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Article

Effectiveness of Kepok Banana (*Musa paradisiaca*) Bread-Based Adsorbent for Fe(III) Removal Using HCl Activation: Freundlich and Langmuir Isotherm Models

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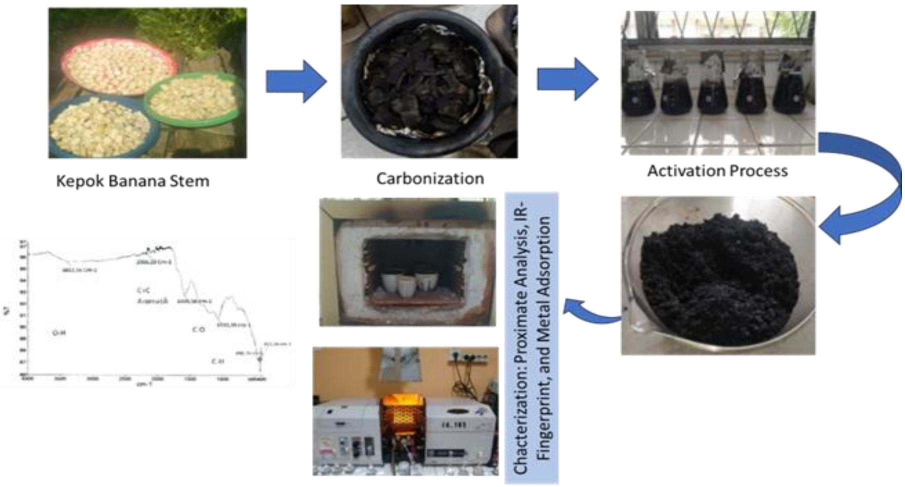
Abstract

Activated carbon can be synthesized from lignocellulosic biomass, such as kepok banana (*Musa paradisiaca*) stems, which are an abundant agricultural waste rich in cellulose (~64%). In this study, kepok banana stems were utilized as a precursor to produce activated carbon using hydrochloric acid (HCl) as the chemical activating agent. The activation process employed HCl concentrations of 1.5, 2.0, 3.0, 5.0, and 7.0 N, with a carbonization temperature of 400°C for 1 hr and an Fe adsorption contact time of 30 minutes. The resulting activated carbon was evaluated based on its physicochemical properties according to the Indonesian National Standard (SNI 06-3730-1995). The sample treated with 3.0 N HCl showed optimal characteristics, including moisture content of 2.34%, ash content of 0.28%, volatile matter content of 2.05%, and fixed carbon content of 95.33%. Its iodine number reached 1116.98 mg/g, and the Fe ion removal efficiency was 99.14%. FTIR spectroscopy confirmed the presence of functional groups typical of activated carbon—O–H, aromatic C=C, C–H, and C–O—suggesting good adsorption potential. Furthermore, adsorption behavior was analyzed using the Freundlich isotherm model, which describes multilayer adsorption on heterogeneous surfaces. The findings demonstrate that activated carbon derived from kepok banana stems is an effective, low-cost, and environmentally friendly adsorbent for iron removal, suitable for applications in water purification and wastewater treatment.

Keywords: *Activated carbon; kepok banana stem; Iron (Fe)*

Graphical Abstract



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Introduction

Activated carbon is a highly porous, amorphous form of carbon widely utilized as an adsorbent in purification, separation, and the removal of contaminants from liquids and gases due to its large surface area and high adsorption capacity [1,2]. It can be produced from various lignocellulosic biomass sources rich in cellulose, such as the stems of kepok banana (Musa paradisiaca), an abundant agricultural waste. These banana stems contain approximately 64% cellulose, along with hemicellulose (19%), lignin (5%), and water (11%) [3,4]. Their composition makes them a promising raw material for producing activated carbon, supporting both waste valorization and environmental sustainability.

The activation process significantly influences the quality of activated carbon. Previous studies using sodium hydroxide (NaOH) as an activating agent yielded carbon with high ash content and low iodine adsorption, thus failing to meet the Indonesian National Standard (SNI 06-3730-1995). In contrast, hydrochloric acid (HCl) activation has been reported to produce better-quality activated carbon with improved adsorption performance and reduced ash content, aligning with SNI requirements (Table 1) [5].

The Freundlich isotherm model is employed in this study to describe adsorption behavior, particularly the relationship between the adsorbed metal ion concentration and the equilibrium concentration in solution, assuming a heterogeneous surface with multilayer adsorption. This study aims to synthesize activated carbon from kepok banana stems using HCl activation, characterize its physicochemical properties, and evaluate its adsorption capacity for Fe(III) ions, particularly in the context of water and wastewater treatment applications.

Adsorption performance is often evaluated using isotherm models. The Freundlich isotherm describes multilayer adsorption on heterogeneous surfaces, where the adsorption capacity (qe) is related to the equilibrium concentration (Ce) by the empirical equation 1 and 2 [9].

$$qe = \frac{(C_o - C_e)V}{W} \qquad \textbf{(1)}$$

Notes:
q_e = Adsorption capacity (mg/g)
Co = Initial Fe concentration (mg/l)
Ce = Final Fe concentration (mg/l)
V = Sample volume (Liter)
W = Adsorbent weight (grams)

$$\frac{X_m}{m} = k_f . Ce^{\frac{1}{n}} \qquad \textbf{(2)}$$

Equation 2 can be derived linearly into equation 3 [8].

$$\text{Log } \left(\frac{X_m}{m}\right) = \log k_f + \frac{1}{n} . \log \text{Ce} \qquad \textbf{(3)}$$

Tabel 1. Requirements for Activated Charcoal According to SNI No.06-3730-1995 [7]

Quality Parameter (%)	Powder Quality Standard
Water Content	≤ 15 %
Ash Content	≤ 10 %
Volatile Matter Content	≤ 25 %
Bound Carbon Content	≥ 65 %
Absorbency to Iodine	≥ 750 mg/g
Absorbency to Benzene	≥ 25 %

The Langmuir isotherm, in contrast, assumes monolayer adsorption on a homogeneous surface, with no interaction between adsorbed molecules. It is expressed as equation 4 [11].

$$qe = \frac{X_m}{m} = \frac{b\,.\,k\,.\,C_e}{1 + k\,.\,C_e} \qquad \textbf{(4)}$$

Equation (4) can be reduced linearly to equation 5 [8]

$$\frac{C_e}{Q} = \frac{1}{k\,.\,b} + \frac{1}{b} . Ce \qquad \textbf{(5)}$$

Notes
Ce = Equilibrium concentration of adsorbate in solution after adsorption (mg/L)
Q = Amount of adsorbed adsorbate per adsorbent weight (mg/g)
k = Adsorption equilibrium constant (L/mg)
b = Maximum adsorption capacity of the adsorbent (mg/g)
1/kb = Intercept
1/b = Slope

In addition to isotherm studies, the surface chemistry of activated carbon plays a pivotal role in adsorption mechanisms. Fourier Transform Infrared Spectroscopy (FTIR) is employed to identify surface functional groups responsible for adsorptive interactions. FTIR detects specific vibrational frequencies associated with functional groups such as hydroxyl (–OH), carbonyl (C=O), carboxyl (–COOH), and aromatic C=C bonds [12]. These functional groups are critical for the interaction with metal ions or organic pollutants. FTIR spectra typically exhibit absorption bands near 3400 cm^{-1} (–OH), 1700 cm^{-1} (C=O), and 1600 cm^{-1} (C=C), which serve as indicators of surface chemistry modifications following activation or adsorption processes.

This study aims to synthesize HCl-activated carbon from kepok banana stems, evaluate its physicochemical properties based on national standards, and investigate its adsorption capacity for Fe(III) ions using Freundlich and Langmuir isotherm models. The outcome is expected to contribute to the development of low-cost, sustainable adsorbents for water and wastewater treatment applications.

Materials and Methods

Chemicals

The primary raw material used in this study was kepok banana (*Musa paradisiaca*) stems, collected from agricultural waste sources, Riau Province. These stems were thoroughly cleaned, sun-dried, and processed prior to further treatment. The equipment utilized included a mechanical grinder, porcelain crucibles, a muffle furnace, desiccator, laboratory oven, burettes, and a 70-mesh sieve. The chemicals employed in the study were analytical grade and included hydrochloric acid (HCl) at varying concentrations (1.5 N, 2.0 N, 3.0 N, 5.0 N, and 7.0 N), 0.1 N iodine solution, 0.1 N sodium thiosulfate ($Na_2S_2O_3$), 1% starch indicator, distilled water, and 100 ppm Fe(II) standard solution prepared from $FeSO_4{\cdot}7H_2O$.

Preparation of Samples

The study employed an experimental approach, incorporating both observational and analytical procedures. Data analysis was conducted using statistical tabulation and graphical interpretation. The main variable studied was the concentration of HCl used as an activating agent in the production of activated carbon from banana stem biomass. The activated carbon preparation process comprised three primary stages: dehydration, carbonization, and chemical activation. The fixed parameters included a carbonization temperature of 400 °C, a carbonization duration of 1 hr, activation time of 4 hr, stirring speed of 400 rpm, mesh size of 70, and a contact time of 30 min between activated carbon and Fe(II) solution.

The preparation of activated carbon involved the following sequential stages: (1) Carbonization: Pre-dried banana stem biomass was subjected to pyrolysis at 400 °C for 1 hr in a muffle furnace. (2). Chemical Activation: The resulting char was impregnated with HCl at the designated concentrations and stirred for 4 hr. (3). Neutralization and Washing: The activated carbon was washed with distilled water until neutral pH was achieved and then oven-dried. (4). Adsorption Testing: The dried activated carbon was exposed to 100 ppm Fe(II) solution for 30 min to assess its adsorption performance. Analytical technique: the physical and chemical properties of the activated carbon were evaluated based on the Indonesian National Standard (SNI 06-3730-1995), including: moisture content analysis [7], ash content analysis [13], volatile matter content analysis [14], fixed carbon content analysis [14], and iodine number determination. The Fe(II) adsorption capacity was measured using an Atomic Absorption Spectrophotometer (AAS), while the surface functional groups were characterized using Fourier Transform Infrared (FTIR) spectroscopy to identify active sites responsible for adsorption.

Activated Carbon

The preparation of activated carbon from *Musa paradisiaca* (kepok banana) stems involved four main stages: sample preparation, carbonization, chemical activation, and neutralization. In the first stage, the banana stems were thoroughly washed with water to remove adhering soil and impurities. The cleaned stems were then cut into small segments to facilitate drying. The segments were sun-dried for seven consecutive days to reduce moisture content, a crucial step to ensure efficient carbonization. The second stage was carbonization, wherein the dried biomass was weighed and subjected to pyrolysis in a muffle furnace at 400 °C for 1 hr under limited oxygen conditions. The resulting biochar was ground using a mortar and sieved through a 70-mesh sieve to obtain a uniform particle size. The third stage was chemical activation. The sieved carbon was impregnated in hydrochloric acid (HCl) at various concentrations (0.1, 0.2, 0.5, 0.7, 1.0, 1.5, 2.0, 3.0, 5.0, and 7.0 N). The mixture was stirred for 4 hr to allow sufficient activation. The final stage was neutralization, in which the activated carbon was washed repeatedly with distilled water until the rinse water reached neutral pH. The product was then dried in an oven at 110 °C until a constant weight was achieved. After cooling in a desiccator, the activated carbon was ready for further analysis.

Metal Adsorption

Adsorption performance was evaluated using a synthetic solution of Fe(II) prepared from $FeSO_4·7H_2O$. A total of 5 g of activated carbon (from each HCl concentration treatment) was added to 50 mL of 100 ppm Fe(II) solution. The mixture was stirred using a magnetic stirrer at 400 rpm for 30 min to ensure uniform contact. After the adsorption process, the solution was filtered, and the filtrate was collected for analysis. The residual Fe concentration was measured using an Atomic Absorption Spectrophotometer (AAS) to determine the adsorption efficiency

IR-Fingerprint

To identify functional groups on the activated carbon surface, Fourier Transform Infrared Spectroscopy (FTIR) analysis was conducted. Approximately 0.1 mg of dried activated carbon was finely ground using an agate mortar until homogeneous. The powder was evenly spread on the FTIR sample holder, ensuring full surface coverage. The sample was then scanned to record its infrared spectrum. Characteristic absorption peaks were analyzed to identify functional groups relevant to adsorption, such as –OH, C=O, C–H, and C=C.

Result and Discussion

Characteristics of Activated Carbon from Kepok Banana Stems

The physical and chemical characteristics of activated carbon derived from *Kepok* banana (*Musa paradisiaca*) stems treated with varying concentrations of hydrochloric acid (HCl) ranging from 1 N to 7 N are presented in Table 2. The water content of the samples varied between 2.3392% and 3.5707%. Notably, the lowest moisture level was observed at a concentration of 3 N HCl, suggesting more effective drying and improved stability of the resulting activated carbon. A lower water content is advantageous because excess moisture can obstruct adsorption sites and diminish overall adsorption efficiency.

The ash content exhibited a decreasing trend as the HCl concentration increased up to 3 N, where it reached a minimum value of 0.2799%. Ash represents the inorganic residues remaining after combustion and can negatively impact the adsorption process by occupying active sites. Therefore, the reduction in ash content at 3 N implies more efficient removal of mineral impurities and an enhancement in the chemical purity of the activated carbon.

Similarly, the volatile matter content showed a consistent decline with increasing acid concentration, achieving the lowest value of 2.0502% at 3 N. Reduced volatile matter is indicative of a higher degree of carbonization and contributes to the development of a more stable and robust carbon structure, which is essential for maintaining adsorption capacity during repeated use. The bound carbon content increased progressively with acid concentration up to 3 N, attaining a maximum of 95.3307%. This finding suggests that a 3 N HCl treatment facilitates the optimal formation of the carbon matrix, thereby enhancing the structural integrity and adsorptive performance of the material.

Moreover, the iodine absorbency, which serves as a key indicator of microporous surface area and porosity, also peaked at 3 N, recording a value of 1116.98 mg/g. High iodine numbers reflect a well-developed microporous network, which is crucial for effective adsorption of small molecules.

In summary, the activated carbon produced using 3 N HCl demonstrated the most favorable combination of physicochemical properties: high bound carbon content, minimal ash and volatile matter, and superior iodine absorbency. These attributes collectively indicate that 3 N HCl constitutes the optimal activation condition for producing high-quality activated carbon from *Kepok* banana stems, offering promising potential for applications requiring efficient adsorbent materials.

Tabel 2. Characteristic Test Data of Activated Carbon from Kepok Banana Stems

Cons. HCl (N)	Water Content (%)	Ash Content (%)	Volatile Matter Content (%)	Bound Carbon Content (%)	Absorbency Iod (mg/g)
1	3.5707	2.3607	5.5505	88.118	1002.75
1.5	3.0194	0.4103	3.6111	92.9592	1078.91
2	2.7575	0.3299	3.5286	93.384	1104.29
3	2.3392	0.2799	2.0502	95.3307	1116.98
5	2.9094	0.8695	2.9094	93.3117	1015.44
7	3.3177	1.3082	3.8677	91.5064	951.975

Tabel 3. Data on Iron (Fe) Metal Absorption Results

HCl Concentration (N)	Initial Concentration (ppm)	Final Concentration (ppm)	Adsorbed Fe Content (%)
1	99.9524	1.7619	98.2373
1.5		1.6667	98.3325
2		1.0952	98.9043
3		0.8571	99.1425
5		1.0476	98.9519
7		1.4762	98.5231

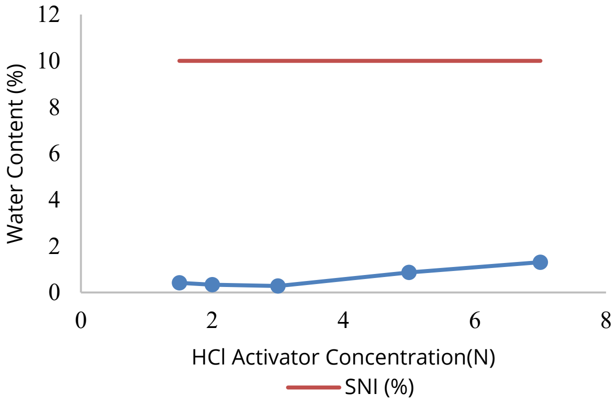

Figure 1. Effect of HCl Activator Concentration on Water Content

In Figure 1, it can be seen that the ash content value decreases with the addition of activator concentration. Activated carbon that has the best concentration is the 3 N concentration of 0.2799%. The higher the concentration of HCl activator used, the smaller the ash content. At 5 N HCl concentration, the ash content produced increased to 0.8695%. High ash content can reduce the adsorption power of activated carbon on adsorbates because of the many metal oxides and minerals that spread and cover the pores of activated carbon. Based on the data obtained from the ash content test, all activated carbon products meet the SNI 06-3730-1995 standard, which is less than 10%.

Ash Content

The relationship between HCl activator concentration and ash content can be seen in Figure 2. In Figure 2, it can be seen that the ash content value decreases with the addition of activator concentration. Activated carbon that has the best concentration is the 3 N concentration of 0.2799%. The higher the concentration of HCl activator used, the smaller the ash content. At 5 N HCl concentration, the resulting ash content increased to 0.8695%. High ash content can reduce the adsorption power of activated carbon on adsorbates due to the large amount of metal oxides and minerals that spread and cover the pores of activated carbon. Based on the data obtained from the ash content test, all activated carbon products meet the SNI 06-3730-1995 standard, which is less than 10%.

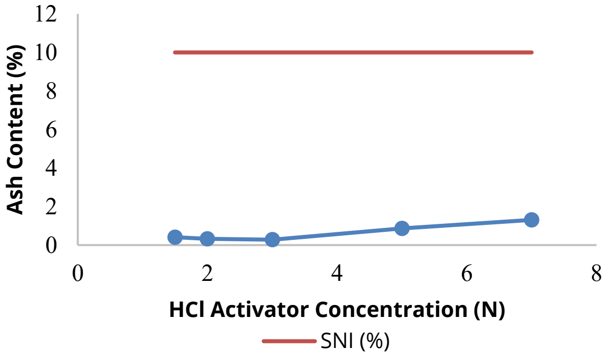

Figure 2. Effect of HCl Activator Concentration on Ash Content

Volatile Matter Content Test. The relationship between HCl activator concentration and moisture content can be seen in Figure 3.

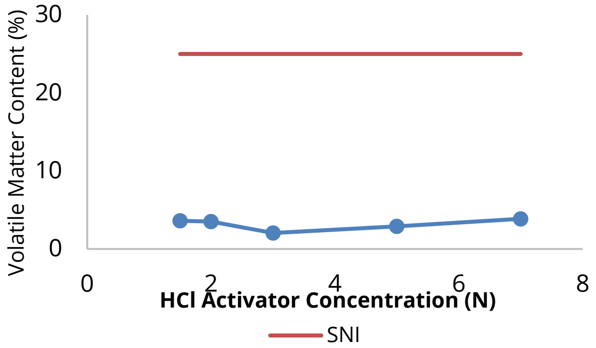

Figure 3. Effect of HCl Activator Concentration on Volatile Matter Content

Figure 3 shows that the volatile matter content decreased with increasing HCl activator concentration. The vaporized substance content decreased from 0.1 N concentration to 3 N concentration. The lowest vaporized substance content at 3 N activator concentration was 2.0502%. The level of vaporized substances increased at a concentration of 5 N, which amounted to 2.9094%. The increase in ash content occurs because of the many metal oxides and minerals that spread and cover the pores of activated carbon. The volatile matter content of all samples has met the SNI 06-3730-1995 standard, which is no more than 25%.

Bound Carbon Content

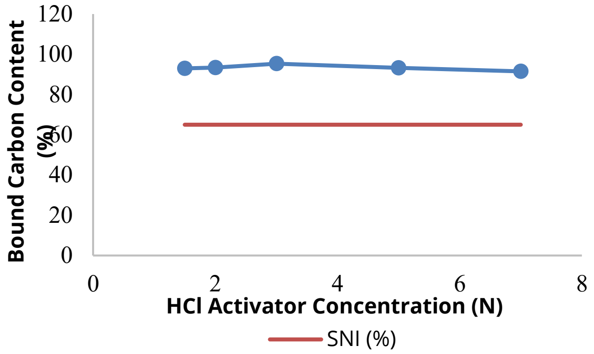

Figure 4. Effect of HCl Activator Concentration on Bound Carbon Content

Based on Figure 4, it can be seen that the percentage of bound carbon content tends to increase with each addition of HCl activator, namely at concentrations of 1.5 ; 2 and 3 N. The increase in percentage is influenced by the low value of moisture content, ash content, and volatile substance content of activated carbon. Based on the bound carbon content of all samples, it has met the quality standards of activated carbon, which is at least 65% with concentrations of 1.5 ; 2 ; 3 ; 5 N and 7 N because the banana stem carbonization time is almost perfect and the carbonization temperature is set according to the condition of the banana stem as raw material.

Iodine Absorbency. The relationship between HCl activator concentration and iodine absorbance can be seen in Figure 5.

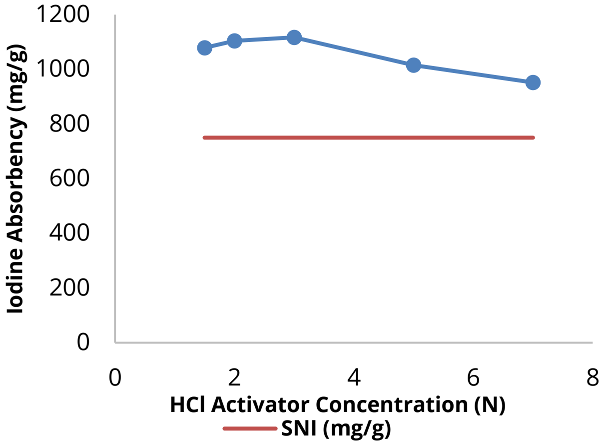

Figure 5. Effect of HCl Activator Concentration on Iodine Absorbency

The percentage of iodine absorption increased with each addition of HCl concentration, namely 1.5; 2 and 3 N concentrations, but decreased at 5 N and 7 N HCl concentrations. This is because the higher the addition of the activator concentration, the greater the effect of the activator in binding the residual compounds to exit through the charcoal micro pores, so that there is a decrease with too high a concentration of NaOH which results in too fast a mass transfer of the activator binding the remaining tar to exit the charcoal micro pores so that the remnants of tar collect on the surface of the charcoal micro pores, as a result the adsorption power of activated charcoal decreases [17]. Based on all the iodine absorption sample data, all samples meet the SNI 06-3730-1995 standard, which is a minimum of 750 mg/g.

Iron (Fe) Metal Absorption Efficiency

Table 3 presents the data on Fe(III) adsorption from solution using the produced activated carbon. Initial Fe concentration was 99.9524 ppm across all tests. The lowest final Fe concentration (0.8571 ppm) and highest Fe removal efficiency (99.1425%) occurred with activated carbon treated at 3 N HCl, again highlighting its superior performance. All treatments achieved Fe adsorption efficiencies above 98%, indicating that even non-optimized activated carbon exhibits strong Fe adsorption capacity.

Adsorption efficiency increased with acid concentration up to 3 N, consistent with improvements in iodine number and carbon content. Beyond 3 N (e.g., 5 N and 7 N), performance declined slightly, likely due to pore collapse or over-etching, which can reduce effective surface area. There is a clear correlation between bound carbon content, iodine number, and Fe adsorption efficiency. Higher bound carbon and iodine numbers reflect more developed porous structures, enabling more effective trapping of metal ions.

The consistent peak performance at 3 N HCl across both tables suggests this concentration yields optimal textural and chemical properties for metal adsorption applications.

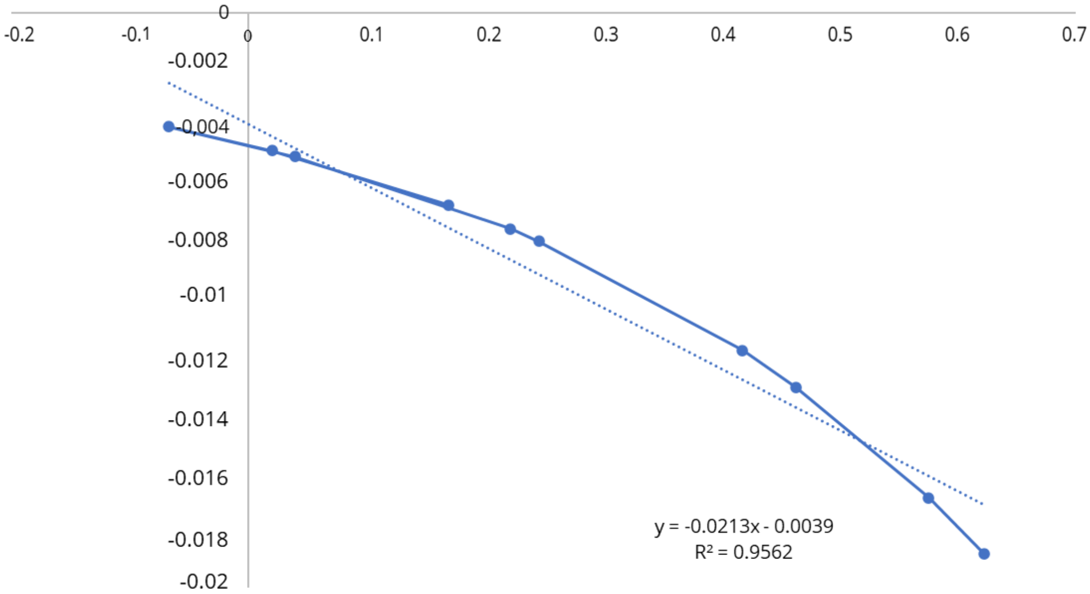

Figure 8. Graphic Isoterm Freundlich Fe

Isoterm Adsorption

From Figures 8 and 9, it can be seen that the regression value that shows a number close to 1 is seen in the Freundlich isotherm graph, this proves that the adsorption isotherm in the research of making activated carbon from kepok banana stems follows the Freundlich isotherm model. The n value describes the adsorption process, where n < 1 indicates chemical adsorption, n = 1 indicates linear adsorption, and n > 1 indicates physical adsorption [17]. The 1/n value is a function of the strength of adsorption in the adsorption process, the smaller the 1/n value, the stronger the interaction between the adsorbent and the adsorbate [19-20].

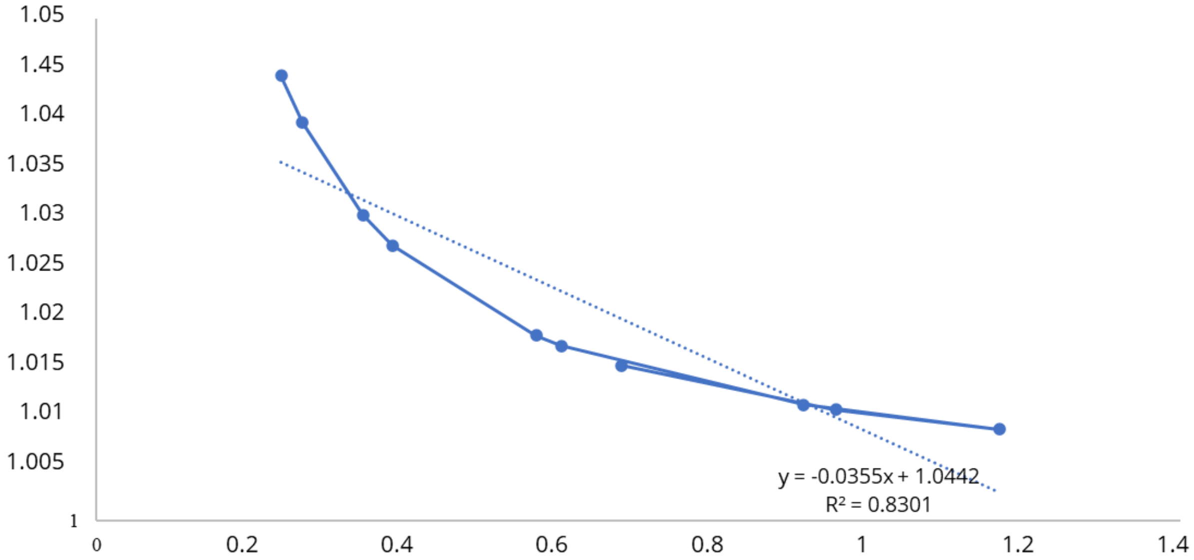

Figure 9. Graphic Isoterm Langmuir Fe

IR In this study, the adsorbent of activated kepok banana stem carbon was identified using FTIR (Fourier Transform Infrared Spectroscopy) (Genesys 20 Visible Spectrophotometer, USA) to determine the chemical components of activated carbon in the form of functional groups and active groups of activated carbon. The resulting infrared spectra are as in Figure 10.

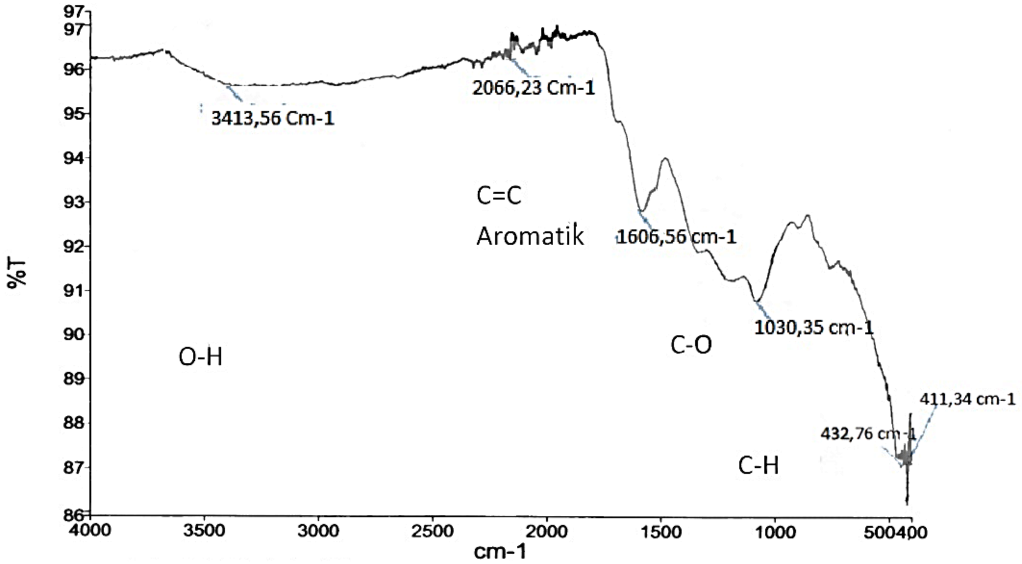

Figure 10. IR Fingerprint activated carbon

From the test sample, bread of kapok banana after being activated, the FTIR spectrum shows distinct peaks indicating the presence of various functional groups. The activated carbon displays a high-intensity peak at 3236.08 cm^{-1}, which corresponds to O-H stretching vibrations, typically from hydroxyl groups found in alcohols or phenols. This indicates surface oxidation and functionalization, which commonly occurs during the activation process [21-23].

In comparison, non-activated carbon generally shows much weaker or broader O-H stretching bands due to the limited surface functional groups and lower porosity. The emergence of a sharp O-H band in activated samples confirms enhanced surface chemistry, favorable for adsorptive interactions [24-26].

Furthermore, absorptions at 1373, 1308, 523, 429, 418, and 406 cm⁻¹ correspond to C-H bending vibrations of alkanes. These bands are more pronounced in activated carbon, suggesting the breakdown of complex lignocellulosic structures and exposure of aliphatic chains after thermal and chemical treatment. In non-activated carbon, such peaks are typically subdued due to the presence of intact macromolecular lignin-cellulose structures.

A prominent peak at 1567.12 cm⁻¹ and 1588.44 cm⁻¹ indicates C=C aromatic stretching, highlighting the presence of condensed aromatic structures formed during carbonization. These peaks are either absent or poorly defined in non-activated samples, as the aromatic domains are less developed before pyrolysis and activation [26].

Additionally, the peak at 1083.28 cm⁻¹ is attributed to C–O stretching, characteristic of alcohols, ethers, or carboxylic acid groups, often enhanced after activation with agents like HCl or H_3PO_4. Such functional groups are valuable for binding polar adsorbates. The corresponding peaks at 446 and 418 cm⁻¹ also reinforce the presence of C-H bonds in alkane structures. The comparison between non-activated and activated carbon FTIR spectra clearly shows that activation significantly enhances the surface functionality of kapok banana-derived carbon. The activated sample is enriched in hydroxyl, aromatic, alkane, and ether/carboxyl groups, all of which contribute to its adsorptive efficiency.

Conclusion

that the concentration of HCl as an activating agent significantly influences the quality of activated carbon derived from Kepok banana stems. Increasing the concentration of HCl generally enhances the physicochemical properties of the activated carbon; however, concentrations exceeding the optimal level may lead to a decline in adsorption capacity due to the saturation of the carbon matrix, which inhibits further effective activation. The optimal condition was achieved at a 3 N HCl concentration, resulting in a maximum Fe adsorption efficiency of 99.14%. The adsorption data also followed the Freundlich isotherm model more accurately than the Langmuir model, as evidenced by a higher regression coefficient (R^2 = 0.9921 for Freundlich compared to 0.9667 for Langmuir), indicating a heterogeneous surface and multilayer adsorption process. Furthermore, the activated carbon produced under these conditions met the requirements of the Indonesian National Standard (SNI), with a moisture content of 2.34%, ash content of 0.23%, volatile matter content of 2.05%, bound carbon content of 95.33%, and an iodine adsorption capacity of 1116.98 mg/g, confirming its high quality and applicability for metal ion adsorption in water treatment.

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Author Contributions

Conceptualization, IS, FNA; Methodology, IS ; Software, ES ; Validation, ES ; Formal Analysis, ASN ; Investigation, ASN ; Resources, FNA ; Data Curation, FNA ; Writing – Original Draft Preparation, FNA ; Writing – Review & Editing, SMN ; Visualization, SMN ; Supervision, FNA ; Project Administration, FNA ; Funding Acquisition, FNA.

Conflict of Interest

The authors declare no conflict of interest.

References

[1] Sujiono EH, Zabrian D, Zurnansyah M, Mulyati M, Zharva V, Samnur S, Humairah. Fabrication and Characterization of Coconut Shell Activated Carbon Using Variation Chemical Activation for

Wastewater Treatment Application. *Result in Chemistry*. 2022;4, 100291. https://doi.org/10.1016/j.rechem.2022.100291

[2] Haryati S, Yulhan AT, Asparia L. Preparation of Activated Carbon from Gelam Bark (*Melaleuca Leucadendron*) Which Originated from Tanjung Api-Api South Sumatra. *Chemical Engineering Journal*. 2017;23(2):77-86. https://doi.org/10.36706/jtk.v23i2.1564

[3] Ashari AW & Sitorus S. Effect of Time Variation on Xylene Using Activated Carbon from Banana Stem Waste (*Musa Paradisiaca L*). *Atomic Journal*. 2021;*5*(2):62-66.

[4] Deepa B, Abraham E, Cherian BM, Bismarck A, Blaker JJ, Pothan LA, Kottaisamy M. Structure, Morphology and Thermal Characteristics of Banana Nano Fibers Obtained by Steam Explosion. *Bioresource Technology*. 2011;102(2):1988-1997.

[5] Campbell NA, Reece JB. 2008. *Biology*. 8th Ed. Pearson Benjamin Cummings.

[6] Udyani K, Purwaningsih DY, Setiawan R, Yahya K. Preparation of Activated Carbon from Mangrove Charcoal using Combined Chemical and Physical Activation with Microwave. *Journal of Science and Technology*. 2019;23(1):39-46.

[7] National Standardization Agency. SNI 06-3730-1995:Test Method for Moisture Content in Solid Materials [indonesian national standard]. BSN 1995.

[8] Foo KY & Hameed BH. Insights into The Modeling of Adsorption Isotherm Systems. *Chemical Engineering Journal*. 2010;156(1):2-10. https://doi.org/10.1016/j.cej.2009.09.013

[9] Metcalf & Eddy. 2014. *Wastewater Engineering*: Treatment and Resource Recovery. 5th Ed. Mcgraw-hill education.

[10] Atkins P & Depaula J. 2010. *Physical Chemistry*. 9th ed. Oxford University Press.

[11] Do DD. 1998. Adsorption Analysis: Equilibria and Kinetics. Imperial College Press London

[12] Setianingsih T. 2020. *Characterization Methods for Carbon Nanomaterials [Metode Karakterisasi Karbon Nanomaterial]*. Universitas Brawijaya Press.

[13] National Standardization Agency. SNI 06-3730-1995: Test Method for Ash Content of Solid Materials [Indonesian National Standard]. BSN 1995.

[14] National Standardization Agency. SNI 06-3730-1995: Test method for volatile matter content in solid materials [Indonesian National Standard]. BSN 1995.

[15] National Standardization Agency. SNI 06-3730-1995: Test method for bound carbon content in solid materials [Indonesian National Standard]. BSN 1995.

[16] Kartika SE & Amran MB. Synthesis and Characterization of Poly (Anthranilic Acid-Co-Formaldehyde) for Adsorption of Pb(II) ion. *Alchemy*. 2021;9(1):15-25.

[17] Syahrir I, Samosir D, Destarini NA, Bariah B. Utilization of Banana Stem Waste (*Musa Paradisiaca L*) as Activated Charcoal Through Activation Process Using NaOH Activator. *National Seminar on Research & Community Service Results (SNP2M)* 2020; 54-59.

[18] Aryani F. Application of Physical Activation and Chemical Activation Methods in the Preparation of Activated Charcoal from Coconut Shells (*Cocos Nucifera L*). *Indonesian Journal of Laboratory*. 2019;1(2):16-20.

[19] Elfia M. Biosorption of Pb(II) Heavy Metal Ions using Kepok Banana Stem Biosorbent (*Musa Acuminata Balbisiana Colla*). *Clinical Science: Journal of Health Analysts*. 2019;7(2):76-82.

[20] Jankowska H, Swiatkowski A, Choma J. 1991. Active Carbon. T.J. Kemp, Editor. Ellis Horwood Ltd New York.

[21] Putri RW, Haryati S, Ramatullah R. Effect of Carbonation Temperature on the Quality of Activated Carbon from Sugarcane Bagasse Waste. *Journal of Chemical Engineering University of Sriwijaya.* 2019; 25(1):1-4.

[22] Rowe RC, Sheskey, PJ, Owen SC. 2006. Carboxy Methyl Cellulose Sodium. Handbook of Pharmaceutical Excipients. Fifth Edition. American Pharmacist Association Washington, 120–122.

[23] Amehaa B, Nadew TT, Tedla TS, Getye B, Mengie DA, Ayalneh S. The Use of Banana Peel as a Low-Cost

Adsorption Material for Removing Hexavalent Chromium from Tannery Wastewater: Optimization, Kinetic and Isotherm Study, and Regeneration Aspects. *Royal Society of Chemistry*. 2024;14(6):3617-4300. https://doi.org/10.1039/d3ra07476e

[24] Chafidz A, Astuti W, Augustia VAS, and Rofiah N. Removal of Methyl Violet Dye Via Adsorption using Activated Carbon Prepared from Randu Sawdust (Ceiba Pentandra). J. IOP Conference Series:Earth and Environmental Science. 2018;167(1):012013. https://doi.org/10.1088/1755-1315/167/1/012013

[25] Rahmawati MA, Salam AN, Munte WN, Chitraningrum N, and Rahmasari L. Synthesis and Characterization Analysis of Banana Peel Carbon Activated as Adsorption of Copper (Cu). J. Jurnal Ilmu Lingkungan. 2025;23(3):647-657.

[26] Cao Y, Zhang J, Yang X, and Shen D. Adsorption Behavior of Functional Groups in Activated Carbon Derived from Biomass. J. Journal of Environmental Chemical Engineering. 2020;8(3):103673. https://doi:10.1016/j.jece.2020.103673