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The Potential of Faloak Bark (*Sterculia quadrifida R.Br.*) as an Activated Carbon Product Through Physical-Chemical Activation Method.

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Abstract

Faloak is a plant species native to the East Nusa Tenggara region and Australia, widely used by the local community in NTT as an herbal medicine, particularly in treating liver disease, digestive disorders, and fatigue. However, this study presents a new application by analyzing its physical-chemical properties and evaluating its effectiveness in the synthesis of activated carbon. This study aims to explore and analyze the potential of Faloak bark as a source of activated carbon, which has not been examined in previous research. This research uses a quantitative approach by conducting controlled laboratory experiments to measure and analyze the variation in activator concentration on the water and ash content of activated carbon. The research applied the physical-chemical activation method. The physical activation process involved heating at temperatures ranging from 250°C to 450°C, while chemical activation was conducted using $ZnCl_2$ *and NaOH at concentrations of 1 N, 2 N, and 3 N. This method was selected to determine the optimal conditions for converting Faloak bark into activated carbon, focusing on temperature and chemical activators. The findings indicate that the optimum temperature for activated carbon formation is 300°C. Additionally, tests using chemical activators showed that Faloak bark performs best with a 2 N NaOH solution, as evidenced by ash and water contents of 0.03% and 0.65%, respectively. Functional group analysis through FTIR testing identified the presence of* OH^- *(hydroxyl), aromatic C=C, and carbonyl C=O groups, further supporting the potential of Faloak bark as a viable material for activated carbon production. The findings suggest that Faloak bark has significant potential to be developed into an activated carbon product.*

Introduction

The Faloak plant (*Sterculia quadrifida R.Br.*) is a native species found exclusively in Australia and East Nusa Tenggara (NTT), Indonesia. In NTT, particularly on Timor Island, locals utilize this plant in traditional medicine to treat conditions such as back pain, ulcers, boils, malaria, and liver problems [1]. Research on the utilization of the Faloak plant has been extensively conducted. Previous research has shown that extracts from the bark of the Faloak tree can serve as antioxidants [2], [3] for Nile tilapia eggs contaminated with heavy metals [4]. Based on observations, the peeling of Faloak bark is carried out intensively, whereas no cultivation of this plant has been initiated. The residents in the Timor Island region usually use boiled Faloak bark water as a substitute for drinking water to treat health issues such as those mentioned before. The boiled bark is then discarded or dried and used as fuel for cooking stoves. If the discarded bark is left to accumulate, it can cause environmental pollution, thus requiring proper management. One approach to managing this waste is converting it into activated carbon. Activated carbon is produced through an activation process involving certain compounds or substances, as well as temperature and other physical components [5], [6].

Activated carbon is a material composed of carbon with a porous structure and a large surface area, enabling it to adsorb various substances such as gases, toxins, or contaminants [7]. Activated carbon is created by processing carbon-rich materials, such as coconut shells, wood, or coal, at elevated temperatures in an oxygen-free environment. This process develops tiny pores that significantly improve its ability to adsorb substances [8]. The process of producing activated carbon consists of two primary steps such as carbonization, which creates charcoal, and activation, which transforms it into activated carbon. Carbonization is the process of heating carbon-rich organic materials at high temperatures without oxygen to remove volatile organic compounds and leave carbon as the residue. Activation aims to create a porous structure in the carbon produced from the carbonization process. Activation can be done physically or chemically. Physical activation involves heating the carbonized material in an oxidizing atmosphere (usually steam or carbon dioxide gas) at high temperatures (800-1000°C). The reaction between carbon and steam forms pores in the carbon, increasing its surface area and adsorption capacity. Chemical activation involves mixing the raw carbon material with activating chemicals (such as phosphoric acid, potassium hydroxide, sodium hydroxide or zinc chloride) before heating. These chemicals help open the carbon pores and enhance its adsorption capacity, particularly with the use of sodium hydroxide and zinc chloride. Chemical activation typically occurs at lower temperatures (around 300-600°C) compared to physical activation [8].

Numerous studies have been carried out on utilizing specific materials for the production of activated carbon, such as using coconut shells [9], oil palm bark [10], [11], [12], sawdust [13], sago tree bark [6], marigold stems [14], and durian peel [15]. These studies typically employ separate activation methods, either physical or chemical. Study [6] explains that activated carbon can be produced from a material containing cellulose, hemicellulose, and lignin compounds. These compounds are also found in Faloak bark [3]. Additionally, Faloak has a complex fiber structure and porosity similar to oil palm bark [10], allowing for a nearly identical carbonation process.

This study explores the use of Faloak bark, which has not been previously investigated in such research. Faloak bark is endemic to NTT and can be utilized to address water pollution from rivers and dyeing wastewater from Timor's ikat weaving process using activated carbon derived from this readily available material.

Therefore, this research is crucial as it provides benefits to the community by utilizing Faloak bark as activated carbon, which plays a role in mitigating water pollution and purifying wastewater from the ikat weaving process. Waste of Faloak bark can be repurposed into activated carbon, ensuring that Faloak is not only vital for the health of NTT's people but also holds economic potential for further development, both in herbal medicine and technology-based products like activated carbon.

Theory and Calculation

The formation of activated carbon can be achieved through two primary methods, carbonization and activation. Carbonization plays a vital role in the production process as it lays the groundwork for the carbon's ability to adsorb molecules, which is essential for industrial uses like water purification, air filtration, and chemical processing. The carbon generated from the carbonization process is porous, but these pores are not fully developed compared to activated carbon. Hence, it must undergo the activation stage to enhance its adsorption capacity and expand its pore structure [16].

Activation is the subsequent step after carbonization, aiming to improve the carbon's adsorption capabilities by creating a broader and more organized pore structure. This process can be performed using two main techniques: physical activation and chemical activation [17]. The differences between the two types of activation methods can be observed in Table 1.

Table 1. The Differences Between Physical and Chemical Activation in Activated Carbon Formation Based on Temperature, Activating Agent, Surface Area, and Energy Efficiency.

Aspects	**Chemical Activation**	**Physic Acitivation**
Temperature	300-600°C	800-1100°C
Activating Agent	Chemical compounds (H_3PO_4, KOH, NaOH, $ZnCl_2$)	Gas (steam or CO_2)
Surface Area	Varying surface area	High surface area
Energy Efficiency	Relatively energy-efficient	Requires more energy

Activated carbon can be utilized once it meets the necessary quality and performance standards for specific applications. Parameters used to test activated carbon include ash content and water content. Testing the ash content measures the amount of inorganic materials within the activated carbon. High ash content can decrease the efficiency of the carbon in adsorption processes and indicate the presence of minerals that do not contribute to adsorption. Water content testing measures the amount of water in activated carbon. Moisture levels can affect the carbon's adsorption capacity and handling properties [18]. Generally, lower water content suggests better performance in applications related to adsorption. Table 2 presents the quality standards for activated carbon as outlined by the Indonesian National Standard (SNI).

Table 2. Quality Standards for Activated Carbon Based on SNI

Description	**Quality Requirements**	
	Granular	**Powder**
Ash Content (%)	Max 2.5	Max 10
Water Content (%)	Max 4.5	Max 15

Experimental Method

Materials and Tools

The equipment utilized in this study includes a furnace, desiccator, mortar and pestle, analytical balance, filter paper, 100-mesh sieve, oven, pH paper, beaker glass, porcelain crucible, and aluminum foil. In turn, the main sample used consists of the bark of the faloak tree, taken from Fafinesu village, Insana District, TTU Regency, East Nusa Tenggara. Supporting materials include $ZnCl_2$, NaOH, and distilled water.

Measure and Analyze

The stages of the research conducted to evaluate the potential of Faloak bark as activated carbon are illustrated in Figure 1.

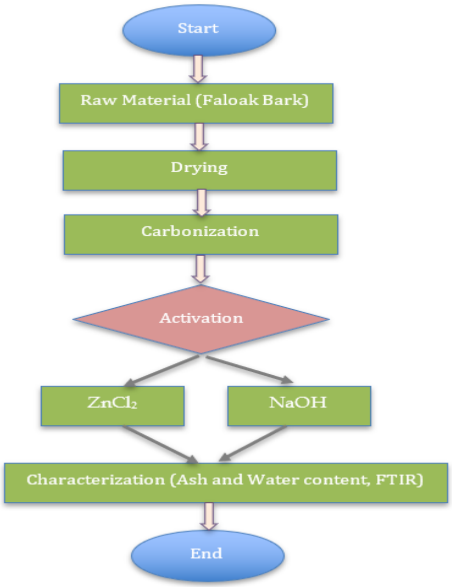

Figure 1. The stages of the research conducted to evaluate the potential of Faloak bark as activated carbon.

Based on Figure 1, The dried faloak bark is burned using a furnace at temperature of 300°C for 60 minutes at each temperature. Due to the similarity in characteristics between Faloak bark and oil palm bark, the carbonation duration was set to 60 minutes at temperature of 300°C based on the findings of this study [10], which indicate that both contain high levels of lignocellulose (cellulose, hemicellulose, and lignin), contributing to comparable mechanical strength and thermal stability. Furthermore, their intricate fiber structures and similar porosity facilitate a nearly identical carbonation process. The resulting carbon was activated using $ZnCl_2$ and NaOH at concentrations of 1 N, 2 N, and 3 N, respectively. The analysis of activated carbon is conducted by measuring ash content, moisture content, and functional group testing using FTIR.

Result and Discussion

Characteristics of Activated Carbon

Numerous studies have explored the use of various materials to produce activated carbon, such as [12], [19], [20]. However, research on converting Faloak bark into activated carbon has not been conducted. This plant is exclusively found in the NTT region, so the findings of this study could benefit the people of NTT in addressing environmental pollution and managing waste from artificial dyes used in Timor ikat fabrics.

The carbonization result of faloak bark is in powder form, obtained from combustion at a temperature of 300°C. Powdered carbon is easier to activate chemically or physically because it has a larger surface area and allows the activator to penetrate more effectively [10]. The carbonized charcoal was activated using $ZnCl_2$ and NaOH activators at concentrations of 1 N, 2 N, and 3 N. The activated carbon was then tested for ash content and water content for each activator used.

Ash Content Parameter

Testing the ash content is crucial for evaluating the performance and quality of activated carbon. The ash content testing showed different results when using $ZnCl_2$ and NaOH. Table 3 presents the ash content of activated carbon when using $ZnCl_2$ as the activator.

Table 3. The results of the ash content testing of activated carbon using $ZnCl_2$ and NaOH as the activators.

Activator	Concentrations	Ash Content (%)
$ZnCl_2$	1 N	0.05
	2 N	0.09
	3 N	1.11
NaOH	1 N	0.15
	2 N	0.03
	3 N	0.04

Based on Table 3, the ash content test results using $ZnCl_2$ and NaOH activators at concentrations of 1 N, 2 N, and 3 N indicate that they meet the standards set by SNI. In the use of $ZnCl_2$, the 1 N concentration exhibits the lowest value among the three concentrations, which is 0.05%. This is because, at a 1 N concentration, $ZnCl_2$ is more easily dissolved, leaving less residue on the surface of the activated carbon after the activation process. At lower concentrations, the activation process is more controlled, allowing the activated carbon to form with a more optimal structure without generating too many by-products that could form ash. Additionally, the washing process after activation is more efficient in removing unused $ZnCl_2$ residues, thus reducing ash contamination in the resulting activated carbon [21].

A different result is shown by the activated carbon treated with NaOH. Based on Table 3, the application of a 2 N NaOH concentration results in the lowest ash content value compared to the other two concentrations, which is 0.03%. This is due to the fact that the 2 N concentration allows for more efficient removal of inorganic impurities, such as minerals or metals, from the raw material. As a strong base, NaOH can break down organic matter more effectively, leaving behind fewer inorganic residues that contribute to ash formation. Additionally, the 2 N NaOH concentration can effectively neutralize or dissolve salts and other minerals, which would otherwise remain as ash after the activation process. [22]. The test results also showed that increasing the NaOH concentration to 3N resulted in higher ash content. This may occur due to an incomplete washing process. A higher NaOH concentration can lead to the formation of insoluble compounds that are more difficult to remove during the washing process. These remaining compounds contribute to the increased ash content in the final activated carbon.

The results of the ash content measurements for $ZnCl_2$ and NaOH at the optimal concentrations of 1 N and 2 N can be observed in Figure 2.

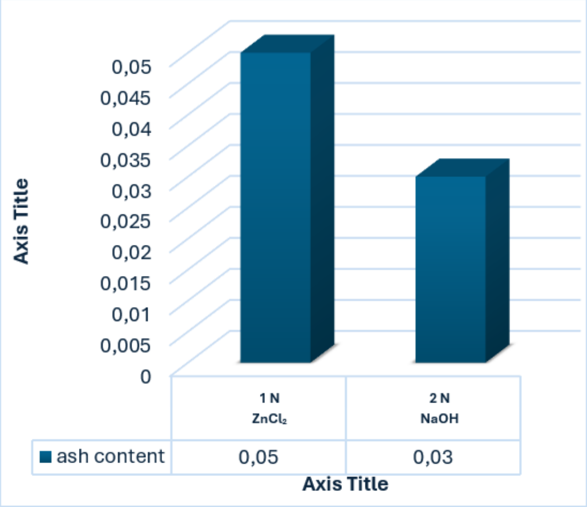

Figure 2. Diagram of the percentage of ash content in activated carbon with $ZnCl_2$ and NaOH activators.

The use of $ZnCl_2$ and NaOH as activating agents in the production of activated carbon from faloak bark does not show a significant difference in the ash content test results. Based on Figure 2, with the addition of $ZnCl_2$ 1 N, the ash content of the activated carbon was 0.05%, while NaOH 2 N resulted in 0.03%. Both types of activating agents meet the SNI standard, which requires ash content to be below 15%. NaOH 2 N is more efficient in removing inorganic impurities, such as minerals and metals, from raw materials compared to $ZnCl_2$ 1 N. Its strong base properties allow it to effectively dissolve or neutralize compounds that contribute to ash content. Activation with NaOH primarily targets the elimination of inorganic impurities, resulting in carbon with a cleaner and purer structure. In contrast, while $ZnCl_2$ effectively creates carbon pores, it can leave behind residues or traces of metal compounds from the activation process. Furthermore, the chemical compatibility of NaOH with the raw material makes it more suitable for producing activated carbon with a lower ash content than $ZnCl_2$.

Water Content Parameter

The aim of testing the water content of activated carbon is to assess the amount of moisture left in the material after the processing stage. Water content measurements were conducted on activated carbon using $ZnCl_2$ and NaOH activators at concentration variations of 1 N, 2 N, and

3 N. Table 4 presents the results of moisture content measurements for activated carbon when using $ZnCl_2$ as the activator.

Table 4. The results of the water content testing of activated carbon using $ZnCl_2$ as the activator.

Activator	Concentrations	Water Content (%)
$ZnCl_2$	1 N	0.69
	2 N	0.67
	3 N	0.76

Based on Table 4, the water content measurements of activated carbon using $ZnCl_2$ as an activator at concentrations of 1 N, 2 N, and 3 N do not show significant differences. All three concentrations indicate that the activated carbon meets the Indonesian National Standard (SNI) requirement of less than 15%. The lowest water content was achieved when $ZnCl_2$ was added at a concentration of 2 N, with a value of 0.67%. Higher concentrations, such as 3 N, may cause overreactions that result in trapped $ZnCl_2$ residues or other byproducts, which can hold moisture. On the other hand, lower concentrations, like 1 N, may not be adequate to completely eliminate bound water, making the material slightly more prone to absorbing moisture. At a concentration of 2 N, $ZnCl_2$ effectively breaks down hydrophilic organic compounds in the raw material, reducing their capacity to retain water in the final product. This concentration also promotes optimal pore formation and water removal without leaving excessive residues or disrupting the process, resulting in lower moisture levels and improved hydrophobicity, which decreases the material's tendency to retain water [23].

Water content measurements were also conducted on activated carbon using NaOH as the activator. Table 5 presents the results of the water content measurements with NaOH as its activator.

Table 5. The results of the water content testing of activated carbon using NaOH as the activator.

Activator	Concentrations	Water Content (%)
NaOH	1 N	0.66
	2 N	0.65
	3 N	0.7

The determination of water content in activated carbon must be less than 10%. According to Table 6, all three NaOH concentration variations meet the standard. The lowest moisture content is found at the 2 N concentration, which is 0.65%. At a concentration of 2 N, NaOH strikes an optimal balance between reactivity and pore formation, enabling efficient water removal without excessive or insufficient reactions. This concentration is effective in breaking down hydrophilic organic compounds and removing bound water more efficiently than 1 N, without leading to excessive reactions that might trap NaOH residues, as seen with 3 N. Higher concentrations like 3 N may leave behind NaOH residues or byproducts that can retain moisture, whereas 2 N achieves effective activation with minimal residues. Consequently, NaOH optimally aids in creating a porous structure, which reduces the material's ability to retain water by improving its hydrophobic properties [24].

From both types of activators, it is known that both $ZnCl_2$ and NaOH have the lowest water content at a concentration of 2 N. The results of the water content measurements for both types of activators are shown in Figure 3.

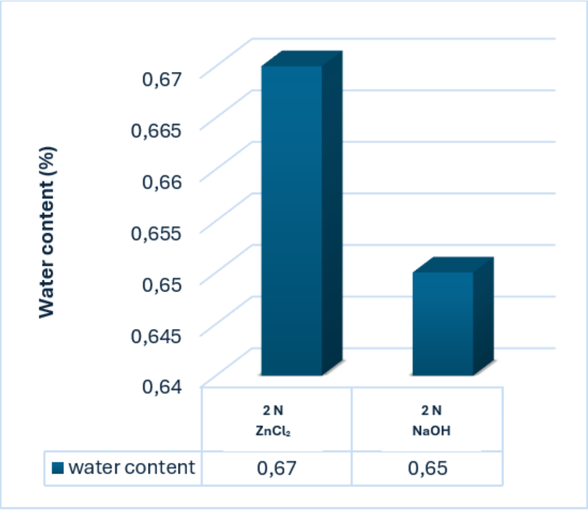

Figure 3. Diagram of the percentage of water content in activated carbon with $ZnCl_2$ and NaOH activators.

At the same concentration, 2 N, the water content values for $ZnCl_2$ and NaOH show different results. The water content in the activated carbon using NaOH is lesser compared to $ZnCl_2$. NaOH, as a strong base, effectively decomposes organic compounds, leading to a reduction in the amount of water retained. It encourages the development of a more advanced and hydrophobic porous structure when compared to $ZnCl_2$. This structure helps reduce the material's ability to hold water, resulting in lower moisture content. NaOH generally creates activated carbon with stronger hydrophobic properties, which naturally repel water. In contrast, activated carbon treated with $ZnCl_2$ tends to absorb more water due to its more hydrophilic characteristics. Although NaOH is a highly soluble strong base, its solubility does not directly determine the hydrophobic or hydrophilic nature of the activated carbon produced [20]. The variation in moisture content between activated carbon treated with NaOH and $ZnCl_2$ is primarily influenced by how each activator modifies the pore structure and surface properties of the carbon [21]. Activation with NaOH generally eliminates more polar compounds and oxygen functional groups from the carbon surface, enhancing its hydrophobic characteristics.

Functional Group (FTIR) Analysis

The functional groups of activated carbon derived from faloak bark were examined using FTIR. Figure 4 displays the results of identifying the functional groups in activated carbon from Faloak bark. Figure 4 shows the spectra of non-activated carbon compared to activated carbon from $ZnCl_2$ and NaOH activation. The spectra of activated carbon show some differences compared to non-activated carbon, including changes in shape, shifts, intensity reductions, and the emergence of new peaks after the activation process suggests changes likely caused by carbonization and activation, which result in dehydration and the breakdown of complex lignocellulosic groups into simpler ones [25].

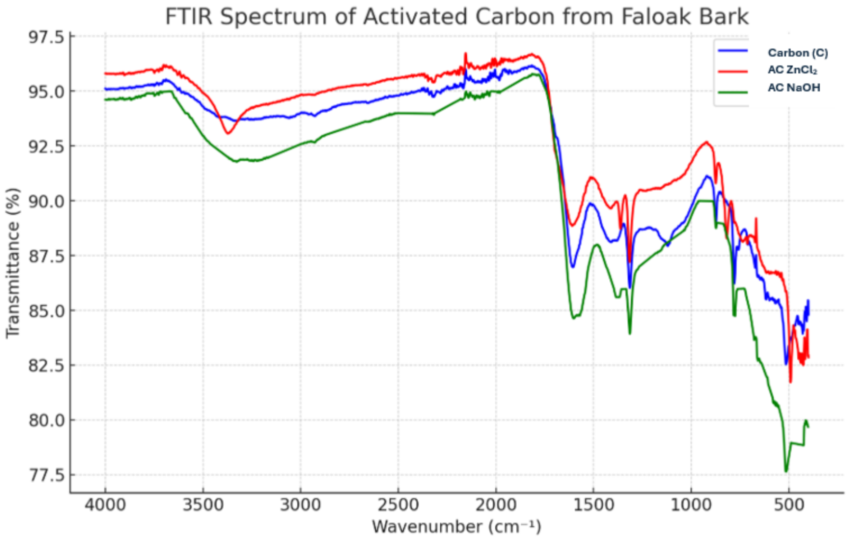

Figure 4. FTIR Analysis of Faloak Bark Carbon (C), Activated Carbon (AC) using $ZnCl_2$ and NaOH Activator.

Based on Figure 4, the identification results of functional groups can be observed in Table 6.

Table 6. Comparison of Functional Groups Based on FTIR Spectrum

Functional Group	**Wavenumber Range (cm^{-1})**	**Faloak Bark Carbon**	**Activated Carbon using $ZnCl_2$**	**Activated Carbon using NaOH**
O-H (Hydroxyl)	3200-3700	3340.65	3373.51 (with lower intensity)	3328.83 (with lower intensity)
C≡C (Alkyne Stretching)	2067-2900	2317.78, 2073.34	2318.00	2317.84
C=O (Carbonyl/Aromatic)	Around 1600	Not present	1609.96	1600
C=C (Aromatic)	~1600	Not present	1609.96	1600
C-N (Amine) / C-O-C (Ether)	1120-1411	1411, 1120	Not present	Not present
M-O (Metal-Oxygen Interaction)	< 500	Not present	< 500 (interaction with Zn)	515, 429

Non-activated carbon [Figure 4 (a)] has a significant -OH group at a wavelength of 3340.65 cm^{-1}. This group is also observed in the carbon activated with $ZnCl_2$ and NaOH, though with reduced intensity, at wavelengths of 3373.51 cm^{-1} and 3328.83 cm^{-1}, respectively. This finding aligns with the research conducted by [26] and [27] which indicates that the OH functional group ranges between 3200-3700 cm^{-1}. In the non-activated carbon sample, the presence of a triple bond C group, attributed to alkyne stretching, is observed at wavelengths of 2317.78 cm^{-1} and 2073.34 cm^{-1}. Similarly, this functional group is detected in carbon activated with $ZnCl_2$ and NaOH at wavelengths of 2318.00 cm^{-1} and 2317.84 cm^{-1}, respectively. These findings align with the study conducted by [28], [29] and [30], which reported that triple bond functional groups typically appear within the wavenumber range of 2067-2900 cm^{-1}. Carbonyl (C=O) or aromatic groups appear in the carbon activated with NaOH and $ZnCl_2$, as indicated by peaks around 1600 cm^{-1} and 1609.96 cm^{-1}, respectively. However, these groups are absent in the non-activated carbon. This indicates that these functional groups enhance the activated carbon's adsorption capacity for polar compounds compared to non-activated carbon. These findings align with the research conducted by [31], which stated that The carbon retains several functional groups that are sensitive to IR.

The activation process using $ZnCl_2$ increases the presence of polar functional groups like C=O and -OH, although the intensity of the -OH group slightly decreases, likely due to the removal of adsorbed water. Peaks observed below 500 cm^{-1} indicate interactions between zinc (Zn) and the carbon surface. This process also contributes to improved porosity in the activated carbon, which, while not directly measurable through IR, can be inferred from changes in the intensity of polar group peaks. For NaOH-activated carbon, the FTIR spectrum reveals a prominent peak at 3328 cm^{-1}, corresponding to hydroxyl (O-H) groups. This spectrum also indicates the presence of oxygenated surface groups, such as carbonyl and aromatic groups, on the activated carbon. These findings align with research by [32], which highlights that polar groups like -OH and C=O enhance the adsorption capacity of activated carbon for polar compounds compared to carbon without activation. The presence of functional groups like -OH (hydroxyl), C=C aromatic, and C=O carbonyl groups in activated carbon derived from Faloak bark indicates that Faloak bark has the potential to be used as a material for producing activated carbon.

Activated carbon produced using $ZnCl_2$ generally has higher porosity, which makes it more effective in adsorbing gases and larger molecules like organic compounds. On the other hand, activated carbon made with NaOH has finer pores and is typically better suited for adsorbing smaller molecules, such as metal ions or water-soluble compounds. This aligns with a study by [33], which discovered that $ZnCl_2$ exhibits higher adsorption efficiency and a larger surface area compared to NaOH. However, NaOH is more suitable for applications that require a simpler activation process, resulting in smaller pores.

The FTIR spectra of NaOH and carbon before activation appear similar because both samples contain similar functional groups, primarily O-H, C=O, C=C, and M-O. Environmental conditions, such as air humidity, can also affect the FTIR spectrum and cause a similar O-H peak. However, differences can still be observed between the two spectra. The peaks at 1411 cm^{-1} and 1120 cm^{-1} appear only in carbon before activation, indicating the possible presence of amine (C-N) or ether (C-O-C) groups, which are not found in NaOH. The peaks at 515 cm^{-1} and 429 cm^{-1} are more intense in NaOH, indicating interactions with metals, which align with its function as an inorganic compound.

Conclusion

The production of activated carbon from faloak bark has been carried out. The carbon was activated using $ZnCl_2$ and NaOH as activators. Based on the ash and water content tests for concentration variations (1 N, 2 N, and 3 N) for each activator, the results met the Indonesian

National Standard (SNI) requirements, with ash content below 15% and water content below 10%. However, NaOH showed the lowest values for both ash and water content at a 2 N concentration, which were 0.03% and 0.65%, respectively. The functional group analysis using FTIR revealed the presence of -OH (hydroxyl) groups, aromatic C=C groups, and carbonyl C=O groups. These results indicate that Faloak bark has potential as activated carbon because it makes Faloak-based activated carbon an efficient and environmentally friendly alternative for applications such as water purification, heavy metal removal, and toxic substance filtration.

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