



Kinetic Analysis of Dodecylbenzene Sulfonate (DBS) Adsorption Using Coconut Residue Char Based on Pseudo-Order Models

Zakiyah Darajat^{1*}, Fauziah Nur Aisyah², Mimin Septiani¹

¹ Department of Chemical Engineering, Politeknik Negeri Ujung Pandang, Makassar

² Chemical Engineering Study Program, Universitas Muslim Indonesia, Makassar

*Corresponding Address: zakiyah.darajat@poliupg.ac.id

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ABSTRACT

This study aims to analyze the adsorption kinetics of Dodecylbenzene Sulfonate (DBS) using coconut residue char as a waste-based adsorbent. The experiment was conducted by varying contact time to observe changes in adsorption capacity. The data were analyzed using pseudo-first-order (PFO) and pseudo-second-order (PSO) kinetic models. The results showed that adsorption capacity increased with contact time until equilibrium was reached at $q_e = 0.0892$ mg/g. The PFO model produced a rate constant (k_1) of 0.0254 min^{-1} with $R^2 = 0.9379$, while the PSO model yielded $k_2 = 1.768 \text{ g mg}^{-1} \text{ min}^{-1}$ with $R^2 = 0.9949$. The theoretical q_e from PSO (0.0906 mg/g) was closer to the experimental value than that from PFO (0.0536 mg/g). These findings indicate that DBS adsorption follows the pseudo-second-order model, suggesting a chemisorption-controlled mechanism. Coconut residue char shows strong potential as a low-cost and environmentally friendly adsorbent for surfactant removal.

Keywords: adsorption, DBS, coconut residue char

I. INTRODUCTION

Water pollution caused by surfactant-containing wastewater has become a significant environmental concern due to increasing industrial activities and domestic detergent usage. (Jena et al., 2023). One of the most commonly used anionic surfactants is Dodecylbenzene Sulfonate (DBS), which enhances detergent performance by reducing the surface tension of water. However, despite its effectiveness in cleaning applications, the presence of this compound in aquatic environments can deteriorate water quality (Abdul et al., 2023). Surfactants in detergents, at certain concentrations, can form foam that covers the water surface. This phenomenon inhibits the diffusion of oxygen from the air into the water, reduces dissolved oxygen levels, and may disrupt aquatic organisms (Larasati et al., 2021).

Various approaches have been developed to reduce surfactant content in wastewater, including biological treatment, chemical processes, and adsorption techniques. Among these methods, adsorption is widely preferred due to its high efficiency in removing contaminants, particularly at low concentrations, as well as its operational simplicity. The performance of this process is strongly influenced by the physical and chemical properties of the adsorbent used (Kulkarni et al., 2025).

The utilization of biomass-based materials as alternative adsorbents has gained increasing attention due to their advantages in terms of availability, cost-effectiveness, and sustainability (Manurung et al., 2025). Biomass reduces reliance on fossil carbon sources and

offers an effective solution for the management of organic waste, such as agricultural and plantation by-products (Yanti et al., 2024). Coconut waste, including shells and residues, contains lignocellulosic components that can be converted into porous carbon via carbonization. Its porous structure and relatively large surface area render this material highly suitable for the adsorption of various pollutants. Several studies have demonstrated that coconut-based activated carbon possesses a high adsorption capacity for dyes and organic compounds in aqueous systems (Saleem et al., 2024), and offers advantages in terms of sustainability compared to conventional materials (Saleem et al., 2025).

Furthermore, the effectiveness of coconut-based adsorbents has been demonstrated in the removal of anionic surfactants such as sodium dodecyl sulfate, which exhibits chemical properties similar to those of DBS (Abdul et al., 2023). Other studies have also shown that this material is capable of significantly adsorbing dyes, indicating its ability to interact with various types of contaminants (Siswanti et al., 2025). This further strengthens the potential of coconut-based charcoal as an alternative adsorbent for wastewater treatment.

To gain a deeper understanding of the adsorption process, kinetic studies are an important aspect to be analyzed. The kinetic approach enables the determination of the adsorption rate as well as the interaction mechanism between the adsorbent and adsorbate. The pseudo-first-order (PFO) and pseudo-second-order (PSO) models are among the most commonly used models in adsorption kinetic analysis. The PFO model is generally associated with physical adsorption processes, whereas the PSO model more closely reflects chemisorption mechanisms, involving stronger interactions between adsorbent surfaces and adsorbate molecules (Ho & McKay, 1999). Several recent studies have also reported that adsorption using coconut-based carbon tends to follow the PSO model, indicating the dominance of a chemical mechanism in the adsorption process (Carmen et al., 2024).

Based on the aforementioned description, this study aims to investigate the adsorption kinetics of dodecylbenzene sulfonate (DBS) using coconut shell charcoal as a waste-based adsorbent. The analysis is conducted by applying pseudo-first-order and pseudo-second-order kinetic models to determine the most suitable model for describing the adsorption process. The novelty of this study lies in the utilization of coconut shell charcoal as a waste-derived alternative adsorbent for DBS removal, as well as a comprehensive evaluation of its adsorption kinetics, which remains limited in the existing literature

II. METHODS

1. Materials and Equipment

1.1 Materials

The materials used in this study include coconut waste (coconut residue) obtained from UMKM “Sarabba” shop at Jl. Sungai Cerekang, Makassar City, synthetic detergent (Brand X) as a surfactant source, distilled water as a solvent, phenolphthalein (PP) indicator, NaOH solution, H₂SO₄ solution, methylene blue, and chloroform (CHCl₃).

1.2 Alat

The main equipment consisted of an adsorption column made of PVC pipe with a diameter of 2 inches and a height of 120 cm, equipped with a screen and an outlet valve. Supporting equipment included a sieve, a UV-Vis spectrophotometer, and standard laboratory glassware.

2. Adsorbent Preparation

Coconut residue was first washed to remove impurities and then dried. Carbonization was carried out by roasting the dried material until black charcoal was obtained. The

resulting charcoal was then ground and sieved to obtain a particle size of -20/+50 mesh. The prepared adsorbent was stored in a sealed container prior to use.

3. Solution Preparation

3.1 DBS Standard Solution

The DBS standard solution was prepared using NaDBS with an initial concentration of 100 ppm. Standard solutions with concentrations of 0, 1, 2, 5, 10, 25, and 50 ppm were then prepared for the construction of the calibration curve.

3.2 Synthetic Detergent Waste Solution

Fifteen grams of synthetic detergent were dissolved in 50 liters of distilled water to obtain the detergent wastewater solution used as the sample in this study.

4. Adsorption Process

The adsorption experiment was conducted using a fixed-bed column method. The adsorbent was packed into the column to a height of 40 cm. The detergent wastewater solution was then passed through the column until the adsorbent was fully submerged. Samples were collected at regular intervals of 20 minutes (0, 20, 40, 60, 80, 100, 120, and 140 minutes). Experiments were performed with variations in adsorbent bed height and particle size.

5. Determination of DBS Concentration

DBS concentration was analyzed using the methylene blue active substances (MBAS) extraction method. A 10 mL sample was placed in a separatory funnel, followed by the addition of 3 drops of phenolphthalein (PP) indicator and NaOH 1 N solution until a pink color appeared. Subsequently, H₂SO₄ 1 N was added until the solution turned colorless.

Then, 2.5 mL of methylene blue solution and 3 mL of chloroform were added. The mixture was shaken for approximately 10 seconds, with occasional venting of the separatory funnel to release gas. The mixture was allowed to settle until two phases formed.

The lower phase was separated and transferred to another separatory funnel. The upper phase was re-extracted by adding 2 mL of chloroform and shaking until two phases formed again. The lower phases from both extractions were combined.

The combined extract was then washed by adding 5 mL of distilled water, shaken, and separated again. The lower phase was collected and transferred into a volumetric flask, then diluted with a dilution factor of 1:5. The absorbance of the final extract was measured using a UV-Vis spectrophotometer at a wavelength of 652 nm.

6. Adsorption Capacity Calculation

At the adsorption capacity at a given time (q_t) was calculated using the following equation:

$$q_t = \frac{(C_0 - C_t)V}{m} \quad (1)$$

The equilibrium adsorption capacity (q_e) was calculated using:

$$q_e = \frac{(C_0 - C_e)V}{m} \quad (2)$$

Dimana:

- C_0 = initial concentration (mg/L)
- C_t = concentration at time t (mg/L)
- C_e = equilibrium concentration (mg/L)
- V = solution volume (L)

- m = mass of adsorbent (g)

7. Adsorption Kinetics Analysis

7.1 Pseudo-First Order (PFO) Model

The pseudo-first-order kinetic model is expressed by the following equation:

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

The adsorption rate constant (k_1) was obtained from the slope of the linear plot of $\ln(q_e - q_t)$ versus time (t) (Lima et al., 2021)(Liu et al., 2021)(Lagergren, 1898).

7.2 Pseudo-Second Order (PSO) Model

The pseudo-second-order kinetic model is expressed as:

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

The adsorption rate constant (k_2) was determined from the slope of the linear plot of t/q_t versus time (t) (Ho & Mckay, 1999).

8. Data Analysis

The experimental data were analyzed by comparing the coefficient of determination (R^2) values obtained from each kinetic model. The model with the highest R^2 value and a theoretical adsorption capacity ($q_{e,cal}$) closest to the experimental value ($q_{e,exp}$) was considered the most appropriate model for describing the adsorption mechanism.

III. RESULTS AND DISCUSSION

1. Effect of Contact Time on the Adsorption Capacity (q_t)

The relationship between adsorption capacity (q_t) and contact time is shown in Figure 1.

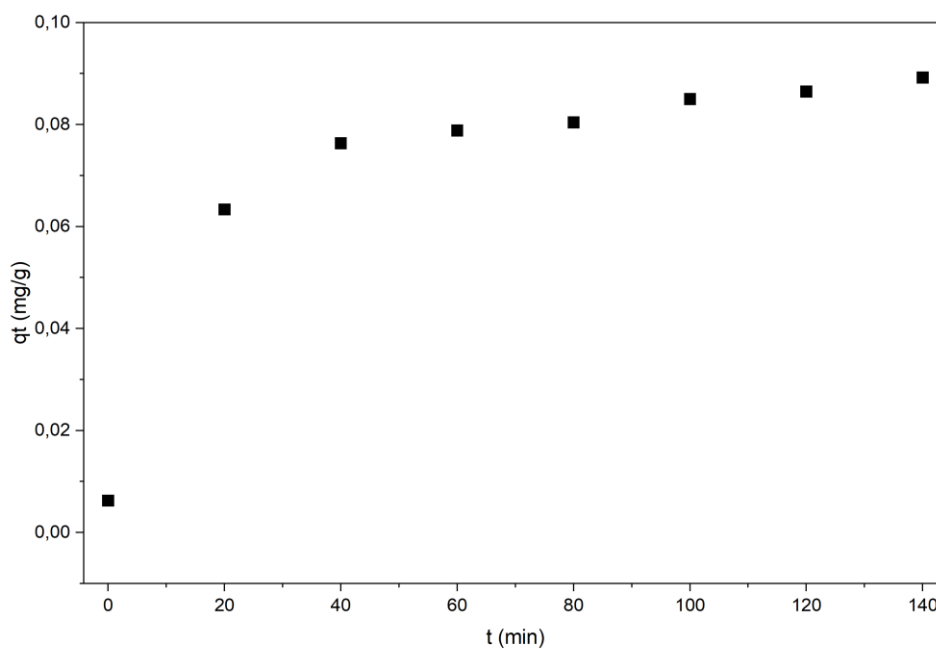


Figure 1. Relationship between contact time (t) and adsorption capacity (q_t) in DBS adsorption using coconut waste charcoal.

Based on the graph, the value of q_t increased with increasing contact time between the adsorbent and adsorbate.

In the initial stage of the process (0–40 min), a significant increase in q_t was observed. This indicates that a large number of active sites on the surface of coconut waste charcoal were still available for binding Dodecylbenzene Sulfonate (DBS) molecules, resulting in a high adsorption rate (Jia et al., 2025). The steep slope of the curve during this stage indicates a high mass transfer rate from the solution to the adsorbent surface.

As contact time increased, the adsorption capacity gradually slowed down and approached equilibrium between 120 and 140 minutes, with an experimental q_e value of 0.0892 mg/g. At this condition, most of the active sites on the adsorbent surface had been occupied by adsorbate molecules, limiting further adsorption. This is reflected by the curve reaching a plateau, indicating adsorption equilibrium, where the adsorption rate equals the desorption rate. Therefore, extending contact time beyond this point does not significantly increase adsorption capacity (Ni et al., 2025).

These phenomena suggest that the adsorption process occurs in several stages. Initially, adsorption proceeds rapidly due to a high concentration gradient between the solution and the adsorbent surface. Subsequently, the adsorption rate decreases due to the reduction of available active sites and increased diffusion resistance within the adsorbent pores. This behavior is a common characteristic of carbon-based adsorption systems and has been widely reported in previous studies (Al-joubory et al., 2023)

2. Pseudo-First-Order (PFO) Kinetic Model Analysis

Kinetic analysis using the pseudo-first-order model was performed by plotting $\ln(q_e - q_t)$ versus time, as shown in Figure 2.

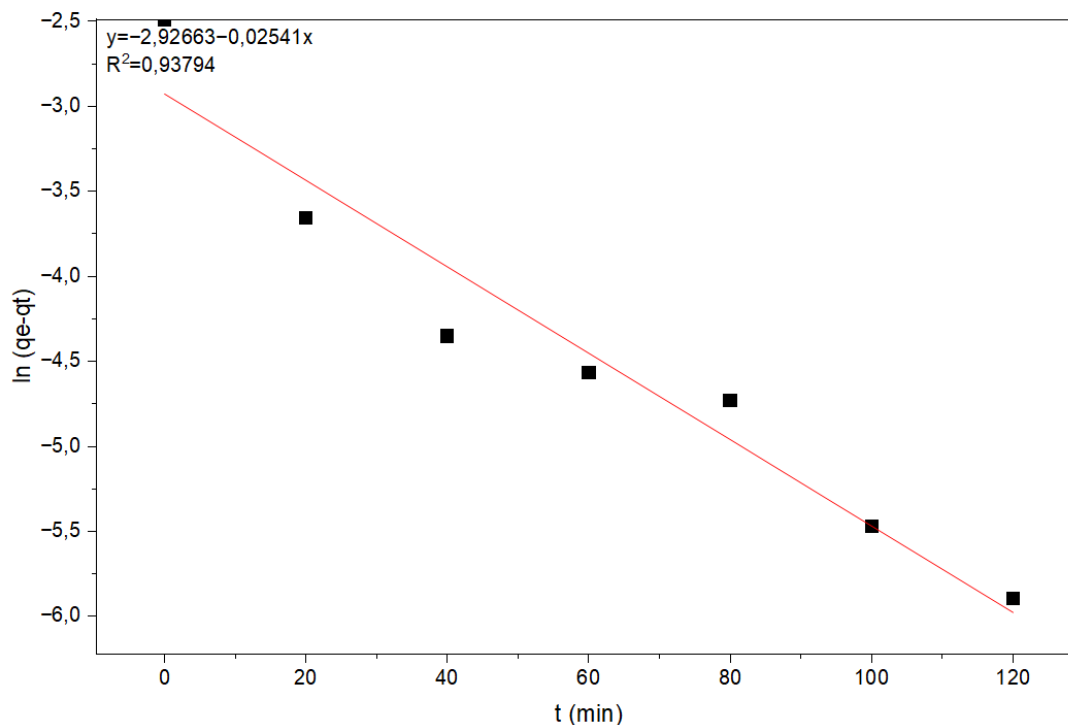


Figure 2. Relationship between contact time (t) and $\ln(q_e - q_t)$ for the pseudo-first-order (PFO) kinetic model in DBS adsorption using coconut waste charcoal.

The results show that the PFO model yielded an adsorption rate constant (k_1) of 0.0254 min^{-1} with a coefficient of determination (R^2) of 0.9379.

Although the R^2 value is relatively high, a significant discrepancy was observed between the theoretical adsorption capacity ($q_{e,cal} = 0.0536 \text{ mg/g}$) and the experimental value ($q_{e,exp} = 0.0892 \text{ mg/g}$). This indicates that the PFO model does not accurately describe the adsorption process. This discrepancy suggests that the adsorption mechanism is not fully governed by physical adsorption or diffusion-controlled processes (Lagergren, 1898), and therefore other models should be considered.

3. Pseudo-Second-Order (PSO) Kinetic Model Analysis

Kinetic analysis using the pseudo-second-order model was performed by plotting t/q_t versus time, as shown in Figure 3.

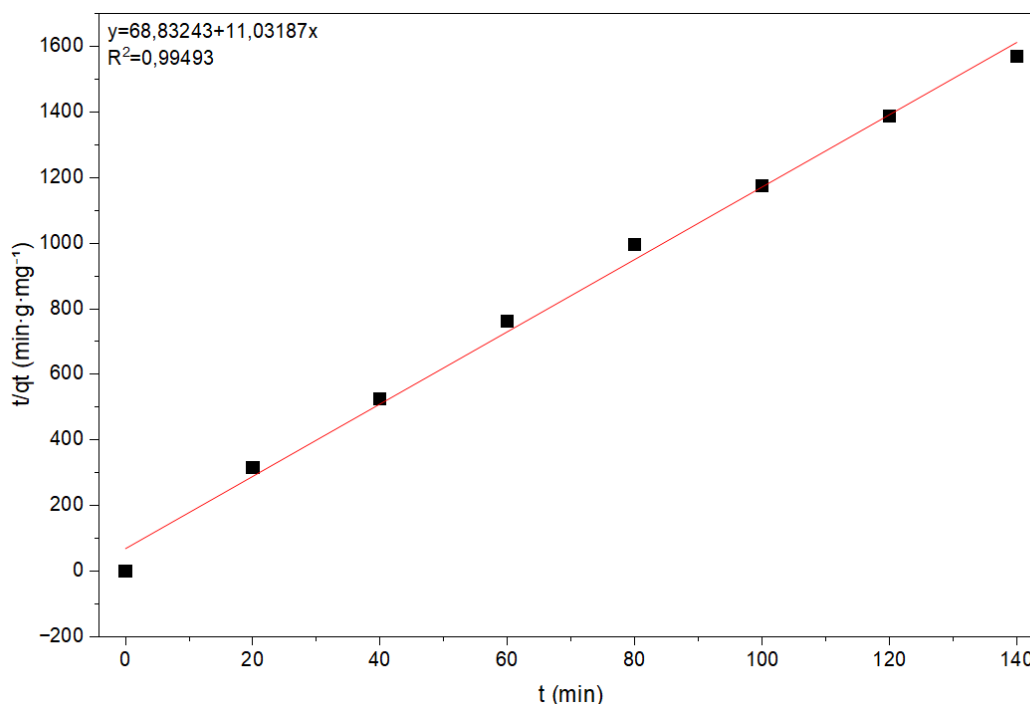


Figure 3. Relationship between contact time (t) and t/q_t for the pseudo-second-order (PSO) kinetic model in DBS adsorption using coconut waste charcoal.

The results show that the PSO model provided an adsorption rate constant (k_2) of $1.768 \text{ g mg}^{-1} \text{ min}^{-1}$ with an R^2 value of 0.9949.

The R^2 value, which is close to 1, indicates an excellent agreement between the model and experimental data. In addition, the theoretical adsorption capacity ($q_{e,cal} = 0.0906 \text{ mg/g}$) is very close to the experimental value ($q_{e,exp} = 0.0892 \text{ mg/g}$).

These results indicate that the PSO model is more appropriate for describing the adsorption kinetics of DBS onto coconut waste charcoal compared to the PFO model. The PSO model is generally associated with chemisorption processes involving chemical interactions between adsorbent and adsorbate, such as bond formation or specific surface interactions (Ho & Mckay, 1999).

4. Adsorption Mechanism

The kinetic analysis results indicate that the adsorption of Dodecylbenzene Sulfonate (DBS) onto coconut waste charcoal follows the pseudo-second-order (PSO) model with a

very high R^2 value (0.9949). This suggests that the adsorption rate is not only controlled by diffusion but also influenced by chemical interactions between the adsorbent and adsorbate. This finding is consistent with recent studies reporting that adsorption of organic compounds using coconut-based activated carbon tends to follow PSO kinetics, reflecting the dominance of chemisorption mechanisms (Saleem et al., 2024)(Carmen et al., 2024).

Structurally, coconut waste charcoal consists of a porous carbon matrix with micro- to mesoporous distribution and a high surface area. These characteristics provide numerous active sites for interaction with DBS molecules. In addition, surface functional groups such as hydroxyl (-OH), carboxyl (-COOH), and carbonyl (C=O) act as active centers that can interact specifically with the adsorbate (Saleem et al., 2025).

As an anionic surfactant, DBS has an amphiphilic structure consisting of a negatively charged sulfonate group ($-\text{SO}_3^-$) and a long hydrocarbon chain. This structure enables complex multi-interaction adsorption mechanisms, including electrostatic and hydrophobic interactions (Talebian & Sagir, 2024). One of the main mechanisms is electrostatic interaction between the sulfonate group and the adsorbent surface. Under certain conditions (e.g., low pH), the carbon surface may become protonated and positively charged, enhancing electrostatic attraction toward negatively charged DBS molecules. Recent studies have shown that pH significantly influences adsorption efficiency by altering surface charge properties (Mustafa et al., 2024).

In addition to electrostatic interactions, hydrophobic interactions also play a significant role in the adsorption process. The long hydrocarbon chain of DBS tends to associate with the non-polar carbon surface, enhancing adsorbate accumulation. The combination of hydrophobic and electrostatic interactions has been shown to improve adsorption efficiency in biomass-based carbon materials (Weiland et al., 2023).

From a transport perspective, the adsorption process occurs through several consecutive steps, including external diffusion, surface adsorption, and intraparticle diffusion into the adsorbent pores until equilibrium is reached. Intraparticle diffusion often becomes the rate-limiting step at longer contact times (Rashda et al., 2024).

Overall, the adsorption mechanism of DBS onto coconut waste charcoal in this study is the result of multiple contributing processes, including external diffusion, surface interactions (electrostatic and hydrophobic), intraparticle diffusion, and chemisorption at active sites.

The complexity of this mechanism explains why the pseudo-second-order kinetic model better describes the adsorption behavior compared to the pseudo-first-order model. Furthermore, these findings support recent studies suggesting that coconut-based biomass adsorbents are effective and sustainable materials for treating wastewater containing organic compounds and surfactants.

IV. CONCLUSION

This study demonstrates that coconut waste charcoal has strong potential as an alternative adsorbent for the removal of Dodecylbenzene Sulfonate (DBS) from aqueous solutions. The adsorption capacity increased with contact time and approached equilibrium at 140 minutes, with an equilibrium adsorption capacity (q_e) of 0.0892 mg/g. Kinetic analysis revealed that the pseudo-second-order (PSO) model provided an excellent fit ($R^2 = 0.9949$) compared to the pseudo-first-order (PFO) model, and yielded a theoretical q_e value that closely matched the experimental data. This indicates that the adsorption process is dominated by a chemisorption mechanism involving chemical interactions between active functional groups on the adsorbent surface and DBS molecules. The adsorption mechanism occurs through multiple stages, including external diffusion, surface interactions (electrostatic and hydrophobic), and intraparticle diffusion within the porous structure of the adsorbent. Therefore, coconut waste

charcoal not only exhibits good adsorption performance but also shows strong potential as a cost-effective and sustainable adsorbent material for wastewater treatment applications containing surfactants.

Further studies are recommended to evaluate the effects of pH, temperature, and adsorbent modification to enhance adsorption capacity.

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VI. REFERENCES

- Abdul, S., Sha, W., Yasid, N. A., Izuan, M., Halmi, E., Othman, A. R., & Shukor, M. Y. (2023). JOURNAL OF ENVIRONMENTAL MICROBIOLOGY Adsorption of Sodium Dodecyl Sulfate onto Activated Coconut Shell- Based Adsorbent : Isothermal Remodelling. *Journal of Environmental Microbiology*, *11*(1), 52–61. <https://doi.org/https://doi.org/10.54987/jemat.v11i1.884>
- Al-joubory, T. G. H., Al-hyali, E. A. S., & Mustafa, R. (2023). Study of the factors affecting the adsorption efficiency of some chemical pesticides activated carbon at the Nanoscale. *International Journal of Advanced Chemistry Research*, *5*(1), 89–98.
- Carmen, L., Tochetto, G., Dervanoski, A., Delise, G., & Pasquali, L. (2024). Kinetic modeling and optimization of triclosan adsorption onto coconut shell activated carbon. *Journal of Hazardous Materials Letters*, *5*(October). <https://doi.org/https://doi.org/10.1016/j.hazl.2024.100131>
- Ho, Y. S., & McKay, G. (1999). Pseudo-second order model for sorption processes. *Process Biochemistry*, *34*, 451–465.
- Jena, G., Dutta, K., & Daverey, A. (2023). Surfactants in water and wastewater (greywater): Environmental toxicity and treatment options. *Journal of Chemosphere*, *1*(November), 341. <https://doi.org/10.1016/j.chemosphere.2023.140082>
- Jia, W., Sun, L., Li, H., & Lv, T. (2025). Adsorption of oxytetracycline hydrochloride by magnetic activated carbon : kinetics , mechanism and site energy distribution analysis. *Frontiers in Marine Science*, *September*, 1–16. <https://doi.org/10.3389/fmars.2025.1542584>
- Kulkarni, D., Jaspal, D., & Itankar, N. (2025). Surfactant removal from wastewater : a comparative review on adsorption versus other techniques. *Journal of Environmental Technology*, *14*(1), 1–8. <https://doi.org/https://doi.org/10.1080/21622515.2025.2528168> ? ABSTRACT
- Lagergren, S. (1898). About the Theory of So-Called Adsorption of Soluble Substances. *Kungliga Svenska Vetenskapsakademiens Handlingar*, *24*(1), 1–39.
- Larasati, N. N., Wulandari, S. Y., Maslukah, L., & Zainuri, M. (2021). Kandungan Pencemar Detejen Dan Kualitas Air Di Perairan Muara Sungai Tapak , Semarang. *Indonesian Journal of Oceanography*, *03*(February). <https://ejournal2.undip.ac.id/index.php/ijoce>
- Lima, E. C., Sher, F., Guleria, A., Saeb, M. R., Anastopoulos, I., Tran, N., & Hosseini-bandegharai, A. (2021). Is one performing the treatment data of adsorption kinetics

- correctly? *Journal of Environmental Chemical Engineering*, 9(2), 1–7.
- Liu, Z., Zhao, G., Brewer, M., Lv, Q., & Sudholter, E. (2021). Comprehensive Review on Surfactant Adsorption on Mineral Surfaces in Chemical Enhanced Oil Recovery Beijing Key Laboratory of Optical Detection Technology for Oil and Gas, College of Science, Unconventional Petroleum Research Institute, China University of Petroleum. *TU Delft: Delft University of Technology*.
- Manurung, M., Ratnayani, O., & Ciawi, Y. (2025). Karbon dari Bahan Alam sebagai Adsorben Ramah Lingkungan: Potensi, tantangan, dan Aplikasinya. *Journal of Environmental Engineering Innovations*, 02(01), 38–48.
- Mustafa, D., Ibrahim, B., & Erten, A. (2024). Adsorptive removal of anticarcinogen pazopanib from aqueous solutions using activated carbon: isotherm, kinetic and thermodynamic studies. *Scientific Reports*, 1–14. <https://doi.org/10.1038/s41598-024-68666-3>
- Ni, L., Juliastuti, S. R., & Mahfud, M. (2025). Microwave-Assisted Synthesis, Characterization, and Performance Assessment of Lemongrass-Derived Activated Carbon for Removal of Fe and Mn from Acid Mine Drainage. *Journal of Renewable Materials*, May, 1–22. <https://doi.org/10.32604/jrm.2025.02025-0044>
- Rashda, R., Albert, A., Kailu, D., Kiran, S., Li, Z., & Han, R. (2024). Adsorption of 2,4-dichlorophenoxyacetic acid and 4-chlorophenol using bio-based activated carbon: Thermodynamics, kinetics and cytotoxicity evaluation. *Environmental Functional Materials*, 3(1), 46–58. <https://doi.org/10.1016/j.efmat.2024.09.002>
- Saleem, J., Khalid, Z., Moghal, B., Pradhan, S., & McKay, G. (2024). High-performance activated carbon from coconut shells for dye removal: study of isotherm and thermodynamic. *Royal Society of Chemistry*, 14, 33797–33808. <https://doi.org/10.1039/d4ra06287f>
- Saleem, J., Khalid, Z., Moghal, B., Tahir, F., & Al-ansari, T. (2025). Environmental Impacts and Adsorption Isotherms of Coconut Shell Activated Carbon: Effect of Acid Activation, Water, and Fuel. *Journal of Carbon Research*, 11(3), 1–18. <https://doi.org/https://doi.org/10.3390/c11010022> Copyright:
- Siswanti, S., Yurist, R., Dopinsa, K., & Anggraita, D. (2025). Adsorption of Rhodamine B by Coconut Shell Activated Carbon. *Eksergi: Chemical Engineering Journal*, 22(3).
- Talebian, S., & Sagir, M. (2024). Adsorption behavior of in-house developed CO₂-philic anionic surfactants. *Nature Portfolio: Scientific Report*, 14. <https://doi.org/https://doi.org/10.1038/s41598-024-76496-6>
- Weiand, E., Rodriguez-ropero, F., Roiter, Y., Koenig, P. H., Angioletti-uberti, S., & Ewen, J. P. (2023). Effects of surfactant adsorption on the wettability and friction of biomimetic surfaces. *PCCP: Royal Society of Chemistry*, 25(8), 21916–21934. <https://doi.org/10.1039/d3cp02546b>
- Yanti, I. F., Wibawa, P. J., & Mukimin, A. (2024). Fabrication of Coconut Shell-Derived Graphitic Activated Carbon for Carbon-based Electrode Materials. *Jurnal Kimia Sains Dan Aplikasi*, 27(9), 456–463. <https://doi.org/https://doi.org/10.14710/jksa.27.9.456-463>