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*Article*

# The Effect of Pyrolysis Temperature on Sawdust-Biomass Activated Carbon Using NaOH and NaCl Activators

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**Abstract.** The biomass pyrolysis refers to the process of heating and degradation of biomass to promising sustainable energy production. For our study, we selected the pyrolysis process to compose the biomass. Pyrolysis reactor (PR) was carried out to process carbonation of sawdust using activated carbon. The yield from this sawmill ranges from 20–40% of the volume of logs, depending on the diameter of the logs being sawed. Sawdust is put into the pyrolysis reactor, and pyrolysis is carried out at temperatures of 300, 325, 350, and 375 °C for 1 hour. The pyrolysis product, in the form of carbonated sawdust biomass, is produced using the activators NaOH and NaCl through an activation process. The adsorbent was then filtered, neutralized, and set at 110 °C for 3 hours. Based on the research that has been carried out, the quality of activated carbon is affected by increasing the pyrolysis temperature. Activation with 15% NaOH increases bound carbon levels, similar to 35% NaCl, but 35% NaCl causes a decrease in fixed carbon levels at 400 °C. Activation with 15% NaOH produces a pore morphology with the largest pore size of 7.17 $\mu$m, while activation with 35% NaCl produces activated carbon with impurities at a pore size of 7.80 $\mu$m. Study results can form the basis for obtaining fuel, chemicals, and environmental improvements.

**Keywords:** Activated carbon, adsorbent, biomass, pyrolysis, sawdust waste.

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## 1. Introduction

One of the Forestry Department's policies is to utilize wood as optimally as possible (zero waste), which means that all wood processing industries, both large and small, must try to minimize the production of wood waste. Wood waste is amenable to numerous applications, including the production of engineered wood commodities and energy generation (heat and electricity). For instance, wood bark comprises lipophilic and hydrophilic extractives that possess the potential to be converted into valuable commodities such as pharmaceuticals or cosmetic compounds [1]. 10 countries control 77% of global furniture production, with Brazil ranking as the sixth-largest producer [2]. The high production of this wood will also be directly proportional to the yield from the processing process. One of the yields that is quite found in the wood processing industry is sawdust. The yield from this sawmill ranges from 20-40% of the volume of logs depending on the diameter of the logs being sawed. The larger the diameter of the log, the higher the yield obtained [3]. In the wood processing process the resulting yield can reach 60% with an average yield value of 48.85%, thus showing that quite a lot of processed wood is not utilized. The low efficiency of wood utilization and yield can increase the rate of exploitation of natural wood, thus becoming a contributing factor to the decline in forest potential [4]. Application of sawdust-biomass adsorbents for adsorptive removal of organic and inorganic pollutants. Other research has been carried out on the use of sawdust, including its use in the form of briquettes and activated carbon [5].

One effort to utilize wood yield in the form of sawdust is to make activated carbon. Making activated carbon can be done using chemical methods with alkali metal hydroxides, carbonate salts, chlorides, sulphates, and phosphates from alkaline earth metals, especially $ZnCl_2$, inorganic acids such as $H_2SO_4$ and $H_3PO_4$, and physics, which is the process of breaking the carbon chain. from organic compounds with the help of heat at a temperature of 800 °C to 900 °C, where activated charcoal can be used as an adsorbent [6-7]. Several studies show that the process of making activated charcoal can be done from biomass waste using a carbonation process. Direct carbonation through combustion or the pyrolysis method are both options for carrying out this carbonation process [8].

Pyrolysis is a process of chemical decomposition of materials by heating in the absence or presence of oxygen. The pyrolysis process takes place at high temperatures and takes place in the reactor. Another term for pyrolysis is the irregular decomposition of organic materials caused by heating without contact with outside air. This implies that if sawdust is heated without contact with air and given a high enough temperature, a decomposition reaction will occur between the complex compounds that make up sawdust and produce substances in three forms, namely solid, gas, and liquid. In the pyrolysis process, biomass in the form of sawdust can be carbonated into charcoal and also produce liquid smoke [9].

Sawdust is waste from processed wood that we often find in wood processing industries such as the furniture industry, which is quite widely spread in big cities. The use of sawdust waste is still relatively low, and this waste is usually destroyed by burning. In large and modern industries, sawdust waste has been used to make charcoal briquettes and sold commercially, while in the small-scale industrial sawmill industry, which numbers up to thousands of units, this waste has not been optimally utilized. One effort to increase the added value of sawdust is to make activated carbon [10], activated carbon is carbon that has a good absorption capacity for anions, cations, and molecules in the form of organic and inorganic compounds, both in the form of solutions and gases. Manufacturing process Activated charcoal can be made through a physical or chemical activation process. Differences in the type of raw material and activation method used cause the properties and quality of activated charcoal to be different. Physical activation of charcoal uses a weak oxidizer, for example, water vapor, $CO_2$, $N_2$, $O_2$, and other oxidizing gases. Therefore, in this process, there is no oxidation of the carbon atoms that fabricate the charcoal, but the oxidizer only oxidizes the components that cover the surface of the charcoal pores. This activation principle begins by flowing light gases, such as water vapor, $CO_2$, or air, into a retort containing charcoal and heating it at a temperature of 800–1000 °C. At temperatures below 800 °C, the activation process with water vapor or $CO_2$ gas is very slow, while at temperatures above 1000 °C, it will cause damage to the hexagonal lattice structure of charcoal [3, 11].

In principle, chemical activation is the process of soaking charcoal with chemical compounds before heating. In the chemical activation process, the charcoal is soaked in the activation solution for 24 hours, then drained and heated at a temperature of 600–900 °C for 1-2 hours. At high temperatures, the activating material will enter between the hexagonal layers and then open the closed surface. Chemicals that can be used are $H_3PO_4$, $NH_4Cl$, $AlCl_3$, $HNO_3$, KOH, NaOH, $KMnO_4$, $SO_3$, $H_2SO_4$, and $K_2S$ [5]. Besides, other chemicals that can be used as active carbon activators are $ZnCl_2$ [6], $K_2CO_3$, and KOH [9, 12]. Another study, used activated carbon from gulf weed + KOH and reached the maximum value, which is 3362 $m^2/g$ [13].

The use of chemicals as activating agents often results in contamination of the activated charcoal produced. Generally, activators leave residues in the form of oxides that are insoluble in water when washing. Therefore, in several processes, dissolution is often carried out with NaOH to rebind chemical residues attached to the surface of the activated carbon and the ash content contained in the activated carbon [14]. Activated carbon is very useful, especially in the industrial sector (water treatment, chemicals, food and beverages, cigarettes, paint, scrubs, soap, shampoo, adhesives, masks, cooling equipment system, and automotive) and the health sector (absorbing toxins in the digestive tract and medicines), the environmental sector (absorbing pesticide residues in drinking water and soil, absorbing metals in liquid waste, absorbing toxic gas emissions in the air, reducing microbial biomass, increasing total organic soil carbon, and soil aggregation), and the agricultural sector (fertility of plant media, preventing root rot, and increasing the success of plant propagation using tissue culture) [15]. Activated carbon is suitable for use as a supercapacitor cell electrode due to its high specific surface area, adjustable pore structure, chemical stability, electrical conductivity, and environmental friendliness [8, 16].

## 2. Materials and Method

### 2.1. Materials Preparation

The preparation step is carried out by cleaning the sawdust from other impurities and then drying it in direct sunlight. Sawdust is put into the pyrolysis reactor, and after the reactor is tightly closed, pyrolysis is carried out at temperatures of 300, 325, 350, and 375 ℃ with a holding time of 1 hour. Reactor loading is represented in the kinetic expression as gas hourly space velocity (GHSV) around 50 km/s, a ratio of the gas rate per unit of catalyst. The pyrolysis product, in the form of carbonated sawdust biomass, will then undergo an activation process. The activated carbon activation process is carried out by drenching carbonated sawdust using the activators of 15% NaOH and 35% NaCl concentration, respectively. The adsorbent was then filtered, neutralized, and placed in an oven at 110 ℃ for 3 hours, as we can see in Fig. 1.

The Ari (P. jiringa) extract is washed clean, dried, crushed by 1 g, and then heated with 100 mL of distilled water at a temperature of 85 ℃ for 30 minutes. After cooling system, the dark red extract was filtered using Whatman No. 1 paper and stored at 4 ℃ for further use. All the chemicals were used as received with further purification.

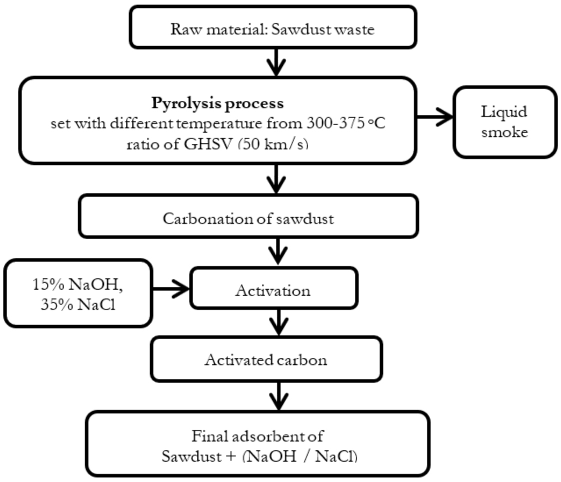

Fig. 1. Procedures for the preparation of the pyrolysis processes.

### 2.2. Equipment

Sawdust is put into the pyrolysis reactor, and after the reactor is tightly closed, pyrolysis is carried out at temperatures from 300-375 ℃ with a holding time of 1 hour. Figure 2 depicts a device circuit of activator and product-assisted MP system. In water content analysis, 1 gram of adsorbent sample is weighed in a porcelain cup. The sample was placed in an oven at 110 °C for 1 hour, then cooled in a desiccator for 15 minutes, and the weight of the sample was weighed.

In the ash content analysis, 1 gram of the adsorbent sample is weighed in a porcelain cup. The sample was placed in a furnace at 815 ℃ for 1 hour, then cooled in a desiccator for 15 minutes, and the weight of the sample was weighed. The ash content analysis, 1 g of the adsorbent sample was weighed in a porcelain cup. The sample was placed in a furnace at 959 ℃ for 7 minutes, then cooled in a desiccator for 15 minutes, and the weight of the sample was weighed. The analysis of iodine absorption capacity, the first thing to do is make a solution of 0.1 N Iodine, 0.1 N sodium thiosulfate, and 1 % starch. Then, 0.5 gram of adsorbent was added to the 0.1 N Iodine solution, agitate for 15 minutes, and left for 2 hours. Filtering was carried out, and then the results were titrated with a 0.1 N sodium thiosulfate ($NaSO_4$) solution.

The morphology and qualitative elemental composition of the absorbent samples were assessed with a scanning electron microscope (SEM), respectively. The functional group of the organic compound was analyzed with Fourier transform infrared spectroscopy (FTIR), with dimensions of 600 (W) × 665 (D) × 295 (H) and a wavelength number of 7,800–350 $cm^{-1}$.

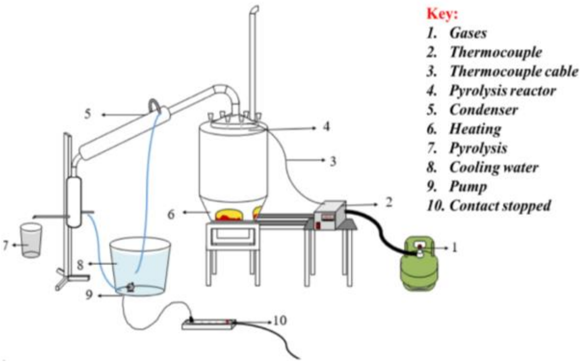

Fig. 2. The schematic illustration of the pyrolysis reactor.

### 2.3. Method of Analysis and Calculation

Equations (1-4) the pyrolysis products, including the moisture, ash content, volatile matter, and fixed carbon were calculated, following by determination of total weight loss (TWL).

$$moisture\ (\%) = \frac{m_2 - m_3}{m_2 - m_1}\ x\ 100\% \quad (1)$$

$$volatile\ matter\ (\%) = \frac{m_2 - m_3}{m_2 - m_1}\ x\ 100\% \quad (2)$$

$$ash\ content\ (\%) = \frac{m_1}{m_2}\ x\ 100\% \quad (3)$$

$$fixed\ carbon\ (\%) = 100\% - (ash + moisture + vol.matter) \quad (4)$$

Here, $m_1$ = initial weight of sample (g)
$m_2$ = initial weight of sample after treatment (g)
A = volume of the iodine solution (mL)
m = mass of the adsorbent used in the aqueous solution (g)

## 3. Results and Discussion

### 3.1. Characterization of Moisture, Ash Content, Volatile Matter, and Fixed Carbon

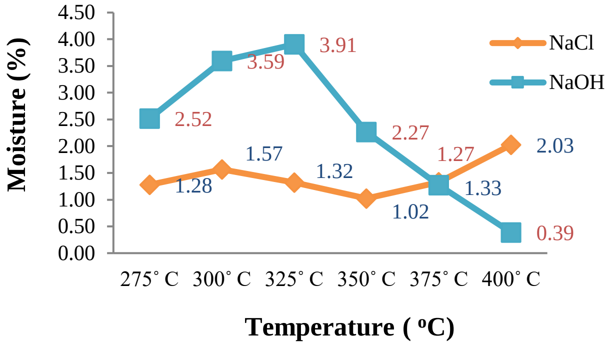

Fig. 3. The effect of the pyrolysis temperature of moisture on NaOH and NaCl-activated carbon.

Based on Fig. 3, the effect of temperature on the moisture of activated carbon using NaCl and NaOH activators, the data obtained from research on water content is 0.39%-3.91%. The percentage of water content is in accordance with SNI No. 06-3730-1995 regarding a maximum water content of 15%, this shows that all activated charcoal with various variations in temperature and carbonization time can meet the expected SNI standards.

The effect of temperature and activator on the moisture of activated carbon is shown in Fig. 3. It can be seen that the moisture or water content decreases as the pyrolysis temperature increases, this is in accordance with research conducted, namely that the higher the pyrolysis temperature, the greater the amount of water that evaporates so that the active carbon pores will be more open and the water content contained inside it will be released with increasing pyrolysis temperature, it appears that increased feedstock moisture leads to greater bio-oil production; however, the greatest organic liquid yield was observed at intermediate feedstock moisture levels [17-19].

The NaOH activator shows a smaller water content compared to the NaCl activator. This is because NaOH is alkaline so that it is in accordance with the conditions and characteristics of the substances contained in the charcoal before activation. Meanwhile, activated carbon which uses the NaCl activator is inversely proportional, this is because it has hygroscopic properties and high mineral content so that during the washing and drying process the loss of content is not maximized [20-23].

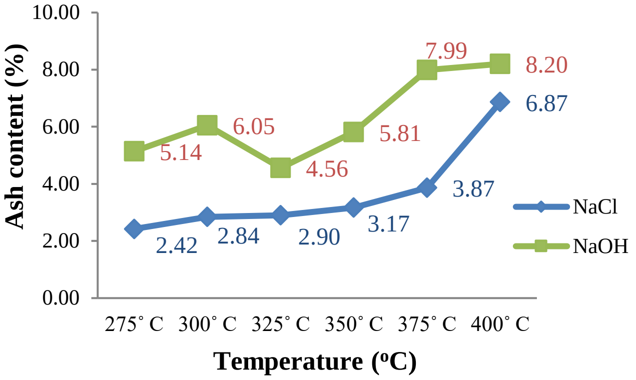

Fig. 4. The effect of the pyrolysis temperature of ash content on NaOH and NaCl-activated carbon.

Based on Fig. 4, the effect of temperature on the ash content of activated carbon using NaCl and NaOH activators, that showed the water content is 2.42%–8.20%. The percentage of ash content is in accordance with SNI No. 06-3730-1995 regarding a maximum water content of 10%, this shows that all activated charcoal with various variations in temperature and carbonization time can meet the expected SNI standards. In Fig. 4, it can be seen that the ash content value increases as the carbonization temperature increases. This is in accordance with research conducted by Seri et al. [24], namely that as the temperature and carbonization time increase, the graph will show an increasing trend towards the ash content value obtained. The NaOH activator provides a higher ash content than NaCl. This is in accordance with research conducted by Emad et. al., [25], where there are $Na^+$ cations from the activating material that are bound in activated carbon, so that when heated at 400 °C for 1 hour, the $Na^+$ cations turn into ash.

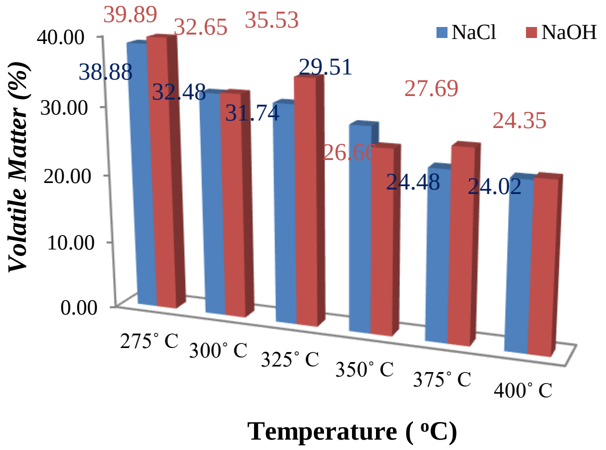

Fig. 5. The effect of the pyrolysis temperature of volatile matter on NaOH and NaCl-activated carbon.

The effect of temperature on the ash content of activated carbon using NaCl and NaOH activators, the data obtained from research on water content is 24.02%–39.89%. The percentage of volatile matter is only some of the data that complies with SNI No. 06-3730-1995 regarding a maximum water content of 25%. This shows that several activated charcoals with various variations in temperature and carbonization time can meet SNI standards.

The decrease in levels of volatile substances as the pyrolysis temperature increases is caused by the incomplete decomposition of non-carbon compounds during the pyrolysis process. The volatile matter value in activated carbon shows that the surface of the activated carbon still contains non-carbon compounds as seen in Fig. 5. The presence of these non-carbon compounds can clog pores and reduce the absorption capacity of activated carbon. The greater the value of volatile matter, the greater the noncarbon compounds covering the active carbon pores. This causes the absorption capacity and surface area of activated carbon to become smaller, and vice versa [9, 26]. NaOH and NaCl have the ability to activate carbon; therefore, the addition of an activator will penetrate, coat, and protect the material from heat. Thus, the addition of an activator reduces the amount of material burned. Adding activators breaks down organic materials as well, which can weaken the structure of activated carbon's surface. This can lead to the release of volatile substances and the formation of microporous structures in activated carbon [27].

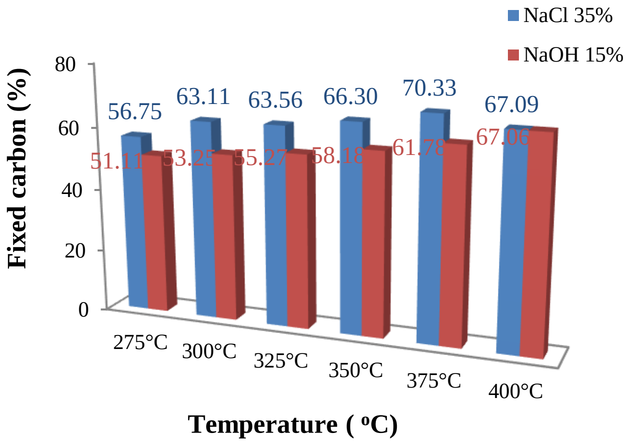

Fig. 6. The effect of the pyrolysis temperature of fixed carbon on NaOH and NaCl-activated carbon.

Based on the Fig. 6, it can be seen that the best activator is NaCl with a concentration of 35%. This is because there is an effect of concentration on the activator. In accordance with research Badreddine et. al., [28], the concentration of the activator has a great effect on the moisture/water content, ash concentration, volatile matter, and fixed carbon activated carbon content analysis, the higher the concentration of the activator, the more optimal the results obtained in making activated carbon. In addition to the type and concentration of the activator, the pyrolysis temperature also has an impact on activated carbon. It can be seen in the graph that with the 15% NaOH activator, the bound carbon content increases as the pyrolysis temperature used increases, as is the case with the 35% NaCl activator. However, the 35% NaCl activator experienced a decrease in fixed carbon levels at a temperature of 400 °C. This is because the high pyrolysis temperature used excessively can result in decreased molecular diffusion and surface adsorption energy effects [15, 29-31]. The higher the level of purity in the bound carbon content, the better the active carbon will absorb. The value of the bound carbon content of activated charcoal can even be higher than that of the charcoal. This is because in the activation process, many non-carbon compounds are lost. The higher the purity level of activated carbon shows that the pores of the activated carbon are clean from impurities; this can be used as a benchmark for the ability of activated carbon adsorbents to have better absorption capacity [32].

### 3.2. Morphology Characterization of Activated Carbon with 15% NaOH and 35% NaCl Activators

Analysis of the carbon pore morphology of teak wood powder without activation and with 15% NaOH activation was carried out using a scanning electron microscope (SEM) with a magnification of 5000 times. The morphology characterization of activated carbon produced using 15% NaOH and 35% NaCl as activators reveals significant enhancements in surface area and porosity, crucial for various applications. Based on the image below, you can see the difference in surface pore morphology of teak sawdust-activated carbon before and after activation using 15% NaOH. SEM analyzing on carbon used a temperature of 400 °C. This is because in the analysis of fixed carbon content, the best results were obtained for 15% NaOH at a temperature of 400 °C as seen in Fig. 7.

Based on Fig. 7, it can be seen that there is an effect before and after being activated with 15% NaOH where the carbon before activation has a flat surface and few pores are formed, while the carbon that has been activated has a pore morphology that is cleaner from impurities and other organic compounds compared to unactivated activated carbon [32, 33]. Besides, carbon that has been activated also has a greater number of pores formed compared to carbon that has not been activated.

Activated carbon treated with NaOH typically exhibits a substantial increase in surface area. For instance, NaOH activation can elevate surface areas to approximately 1935 m²/g, significantly enhancing adsorption capacity. The combination of NaOH and NaCl can create a unique pore structure, with NaOH contributing to microporosity and NaCl potentially aiding in the formation of mesopores, thus optimizing the overall porosity [12, 34].

The studies indicate that NaOH activation leads to a highly microporous structure, characterized by smaller pore sizes and increased pore volume. The presence of NaCl may influence the morphology by modifying the surface texture, potentially leading to a more uniform pore distribution. In contrast, while NaOH is effective in enhancing surface area and microporosity, the role of NaCl in the activation process is less understood and may require further investigation to fully elucidate its impact on the morphology of activated carbon [33].

In Fig. 8. regarding the pore size of activated carbon with a magnification of 5000, it can be seen that carbon that has not been activated has a size of 11.3 $\mu$m, while carbon that has been activated has the largest pore size of 7.17 μm. This is in contrast to research that has been carried out Anjali et. al., [34], which states that using the NaOH activator on carbon can expand the surface of the activated carbon by attracting the functional groups on the carbon surface. This discrepancy can occur because pore measurements only focus on one carbon pore object, while carbon has a very large number of pores. This can be seen in Fig. 9, where the carbon after activation has a large number of pores.

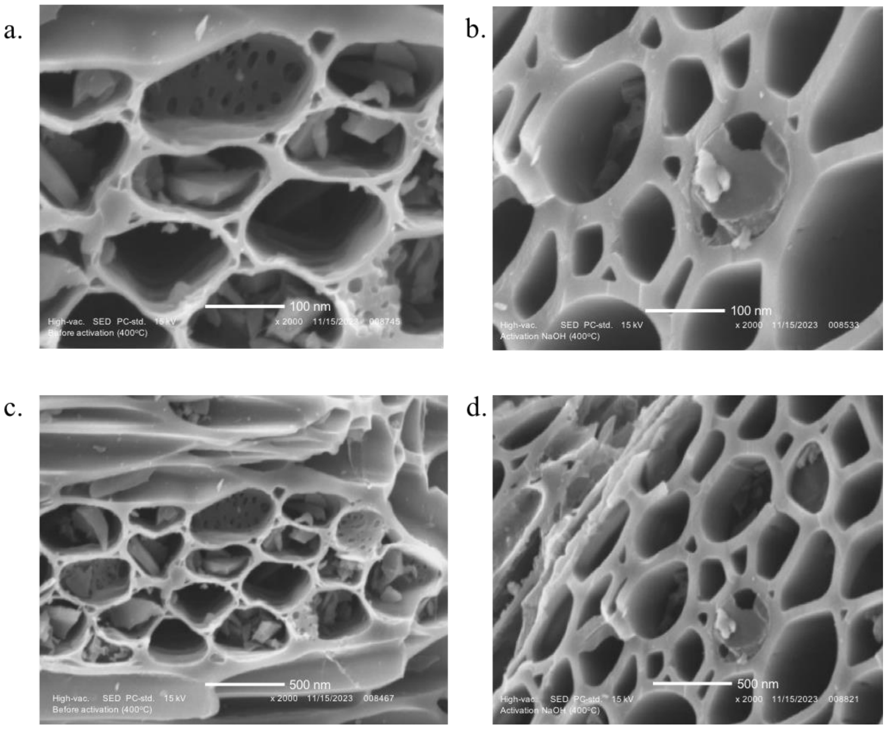

Fig. 7. SEM images of before NaOH activation (a) 2000x (c) 5000x; and after NaOH activation (b) 2000x (d) 5000x

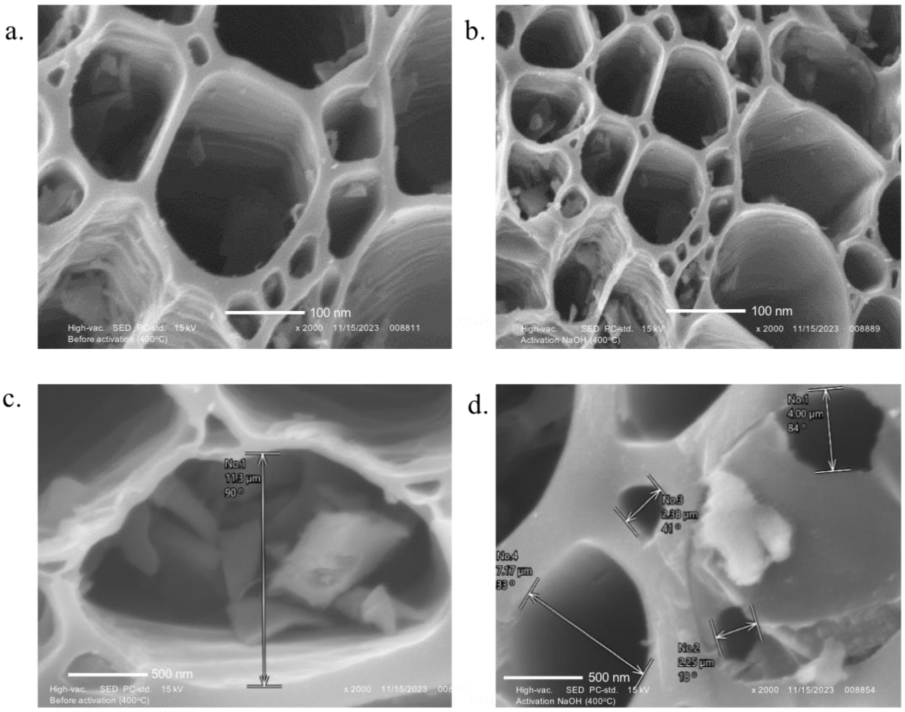

Fig. 8. SEM images of before NaCl activation (a) 2000x (c) 5000x; and after NaCl activation (b) 2000x (d) 5000x.

Regarding the pore size of activated carbon with a magnification of 100 and 500 nm, it can be seen that carbon that has not been activated has the largest pore size, namely 4.64 $\mu$m, while activated carbon has the largest pore size of 7.80 $\mu$m. This is in accordance with research, which states that the right concentration of activator can effectively increase the yield, specific surface area, and pore structure of activated carbon and can increase the surface functional groups of activated carbon. The shape of the pore surface is one of the factors that plays a role in the ability of an adsorbent to adsorb. The pores in activated charcoal can increase its ability to adsorb adsorbate because these pores are gaps that expand the surface of activated charcoal [8, 22, 35].

Moreover, the SEM analysis indicates that the difference in the shape of the carbon pore surface of teak wood powder before and after activation. In this research, characterization was carried out using SEM so that a picture of the condition of the pore surface can be seen, namely the number of pores formed, the size of the pore cavity, and the elements contained. SEM analyzing was carried out on the best treatment and the control treatment as a comparison between activated carbon without activation and activated carbon. The control treatment was taken at the same temperature as the best treatment obtained from the analysis [36].

### 3.3. Characterization of Activated Carbon Functional Groups with 15% NaOH and 35 NaCl Activators

FTIR analyzing is carried out to see and detect functional groups of organic compounds in samples. The results of FTIR analyzing of activated carbon samples before and after 15% NaOH activation can be seen in Figs. 9 and 10.

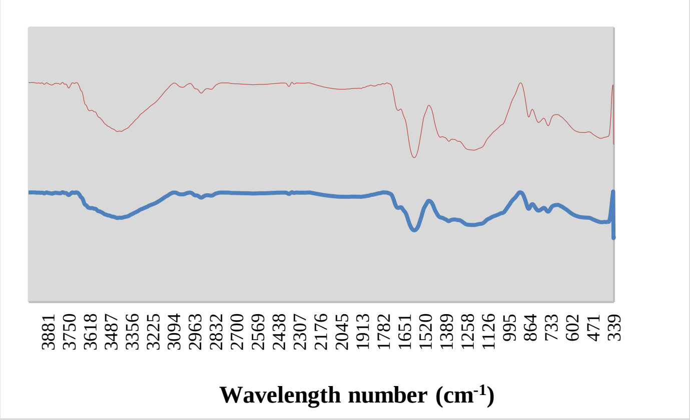

Fig. 9. The FTIR analysis of 15% NaOH activator (before and after activation) at 400 °C.

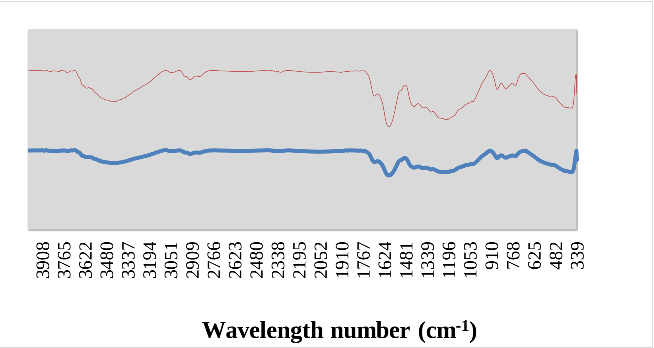

Fig. 10. The FTIR analysis of 35% NaCl activator (before and after activation) at 375 °C.

Figure 9 of FTIR analysis results on teak wood powder activated carbon show the same functional composition with peaks at certain wave numbers. The similarity lies in the presence of a hydroxyl group (OH) at 3426 $cm^{-1}$, a carbonyl group (C=O) at 1638 $cm^{-1}$, and a C-O-C group at 1034 $cm^{-1}$, which have broad capabilities in adsorption, catalysis, and storage of energy. However, the main difference between the two graphs lies in the intensity of the OH peak at wave number 3426 $cm^{-1}$. After carbon activation, shows a 1.5-fold higher intensity of the OH peak, indicating an increase in OH concentration upon activation. This leads to the conclusion that activation can increase the adsorption ability of teak wood powder-activated carbon [37].

The FTIR analysis results show that the active carbon in teak wood powder has hydroxyl groups (OH), carbonyl groups (C=O), and C-O-C groups, both before and after it has been activated as seen in Fig. 10, Activation increases the concentration of hydroxyl groups (OH) on activated carbon while slightly decreasing the concentration of carbonyl groups (C=O) and C-O-C groups. An increase in the concentration of hydroxyl groups (OH) after activation, for example, with a higher peak intensity at wave number 3426 $cm^{-1}$ in the graph after activation, can increase the adsorption properties and ability to bind active carbon pollutants [12, 38, 39]. However, a decrease in the concentration of carbonyl groups (C=O) and C-O-C groups, for example, with peak intensities at wave numbers 163 $cm^{-1}$ and 1034 $cm^{-1}$ which are slightly lower in the graph after activation, can affect the catalytic properties and thermal stability of activated carbon. Some possible uses for teak wood powder activated carbon that has a lot of hydroxyl groups (OH) are to clean up water and air pollutants, speed up chemical reactions, and store energy [40, 41].

## 4. Conclusions

The conclusion of this research is that the quality of activated carbon is greatly affected by the pyrolysis temperature, and increasing the pyrolysis temperature improves the quality of the activated carbon. The use of a 15% NaOH activator on activated carbon showed an increase in bound carbon content along with an increase in pyrolysis temperature, similar to a 35% NaCl activator. However, the use of 35% NaCl resulted in a decrease in fixed carbon levels at a temperature of 400 °C. Also, activating activated carbon with 15% NaOH makes the pores cleaner from impurities and other organic compounds than activated carbon that hasn't been activated. Activated carbon shows the largest pore size of 7.17 $\mu$m. On the other hand, activation with 35% NaCl produces activated carbon, which still has impurities and other compounds attached to it, even though the resulting pore size is quite large, namely 7.80 $\mu$m.

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