNI-06-3730-1995
Water Content (%)	10.4	Max 15%
Ash Content (%)	4.6	Max 10%
Volatility Level (%)	6.7	Max 25%

3.1.1 Morphological Characteristics of Pineapple Crowns

Morphological characteristics of pineapple crowns using Scanning Electron Microscopy (SEM) to observe surface structure and pore distribution formed to evaluate changes in material microstructure and its potential role in increasing pore surface area in absorption effectiveness, as shown in Figure 1.

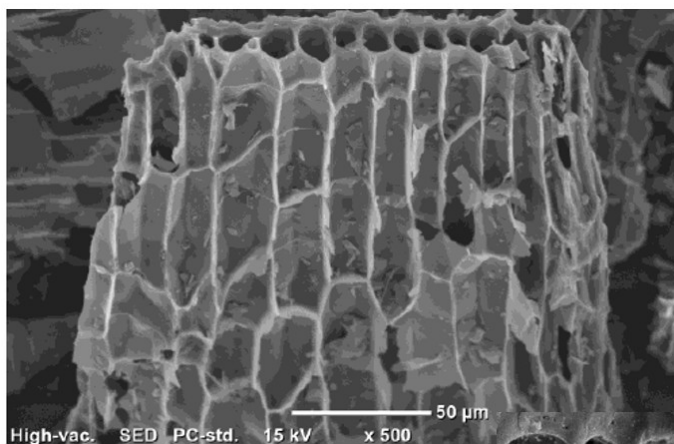


Figure 1. Morphological Characteristics of Pineapple Crowns Using SEM at 500×

Figure 1 above shows that the SEM test results with 500× magnification reveal a regular pore structure, resembling a cellular network with elongated and interconnected pores.

This morphology is a characteristic feature of lignocellulosic biomass, in which the cell wall structure is preserved after thermal or chemical treatment. The presence of open macro pores plays a crucial role in facilitating the diffusion of adsorbates into the material's structure, as well as supporting the formation of micropores during the advanced activation stage, as reported in various biomass based biochar studies (Mukherjee et al., 2025; Tan et al., 2017). This well defined porous structure demonstrates the material's potential as an adsorbent or carbon based functional material.

3.1.2 Pineapple Crown Adsorbent Function Cluster

Analysis of pineapple crown functional groups using Fourier Transform Infrared Spectroscopy (FTIR) to identify the types of chemical bonds and surface functional groups formed after the activation process.

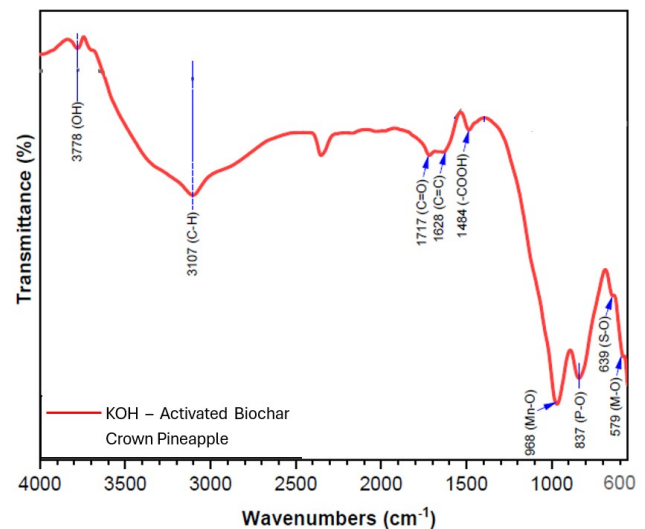


Figure 2. FTIR Spectrum Pineapple Crown Adsorbent

The FTIR results in Figure 2 above show that KOH activated pineapple peel biochar has main functional groups in the form of -OH, aromatic C-H, C=O, and aromatic C=C. The -OH band at around 3778 cm⁻¹ is related to hydroxyl groups or adsorbed water on the biochar surface, while the aromatic C-H peak (3107 cm⁻¹) indicates the presence of aromatic structures. The carbonyl (C=O) band at 1717 cm⁻¹ and the aromatic C=C bond at 1628 cm⁻¹ indicate an increase in the degree of aromatization due to the carbonization and activation processes using KOH (He et al., 2024). These oxygen groups serve as active surface sites, enhancing the adsorption capacity of biochar (Jiang et al., 2024; Pasiieczna-Patkowska and Cichy, 2025).

3.1.3 Surface Texture Characteristics of Pineapple Crown Adsorbent

The surface texture characteristics of pineapple crown adsorbents were analyzed using the Brunauer-Emmett-Teller

(BET) method to determine the specific surface area and pore volume, as shown in Table 2.

Table 2. Specific Surface Area and Pore Volume of Pineapple Crown Adsorbents Based on BET Analysis

Material	Specific Surface Area BET (m ² /g)	Pore Volume (cc/g)
Activated Biochar	3.28	0.014

Table 2 above shows that the BET analysis of activated biochar has a specific surface area of 3.28 m²/g and a pore volume of 0.014 cc/g, indicating limited pore development. Such low BET values have been reported in biomass based biochar with dominant mesopores or pores partially blocked by mineral residues, as shown in a recent study He et al. (2024).

3.2 BOD₅ Removal

Table 3 illustrates substantial fluctuations in adsorption efficiency and capacity resulting from variations in stirring speed. At 50 rpm, efficiency ranged from 90.32% to 90.81%. The highest capacity, 60.38 mg/g, was observed with 0.5 g of adsorbent, while 1.5 g resulted in the lowest at 20.03 mg/g. Increasing the speed to 100 rpm raised the efficiency to 94.35% for 0.5 g, with an adsorption capacity of 62.78 mg/g. At a dosage of 1.5 g, efficiency dropped to 90.63% and capacity decreased to 20.10 mg/g. At 150 rpm, the highest removal efficiency, 95.11%, was achieved with 1.5 g, but the highest capacity, 62.00 mg/g, was obtained with 0.5 g. Thus, higher stirring speeds can enhance the interaction between the adsorbent and solution, thereby improving decomposition. However, increasing the adsorbent dosage does not always increase capacity, as saturation occurs faster at a constant solution concentration (Abbas and Trari, 2024).

Figure 3 (A) shows that the removal efficiency exceeds 90% for all treatments, indicating high performance. At a dosage of 0.5 g, the highest efficiency occurs with 100 g of adsorbent. At a dosage of 1 g, efficiency slightly decreases in all treatments. At a dosage of 1.5 g, efficiency increases again, peaking at nearly 98% with 150 g of adsorbent. Overall, separation efficiency is stable and high, with 150 g of adsorbent at 1.5 g showing optimal performance (Bayuo et al., 2024; Xu et al., 2025). Figure 3 (B) shows that the highest BOD₅ adsorption capacity occurred at an adsorbent dosage of 0.5 g (60.38–62.78 mg/g). Increasing the dosage to 1 g and 1.5 g reduced the capacity to 29–30 mg/g and 20–21 mg/g, respectively. This indicates that increasing the adsorbent dosage decreases the effective capacity per g, likely due to a reduced available surface area per unit and limited contaminant levels (Sinaga et al., 2023; Mishra et al., 2024).

3.3 COD Removal

The COD removal efficiency using the pineapple crown is presented in Table 4. The separation efficiency ranges from 86.53% to 95.20%. The highest efficiency and adsorption capacity were observed at 100 rpm and 0.5 g (95.20%; 199.81 mg/g), while the lowest values were obtained at 150 rpm and 1 g (86.53%; 90.81 mg/g). As the adsorbent dosage increases, the adsorption capacity decreases, although the separation efficiency remains high (Chouchane et al., 2023). This suggests that increasing the adsorbent dosage reduces the capacity per g due to surface saturation, while operating at 100 rpm enhances contact efficiency (Sinaga et al., 2023; Cano et al., 2025).

Separation efficiency was above 85% for all treatments: 50, 100, and 150 g. At 0.5 g, the highest efficiency was observed at the 100 g treatment (approximately 96%), while the 150 g treatment had the lowest efficiency. When mass increased to 1 g, efficiency decreased in the 100 and 50 g treatments but increased in the 150 g group. At 1.5 g, efficiency peaked in the 150 g treatment, while the others remained stable or slightly declined. These results demonstrate that combinations of dosage and treatment influence trends, yet consistently achieve high efficiency (Chouchane et al., 2023; Gaber et al., 2025).

Figure 4 illustrates that as the adsorbent dosage increases, the adsorption capacity per g decreases. At 0.5 g, the adsorption capacity is the highest (approximately 195–200 mg/g). This capacity falls sharply at 1 g and drops further at 1.5 g. The decrease occurs in all treatments. Thus, more adsorbent does not always raise efficiency per unit mass. This may be due to surface saturation or a reduced concentration gradient between the solution and the adsorbent (Mishra et al., 2024; Saghiri et al., 2025).

3.4 Isotherm Models

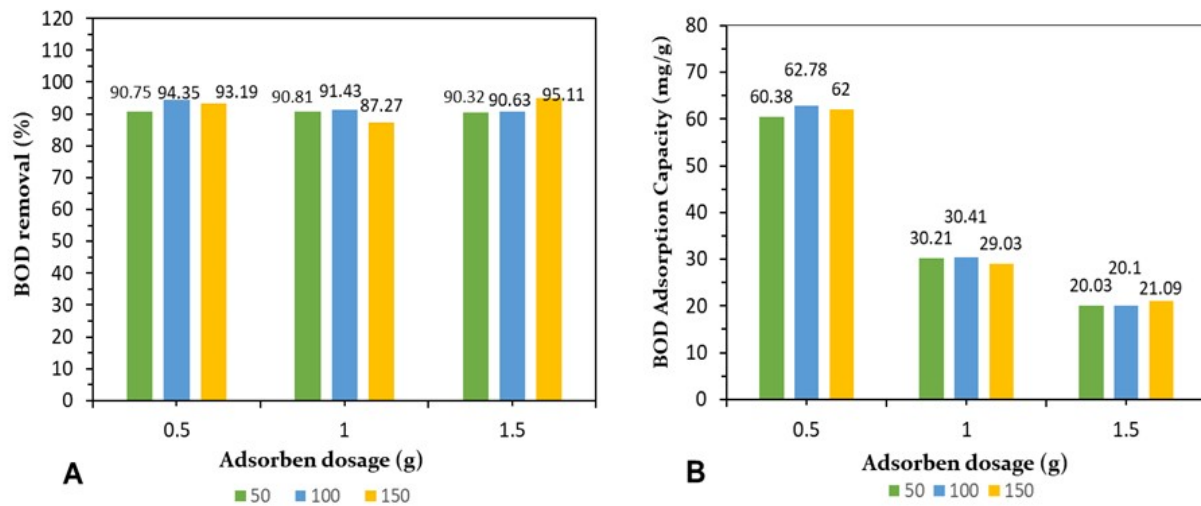
3.4.1 Langmuir Isotherm and Freundlich Isotherm

The Freundlich isotherm model outperforms the Langmuir model, as evidenced by its higher R² value. This suggests that the adsorption process is physical in nature, occurs on a heterogeneous surface, and involves multiple layers (Murphy et al., 2023; Bbumba et al., 2024). Notably, such a pattern is common among chemically activated biomass adsorbents. To determine the most suitable isotherm model, the regression values of each graph were analyzed. Subsequently, the results of the Freundlich isotherm calculation for a dosage of 0.5 g.

To calculate the Freundlich and Langmuir isotherm equations, the values of C_e , C_e/Q_e , $\log C_e$, and $\log Q_e$ were calculated. Graphical mapping was performed by combining the C_e values with C_e/Q_e to obtain the Langmuir equation and the $\log Q_e$ values with $\log C_e$ to obtain the Freundlich equation (Mishra et al., 2024; Cano et al., 2025). The Freundlich isotherm graph for the BOD₅ parameter was shown in Figure 4(A). Figure 4A shows the Freundlich isotherm curve for BOD₅ adsorption. Plotting $\log C_e$ (mg/L) against $\log Q_e$ (mg/g) gives a linear regression, $y = -2.0878x +$

Table 3. BOD₅ Removal

Stirring Speed (rpm)	Dosage (g)	Initial Concentration (mg/L)	Final Concentration (mg/L)	Removal Efficiency (%)	Adsorption Capacity (mg/g)
50	0.5	166.34	15.38	90.75	60.38
	1.0	166.34	15.28	90.81	30.21
	1.5	166.34	16.11	90.32	20.03
100	0.5	166.34	9.39	94.35	62.78
	1.0	166.34	14.26	91.43	30.41
	1.5	166.34	15.58	90.63	20.10
150	0.5	166.34	11.33	93.19	62.00
	1.0	166.34	21.18	87.27	29.03
	1.5	166.34	8.14	95.11	21.09

**Figure 3.** BOD₅ Removal Efficiency (A) and Adsorption Capacity (B) in Different Adsorbent Dosages and Stirring Speeds**Table 4.** COD Removal

Stirring Speed (rpm)	Dosage (g)	Initial Concentration (mg/L)	Final Concentration (mg/L)	Removal Efficiency (%)	Adsorption Capacity (mg/g)
50	0.5	524.74	45.65	91.30	191.63
	1.0	524.74	50.20	90.43	94.90
	1.5	524.74	57.02	89.13	62.36
100	0.5	524.74	25.20	95.20	199.81
	1.0	524.74	47.93	90.87	95.36
	1.5	524.74	52.47	90.00	62.96
150	0.5	524.74	36.56	93.03	195.27
	1.0	524.74	70.66	86.53	90.81
	1.5	524.74	28.61	94.55	66.15

3.8381, with $R^2 = 0.9593$. An R^2 close to 1 shows that the model fits the data well. The negative slope means that as C_e increases, Q_e decreases. Thus, higher C_e results in lower adsorption, possibly due to saturation of the adsorbent surface (Riyanti et al., 2024c).

Determine regression values Plot Q_e on the X axis and

C_e/Q_e on the Y axis to create the Langmuir isotherm graph. A negative slope shows the adsorption process does not follow the Langmuir model. Figure 4(B) shows the Langmuir isotherm for BOD₅. A strong correlation coefficient (R^2) of 0.9083 for the Langmuir isotherm model using pineapple crown adsorbents. The negative slope observed in the graph

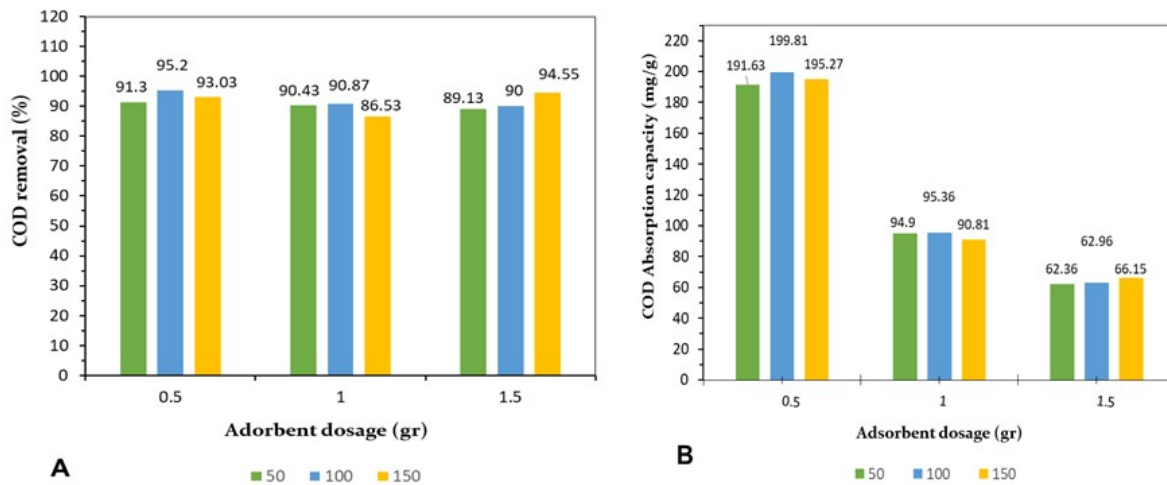


Figure 4. COD Removal Efficiency (A) and Adsorption Capacity (B) in Different Adsorbent Dosages and Stirring Speeds

indicates the nature of the adsorption process, which should be taken into account when interpreting the results. Table 5 compares the values obtained from the adsorption process of BOD₅ in rubber industry waste, based on the equations in the two graphs above.

Table 5. Comparison of BOD Values using the Isotherm Equation

Isotherm	Parameter	Value
Freundlich	K_f	6886.52
	$1/n$	2.0878
	N	0.478
	R^2	0.9593
Langmuir	Q_m	10.940
	K_L	0.125
	R_L	0.045
	R^2	0.9083

Figure 5 above shows that BOD₅ adsorption follows the Langmuir ($R^2 = 0.9083$) and the Freundlich ($R^2 = 0.9593$) isotherm models, with the Freundlich model indicating a better fit and suggesting multilayer adsorption on a heterogeneous surface. The Langmuir R_L value of 0.045 shows positive adsorption. Freundlich's K_f is 6886.52, and the $1/n$ value is 2.0878, suggesting less heterogeneity and weak adsorbent-adsorbate interaction. These conclusions are based on regression values. Table 4 presents the Freundlich isotherm results using 0.5 g of adsorbent (Mason et al., 2018; Riyanti et al., 2024b). Freundlich isotherm model for pineapple crown adsorbents yields a correlation coefficient (R^2) of 0.9391, indicating a very strong correlation (Taqui et al., 2023; Hoang et al., 2024) (Figure 5A).

The Langmuir isotherm showing the Q_e value as the

X axis and the C_e/Q_e value as the Y axis. Figure 6 shows the Langmuir isothermal graph for the COD parameter (Dehghani et al., 2023; Saghir et al., 2025). The Langmuir isotherm model applied to pineapple crown adsorbents yielded a correlation coefficient (R^2) of 0.8949, indicating a strong correlation (Taqui et al., 2023) (Figure 5B). Table 5 compares these results with values for COD adsorption from rubber industry waste.

Table 6. Comparison of COD Values using the Isotherm Equation

Isotherm	Parameter	Value
Freundlich	K_F	19742.40
	$1/n$	1.4176
	N	0.705
	R^2	0.9391
Langmuir	Q_m	43.66
	K_L	0.048
	R_L	0.038
	R^2	0.8949

Table 6 shows that COD The selection of adsorbent dosage in this study rption follows the Freundlich isotherm model, with an R^2 value of 0.9391, showing that the material surface is uneven and made of layers. This model applies to physical adsorption because the strength of attachment varies across the surface. (Naswir et al., 2020; Mishra et al., 2024). The Freundlich constant (K_f) of 19.742,40 indicates that the adsorbent strongly binds COD. However, the $1/n$ value of 1.4176, which means the unevenness and strength of the adsorption, suggests that the COD adsorption is not entirely uneven. This isotherm model helps measure the amount of COD that the adsorbent can hold, using results

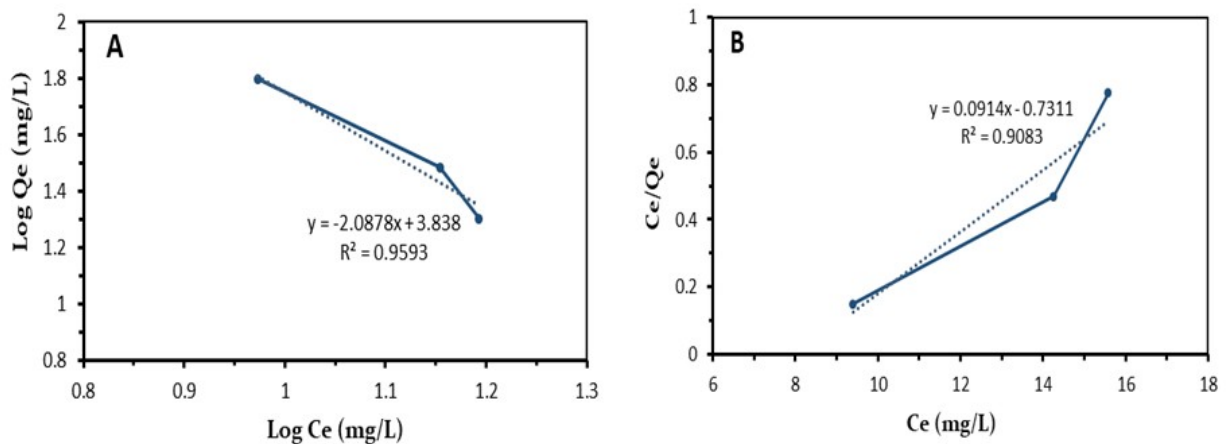


Figure 5. Freundlich (A) and Langmuir (B) Isotherm of BOD₅

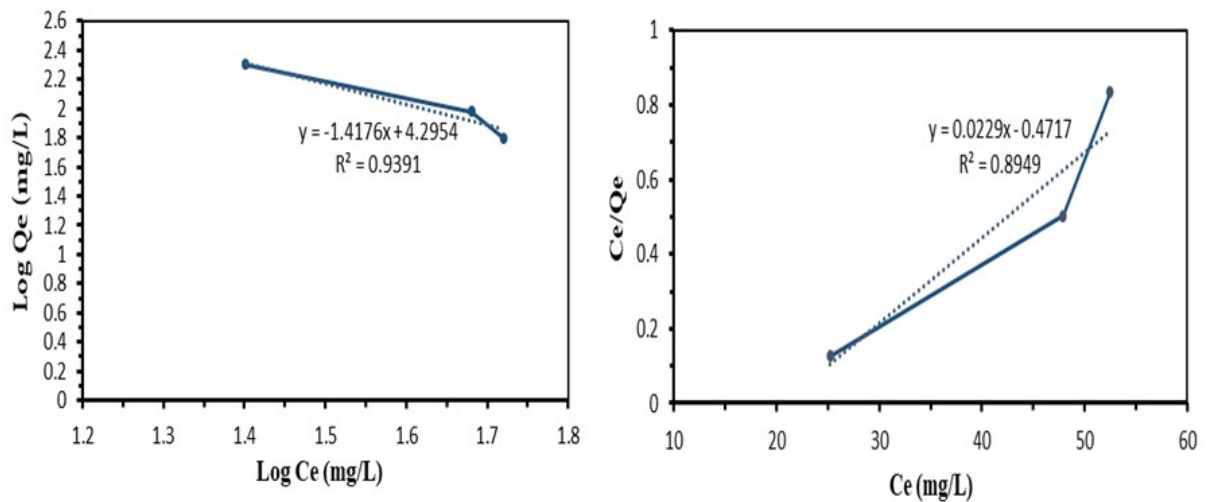


Figure 6. Freundlich (A) and Langmuir (B) Isotherm of COD

from the equilibrium graph (Mishra et al., 2024).

This study is also consistent with the characteristics of porous carbon-based adsorbents, where a combination of surface heterogeneity and the presence of active functional groups supports adsorption mechanisms involving predominantly physical interactions with contributions from chemical interactions. The suitability of the Freundlich model is also in line with kinetic results that show the significant role of initial diffusion before adsorption equilibrium is reached (Putri, 2024).

3.4.2 Adsorption Kinetics Study

Adsorption kinetics analysis was performed to evaluate the adsorption rate and mechanism of BOD and COD on the adsorbent used. The kinetic models applied included the first

order and second order pseudo order models, each of which was analyzed through a linear approach using experimental data at various contact times. The results of the kinetic modeling are presented in Figures 7 and 8.

Table 7. BOD and COD Adsorption Kinetics Parameters

Adsorption	Pseudo First Order			Pseudo Second Order		
	K ₁	Q _e	R ²	K ₂	Q _e	R ²
BOD	-0.04	10.50	0.65	1.39	0.122	0.71
COD	-0.05	11.69	0.86	1.46	0.001	0.83

The kinetic analysis of BOD and COD adsorption in Table 7 above was conducted to determine the adsorption rate and adsorption mechanism in the adsorbent. Two

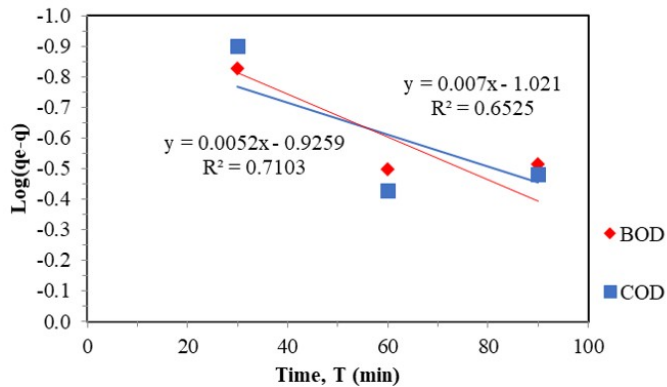


Figure 7. First Order Adsorption of BOD and COD

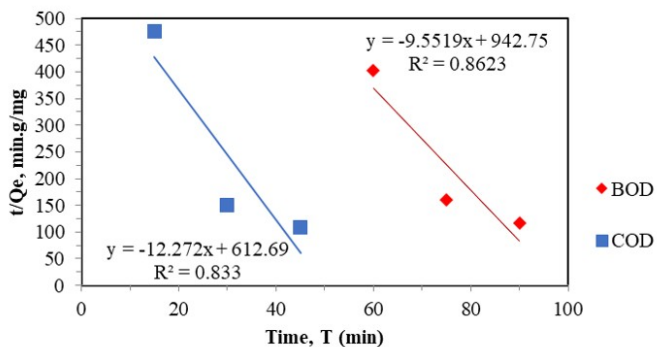


Figure 8. Second Order Adsorption of BOD and COD

general kinetic models, first order and second order, were applied through a linear approach based on experimental data at various contact times. Kinetic parameters obtained from linear regression are presented in tables and graphs. The modeling results show that the first order pseudo model provides a coefficient of determination (R^2) value of 0.7103 for BOD and 0.6525 for COD, which reflects a less than optimal fit to the experimental data. In contrast, the pseudo second order model showed higher R^2 values, namely 0.8623 for BOD and 0.8331 for COD, as well as stronger linearity in the t/q_t versus time graph. This comparison indicates that the adsorption of BOD and COD is better explained by the pseudo second order model.

Model validation was performed by comparing the R^2 values and the consistency of the kinetic parameters of both models. The higher R^2 value in the pseudo second order model indicates that the adsorption rate is controlled by a chemisorption mechanism involving interactions between active groups on the adsorbent surface and adsorbate molecules, in accordance with recent adsorption kinetics reports that also show the dominance of the pseudo second order model in wastewater contaminant adsorption systems (Alrowais et al., 2024).

According to Adawiyah et al. (2021), the results of this

kinetic study are consistent with the pseudo-second-order (PSO) model, which provides the best fit, indicating that the adsorption rate is controlled by a chemisorption mechanism through the formation of chemical bonds on the adsorbent surface. Thus, based on the R^2 value and the fit of the kinetic parameters, the second pseudo order model is validated as the most suitable model to describe the adsorption kinetics of BOD and COD in this system.

4. CONCLUSIONS

This study concluded that pineapple crowns activated with potassium hydroxide (KOH) serve as effective adsorbents for removing pollutants from rubber industry wastewater, achieving removal efficiencies of 94.35% for biochemical oxygen demand (BOD₅) and 95.19% for chemical oxygen demand (COD). The adsorption efficiency is significantly influenced by the dosage of the adsorbent and the stirring speed, with optimal conditions obtained using 1 g of adsorbent and a stirring speed of 100 rpm. Furthermore, the adsorption process is better described by the Freundlich isotherm model than by the Langmuir model, indicating that the adsorption mechanism is physical in nature and occurs on a heterogeneous, multilayered adsorbent surface. Future research should investigate the regeneration and reuse potential of the activated pineapple crown adsorbent, as well as explore its effectiveness in treating other types of industrial or heavy metal wastewater. Additionally, studies on the kinetics of adsorption and the influence of different activation agents or process conditions could provide deeper insights into optimizing the adsorption performance and practical application of this environmentally friendly material.

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