

# Activated Carbon from Sawdust Biomass Via $\text{ZnCl}_2$ and NaOH Activation for Water Biofiltration Applications

Syarwan Hamid<sup>1</sup>, Gusnawati<sup>1</sup>, Thahirah Arief<sup>1</sup>, Muh. Ilham Anggamulia<sup>2</sup>, Hijrah Amaliah Azis<sup>3</sup>, Muh Arman<sup>1,\*</sup>

<sup>1</sup>Chemical Engineering Department, Faculty of Industrial Technology, Universitas Muslim Indonesia, Makassar, Indonesia

<sup>2</sup>Environmental Engineering Department, Faculty of Engineering, Universitas Muslim Indonesia, Makassar, Indonesia

<sup>3</sup>Chemistry Department, Faculty of Engineering, Universitas Teknologi Sulawesi, Indonesia.

\* Corresponding author: [m.arman@umi.ac.id](mailto:m.arman@umi.ac.id) (Muh Arman)

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**Abstract:** The declining availability of fossil energy sources in Indonesia has driven the development of renewable and environmentally friendly alternatives, including the utilization of biomass waste such as teak sawdust (*Tectona grandis* L.F.). This study aims to produce activated carbon via pyrolysis and chemical activation using  $\text{ZnCl}_2$  and NaOH for water filtration applications. Pyrolysis was conducted at 300-400°C with biomass-to-activator ratios of 1:3, 1:5, and 1:7. SEM analysis revealed that chemical activation increased pore number and size;  $\text{ZnCl}_2$  produced larger and more complex pore structures, while NaOH resulted in more uniform pores. FTIR spectra showed a reduction in hydroxyl (O-H), carbonyl (C=O), and ether (C-O) groups with increasing temperature, along with the emergence of aromatic (C=C) bands, indicating enhanced carbonization and structural stability. NaOH activation at 380°C yielded the highest iodine adsorption (1124 mg/g), while  $\text{ZnCl}_2$  was optimal at 320 °C (980 mg/g). These results demonstrate that teak sawdust-derived activated carbon possesses a microporous structure and functional surface groups suitable for water purification and efficient removal of organic contaminants.

**Keywords:** Environmental; Pyrolysis; Teak sawdust; Waste; Wood.

## 1. Introduction

In Indonesia, environmental problems such as pollution and the accumulation of organic waste are increasingly worrying. One way to address this is by utilizing biomass, such as wood waste, which is often considered useless [1]. This waste can be processed into something useful, such as activated carbon. This activated carbon can absorb harmful substances and effective for cleaning water and air. By utilizing waste into useful products like this, we can help reduce pollution while supporting a more eco-friendly and sustainable way of life [2].

Activated carbon is commonly produced from carbon-rich organic materials, such as wood, coal, or agricultural waste, through pyrolysis and chemical activation processes. Chemical activation uses a variety of chemicals, such as  $\text{ZnCl}_2$  and NaOH, has been shown to be effective in increasing the adsorption capacity of activated carbon [3]. However, the use of more environmentally friendly and inexpensive biomass materials, such as teak wood sawdust, is still rarely researched. Teak wood (*Tectona grandis* L.F.) is one of the most abundant wood species in Indonesia and can be a potential source of biomass [4,5,6-8].



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This study aims to evaluate the production process of activated carbon from teak wood sawdust through the pyrolysis method followed by chemical activation using  $\text{ZnCl}_2$  and  $\text{NaOH}$ . The focus of this study is to analyze the extent to which the process can enhance the adsorption capacity of activated carbon in water purification applications. In addition, this study also compared the effectiveness of both types of activation agents in forming pore structures that support adsorption efficiency. The resulting activated carbon is expected to be able to effectively adsorb various pollutants in water, including heavy metals and organic compounds [9-11].

This research offers the novelty of using teak (*Tectona grandis* L.f.) sawdust as a raw material for activated carbon production. In addition, this study also compared two commonly used activators,  $\text{ZnCl}_2$  and  $\text{NaOH}$ , in the activated carbon activation process. This comparison provides new insights into how variations in activator materials and pyrolysis conditions affect the characteristics of activated carbon, particularly in terms of adsorption capacity and pore structure. This study also contributes to the development of more environmentally friendly and sustainable biomass feedstocks [12].

The production of activated carbon from biomass, particularly sawdust, has been widely researched in the past decade. Studies show that chemical activation using  $\text{NaOH}$  can produce activated carbon with high iodine adsorption capacity, making it effective in filtration applications. In addition, activated carbon from wood waste has also been widely used to adsorb gaseous pollutants and other harmful compounds in the air. However, research that directly compares the effectiveness of chemical activators  $\text{ZnCl}_2$  and  $\text{NaOH}$  in the activation process of activated carbon from teak wood powder is still relatively limited. Therefore, this study aims to fill the gap by examining the characteristics of activated carbon produced from teak wood sawdust activated using both types of chemicals [13,14].

The expected result of this research is the identification of optimal pyrolysis conditions and activator materials to produce activated carbon with high adsorption capacity. Characterization the SEM and FTIR is expected to show a larger and more regular pore structure, which supports applications in water purification and pollutant removal. In addition, it is also expected to find significant differences in adsorption ability between activated carbons activated with  $\text{ZnCl}_2$  and  $\text{NaOH}$ , which will provide further guidance in the selection of suitable activators for various environmental applications [15].

## 2. Research and Methodology

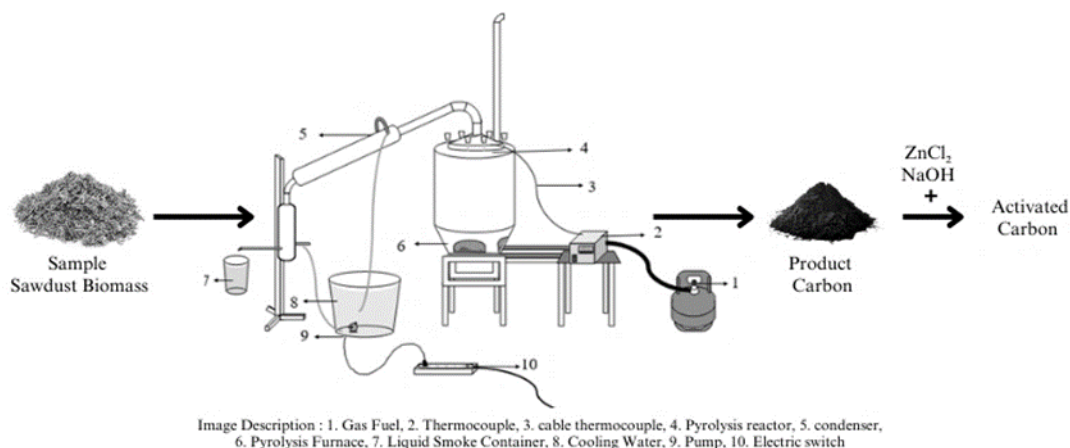
### 2.1 Materials

The theoretical section extends the analytical background of the article and develops a new formulation of the problem. Calculations are achieved here using the developed equations and the modifications should be pointed out. They should be described with sufficient detail to allow others to replicate and build on published results. Please state manufacturer, city and country from where materials have been sourced.

### 2.2 Experiments

This research uses various tools and materials to produce activated carbon from teak wood (*Tectona grandis* L.f.) sawdust waste. The pyrolysis process is carried out using a pyrolysis reactor that can reach temperatures of up to 600 °C to heat sawdust at a temperature of 300-400 °C. Carbon activation was carried out with Merck brand  $\text{ZnCl}_2$  (Zinc Chloride) and Merck brand  $\text{NaOH}$  (Sodium Hydroxide) chemicals, each with a concentration of 5 %. Teak wood sawdust used will be dried

obtained from the wood processing industry. For morphological characterization of activated carbon, SEM (Scanning Electron Microscope) brand JEOL JCM 6000 plus was used and for functional group analysis, FTIR (Fourier Transform Infrared Spectroscopy) brand Shimadzu IRPrestige-21 was used. Iodine absorbance was tested using 0,1 N standard iodine solution and volumetric tools. Testing the effectiveness of activated carbon as a water biofilter using pH, TDS (Total Dissolved Solid) and TSS (Total Suspended Solid) tests.



**Figure 1.** Design of pyrolysis device and method of making activated carbon

### 2.3 Carbonization of sawdust waste and preparation of activated carbon

At the initial stage, teak wood sawdust as raw material is conditioned by cleaning it from physical impurities such as stones, soil, and metal residues, then dried naturally under direct sunlight for several days until it reaches the minimum moisture content. After drying, the sawdust was put into the pyrolysis reactor, then the reactor was sealed to prevent oxygen from entering. The pyrolysis process was carried out at five temperature variations, namely 300 °C, 325 °C, 350 °C, 375 °C, and 400 °C, with a holding time of 1 hour for each treatment. This process produces carbonated charcoal as the main result.

The next stage is chemical activation. The carbonated charcoal was soaked in an activator solution with a concentration of 5 % using two types of activators, namely sodium hydroxide (NaOH) and zinc chloride (ZnCl<sub>2</sub>), for each treatment. The soaking process was carried out for 24 hours at room temperature to ensure penetration of the solution into the charcoal pores. After soaking, the samples were filtered and washed repeatedly using deionized water until they reached a neutral pH. The clean adsorbents were then oven dried at 110 °C for 3 hours to remove moisture before further characterization.

Iodine absorbency analysis. The iodine absorption test was conducted to determine the adsorption capacity of activated carbon on small molecules, which is an indicator of the specific surface area of the adsorbent. The initial stage begins by preparing three standard solutions, namely 0.1 N iodine solution, 0.1 N sodium thiosulfate (Na<sub>2</sub>S<sub>2</sub>O<sub>3</sub>) solution, and 1% amylum indicator solution. A total of 0.5 grams of activated carbon sample was added to 50 mL of 0.1 N iodine solution, then the solution was shaken using a shaker for 15 minutes to ensure interaction between iodine and the

adsorbent surface. After that, the mixture was allowed to stand for 2 hours at room temperature to optimize the adsorption process [12].

After the incubation time was complete, the solution was filtered to separate the adsorbent from the remaining iodine solution. The filtrate obtained was then titrated using 0.1 N sodium thiosulfate solution until a color change from brown to transparent occurred. Next, a few drops of 1% amylum solution were added as an indicator to detect the end point of the titration, which was indicated by the color change of the solution to blue, then back to colorless when all the iodine had been reduced. The volume of sodium thiosulphate used was recorded to calculate the adsorption capacity of iodine by activated carbon. Reaction between iodine and sodium thiosulphate (titration reaction):



To calculate the adsorption capacity on iodine (mg/g) can be done using the following equation:

$$Iod\ absorbency\ (\%) = \left( A - \frac{(B \times N(Na_2S_2O_3))}{N(iodin)} \times 126,93 \times fp \right) / a \times 100\% \quad (2)$$

SEM analysis. Characterization of activated carbon surface morphology was carried out using a Scanning Electron Microscope (SEM) brand JEOL JCM-6000Plus to observe the pore structure and surface texture of the samples. The dried activated charcoal samples were put into a desiccator to avoid moisture before analysis. Next, about 0.01-0.02 grams of activated carbon powder was placed on a sample stub that had been coated with carbon tape to ensure electrical conductivity and position stability during observation.

Prior to analysis, the samples were coated with a thin layer of conductive metal (usually gold or gold-palladium) using a sputter coater for 60-120 seconds, to prevent overcharging during electron exposure. After coating, the sample was put into the SEM vacuum chamber. Observations were made at 1000x to 3000x magnification to obtain clear surface visualization, especially on pore morphology and distribution. The accelerating voltage was adjusted in the range of 10-15 kV, depending on the need and contrast of the resulting image. The scanned images were then analyzed to evaluate the surface structure, pore size and distribution, as well as an indication of the success of the carbon activation process. These SEM images form the basis for interpreting the surface area and adsorptive potential of the activated carbon produced.

FTIR analysis. Analysis of functional groups on activated carbon samples was carried out using Fourier Transform Infrared Spectroscopy (FTIR) brand Shimadzu IRPrestige-21 to identify the presence of functional groups that play a role in the adsorption process. The dried activated carbon samples were finely crushed and mixed with pure potassium bromide (KBr) in a mass ratio of 1:100 (1 mg sample: 100 mg KBr). The mixture was then pressed using a pellet press to form a transparent disc with a diameter of  $\pm 1$  cm.

The KBr-sample discs were then inserted into the sample chamber of the FTIR instrument, and scans were performed in the spectral range of 4000-400  $\text{cm}^{-1}$  with a spectral resolution of 4  $\text{cm}^{-1}$  and a scan count of 32 times. The instrument was first calibrated using pure KBr discs as a blank to eliminate spectral interference [15].

The resulting infrared spectra were analysed to identify the main functional groups such as hydroxyl (-OH), carbonyl (C=O), ether (C-O-C), and other groups related to the surface activity of activated carbon. Changes in peak intensity and position compared between samples before and

after activation provide information about chemical modifications on the carbon surface due to chemical activator treatments such as NaOH and  $\text{ZnCl}_2$ .

## 2.4 Testing activated carbon as a water biofilter

Water quality testing in this study was carried out through three main parameters, namely pH, Total Dissolved Solids (TDS), and Total Suspended Solids (TSS). The pH test was conducted to determine the acidity or basicity of water using a digital pH meter that had been calibrated beforehand using a standard buffer solution of pH 4, 7, and 10. A total of 50 mL of water sample was put into a clean container, then the pH meter electrode was dipped into the sample and the pH value was read directly on the screen of the device, with the test conducted at room temperature [16]. Furthermore, the TDS test aims to measure the concentration of total dissolved solids in water, which is carried out using an electrical conductivity-based TDS meter. A 100 mL water sample is put into a clean measuring cup, then the device is activated and dipped into the solution until the TDS value in mg/L appears on the digital screen. As for the TSS test, a 100 mL water sample is filtered using a paper filter with a standard pore size, then the filter that has held the solids is dried in an oven at 105 °C for 1-2 hours. After drying, the filter was weighed using a high-precision analytical balance, and the TSS value was calculated based on the difference in filter mass before and after filtration. These three methods were used to evaluate the effectiveness of activated carbon in improving water quality through the biofiltration process [17].

## 2.5 Product characterization

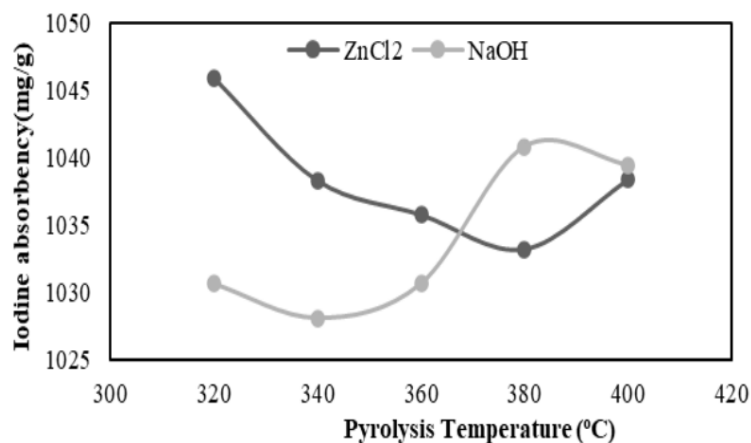
The products (biomass biochar and hybrid biochar) recovered from the process were characterized to ascertain some of their properties using Scanning Electron Microscope with energy Dispersive X-ray Spectroscopy (SEM-EDS), Fourier Transform Infra-Red Spectroscopy (FTIR) and Brunauer-Emmet-Teller (BET) analysis. Scanning Electron Microscopy (SEM, Phenom proX, Phenom-World BV, Netherlands) was used to study the surface morphology of the particles of the biochar. A double adhesive was placed on a sample stub. The sample was sprinkled on the sample stub and subsequently taken to a sputter coater (quorum-Q150R Plus E) and coated with 5 nm of gold.

## 3. Results and Discussion

### *Iodine absorbency analysis*

Determination of iodine adsorption capacity on activated carbon is a standard method to assess the specific surface area and adsorption potential of carbon. In this study based on Fig. 2, activated carbon activated with  $\text{ZnCl}_2$  showed the highest iodine adsorption capacity at a carbonization temperature of 320 °C, which was 1045.9 mg/g, and the lowest at 380 °C of 1033.2 mg/g. Meanwhile, activation using NaOH produced the highest absorption at 380 °C of 1040.82 mg/g, and the lowest at 340 °C of 1028.12 mg/g. These values fulfil the SNI 06-3730-1995 standard, which sets the minimum limit of iodine absorbency at 750 mg/g. The increase in iodine absorbency indicates that the activation process successfully increased the surface area of activated carbon, which contributed to the increase in adsorption capacity. This is in line with previous findings showing that chemical activation can increase the surface area and pore volume of activated carbon, thereby increasing the iodine adsorption capacity [18].

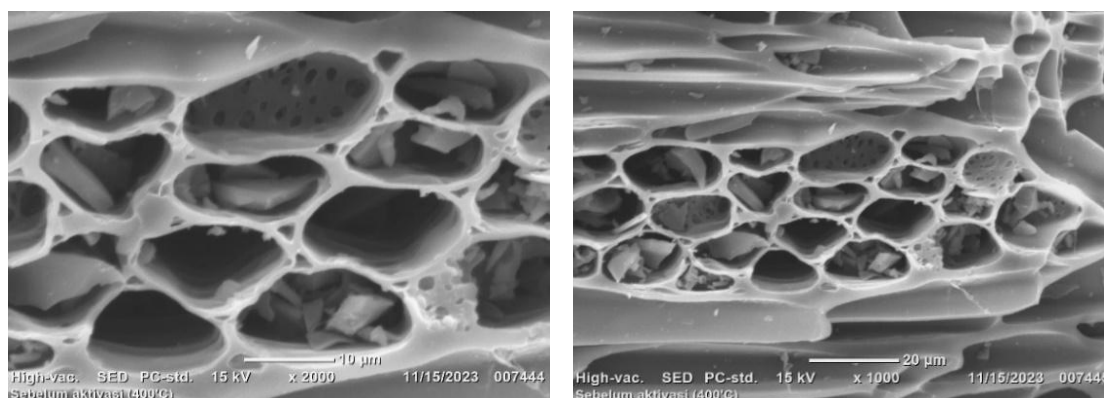




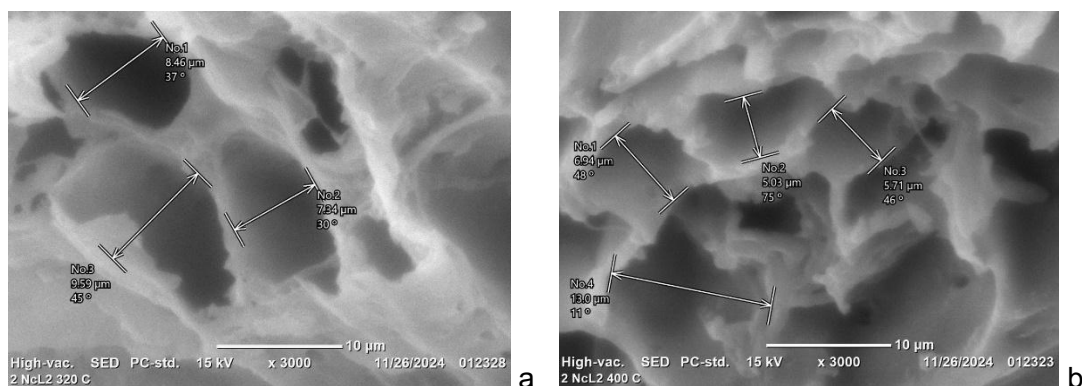
**Figure 2.** The effect of pyrolysis temperature on iodine absorbency

Although an increase in carbonization temperature is generally associated with an increase in surface area and adsorption capacity, this study shows that the change in iodine adsorption capacity is not very significant with an increase in carbonization temperature. This may be due to the specific conditions in this study, such as the type of raw material and carbonization process conditions. Previous studies have also shown that too high a carbonization temperature can cause damage to the pore structure of activated carbon, which can decrease the adsorption capacity [19]. However, the results of this study still show that the pore structure formed during the activation process has a significant effect on the iodine adsorption capacity of activated carbon. Therefore, control of the carbonization temperature and selection of the right activation agent are essential to produce activated carbon with optimal adsorption capacity [20, 21].

#### *Surface morphology analysis using SEM*



**Figure 3.** SEM morphology results of teak wood sawdust before activation



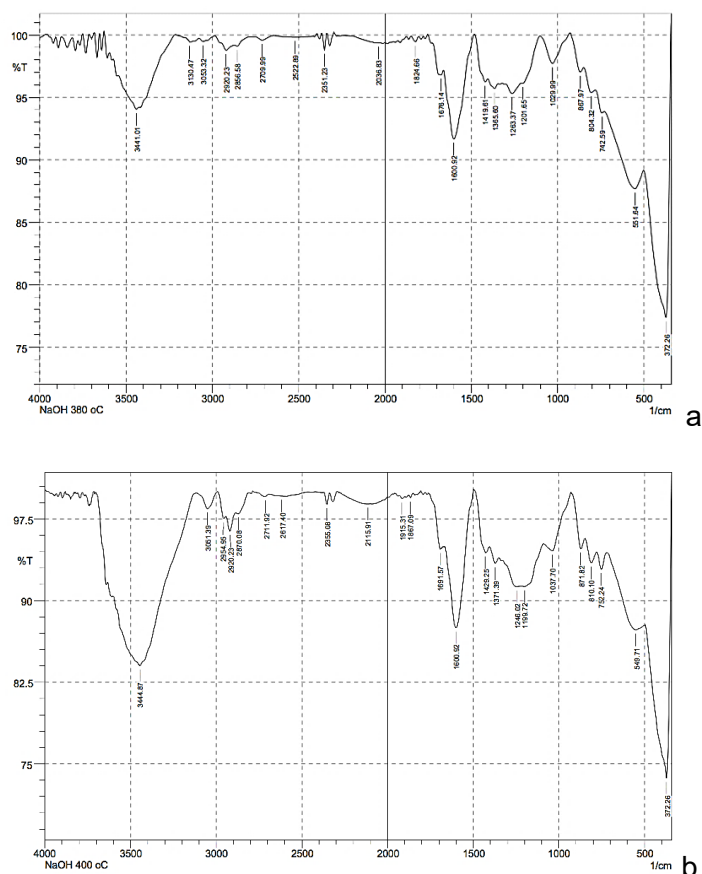
**Figure 4.**  $\text{ZnCl}_2$  analysis results 320 °C (a) and 400 °C

Observation of the surface morphology of activated carbon from teak wood powder after activation with 5 % NaOH and 5 %  $\text{ZnCl}_2$  was carried out using a Scanning Electron Microscope (SEM) with a magnification of 3,000 times at a carbonization temperature of 380 °C (Figures 3 and 4). Based on the observation, there is a striking difference in the pore morphology of activated carbon produced from the two activators. Activated carbon activated with 5 % NaOH showed a more regular clear pore structure, with larger voids and cleaner from impurities and organic compounds. In contrast, activated carbon activated with 5 %  $\text{ZnCl}_2$  showed a larger porous structure, but more complex and less regular than with NaOH [22].

SEM results show that the resulting activated carbon has a heterogeneous surface morphology with a predominance of micropores. The presence of macropores was also detected, which serve as directional channels for molecules towards mesopores and micropores. The presence of these pores increases the efficiency of activated carbon in applications such as heavy metal or gas adsorbers. Further observations showed that the pore sizes on activated carbon activated with 5 % NaOH at 380 °C had average sizes of 10.5  $\mu\text{m}$ , 7.34  $\mu\text{m}$ , and 11.2  $\mu\text{m}$  [23]. This indicates an even distribution of pores, which is very important for increasing the adsorption capacity of activated carbon. Comparison with the results of previous studies, such as the one conducted showing that activated carbon with large surface area and high hypochlorite adsorption capacity (40.9 %) indicated that a concentration of 15 % was the optimal condition for the activation process. These results indicate that activated activated carbon has good potential for various applications, such as water purification, removal of gaseous pollutants, and adsorption of organic matter [24, 25].

#### *Functional group analysis using FTIR*

Fourier transform infrared (FTIR) spectroscopy was used to identify changes in chemical functional groups in pyrolyzed sawdust waste, with chemical activation using NaOH and  $\text{ZnCl}_2$  at various temperatures. Based on Figure 5(a), the FTIR results at 380°C with NaOH activator show a broad absorption band around 3400  $\text{cm}^{-1}$  which is characteristic of the O-H stretch of hydroxyl groups, as found in phenol and alcohol compounds. In addition, absorption bands around 1700  $\text{cm}^{-1}$  indicate the presence of carbonyl ( $\text{C}=\text{O}$ ) groups, while bands in the 1000-1300  $\text{cm}^{-1}$  range indicate the presence of C-O bonds from ether, primary alcohol, or ester groups [26].

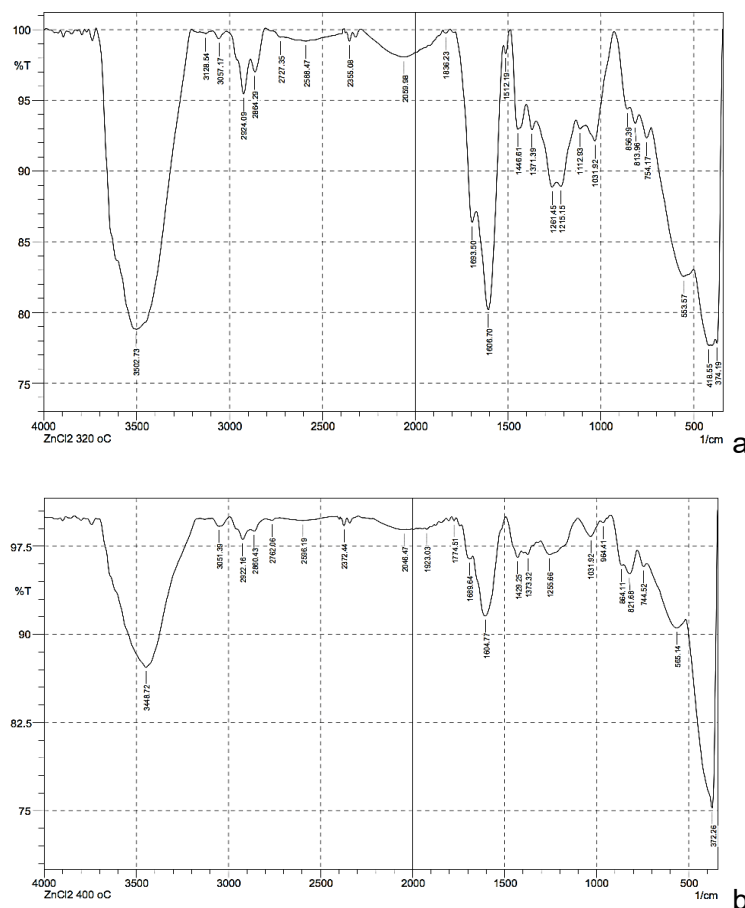


**Figure 5.** FTIR test results of (a) NaOH at 380 °C and (b) 400 °C

In Figure 5(b), which represents NaOH activation at 400 °C, there is a significant decrease in the intensity of the O-H and C-O bands. This indicates the decomposition of hydroxyl groups and other oxygen functional groups due to higher thermal treatment. In contrast, the band at 1600 cm<sup>-1</sup> becomes more pronounced, reflecting an increase in aromatic structures formed during advanced pyrolysis. This phenomenon signifies the aromatization process and increased stability of aromatic carbons in response to high temperatures.

Meanwhile, in Figure 6(a) showing the results of activation using ZnCl<sub>2</sub> at 320 °C, there is a strong band in the 1000-1300 cm<sup>-1</sup> range indicating the preservation of C-O groups from polysaccharide compounds, such as cellulose and hemicellulose. The band around 1600 cm<sup>-1</sup> indicates the beginning of the formation of aromatic structures because of partial condensation reactions. Whereas Figure 2(b), which shows ZnCl<sub>2</sub> treatment at 400 °C, displays a shift and decrease in the intensity of the oxygenation bands, especially in the 1000-1300 cm<sup>-1</sup> area, indicating the degradation of oxygenated organic compounds. In contrast, the intensity of the band at 1600 cm<sup>-1</sup> increases markedly, indicating that dehydration and aromatization processes are dominant, in line with ZnCl<sub>2</sub> role as a dehydrating agent that accelerates the formation of polymerized aromatic carbon structures [27].





**Figure 6.** FTIR test results of  $\text{ZnCl}_2$  at (a) 320 °C and (b) 400 °C

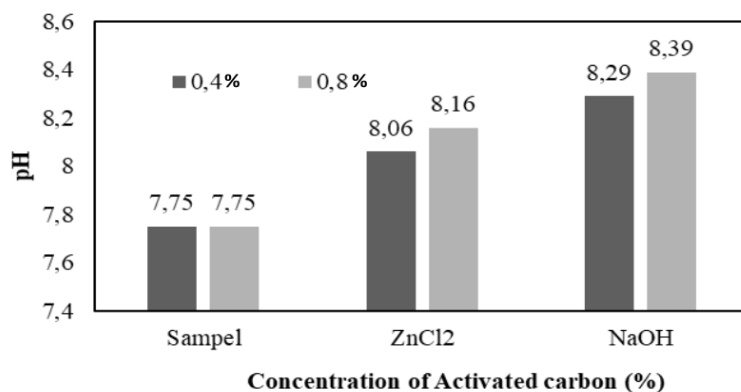
These spectral changes indicate that both activation using NaOH and  $\text{ZnCl}_2$ , accompanied by an increase in pyrolysis temperature, results in a reduction of polar functional groups and an increase in aromatic structures. This transformation is important as it is directly related to the increased surface area and thermal stability of the resulting biochar, which is useful for applications in the fields of adsorption, environmental remediation and energy storage.

Based on the results of FTIR spectrum analysis of sawdust waste chemically activated using NaOH and  $\text{ZnCl}_2$  at different pyrolysis temperatures, it can be concluded that increasing the pyrolysis temperature from 320-400 °C causes a decrease in the band intensity of hydroxyl groups (O-H) and other oxygen groups (C=O and C-O), as well as an increase in aromatic bands (C=C), which indicates the decomposition of polar organic compounds and the formation of more stable aromatic carbon structures. NaOH activator tends to accelerate the degradation of polar functional groups, while  $\text{ZnCl}_2$  acts as a dehydrating agent that preserves the intermediate structure and promotes gradual aromatization. These chemical transformations show that activation conditions and temperature greatly influence the final chemical composition of biochar, which has a direct impact on its potential applications in the fields of adsorption and functional carbon materials [26, 27].

#### *Testing results of activated carbon as a water biofilter*

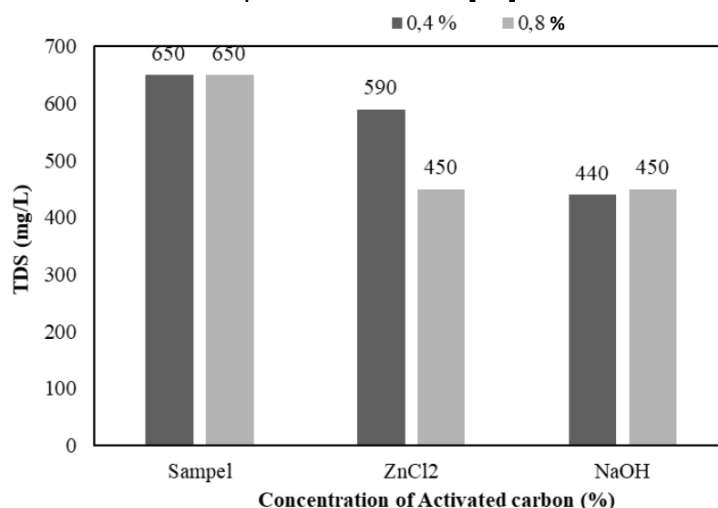
The effectiveness of activated carbon as a water biofilter was tested based on several water quality parameters, namely pH, total dissolved solids (TDS), and total suspended solids (TSS). The activated carbon used comes from teak wood powder that has been chemically activated using 5 %

NaOH and 5 %  $\text{ZnCl}_2$  solutions. Filtration tests were carried out with two variations of activated carbon concentration, namely 0.4 % b/v and 0.8 % b/v to the volume of water. The test results showed that after the filtration process, there were significant changes in pH, TDS, and TSS values, indicating that activated carbon from teak wood powder is effective in improving water quality.



**Figure 7.** pH of water before and after activated carbon filtration

Based on your test results, the pH of the water after filtration with activated carbon from teak wood powder in the range of 8.06 to 8.39 is still within safe limits according to SNI 01-3553-2006 and WHO, which allows water pH between 6.5 to 8.5 for human consumption. The increase in pH that occurs after filtration shows that the activated carbon used is effective in increasing pH, which can be influenced by the remaining bases from the activation process (NaOH and  $\text{ZnCl}_2$ ) and the interaction of activated carbon with components in water [28].



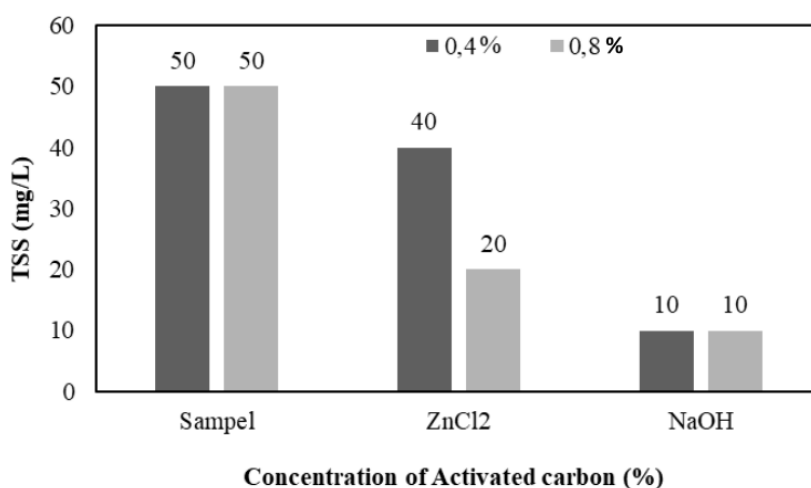
**Figure 8.** TDS value of water before and after activated carbon filtration

The TDS test results showed a significant decrease after water was filtered using activated carbon from teak wood powder, with variations in the concentration of activated carbon 0.4 % b/v and 0.8 % b/v to the volume of water. Before filtration, the TDS concentration was recorded at 650 mg/L, indicating a relatively high content of dissolved solids in the water. After the filtration process with activated carbon activated using 5 % NaOH and 5 %  $\text{ZnCl}_2$ , the TDS value decreased to a range of 590-440 mg/L, depending on the concentration of activated carbon used. This decrease indicates

that activated carbon is effective in reducing dissolved solids in water, and higher concentrations of activated carbon (0,8 % b/v) tend to result in greater TDS reduction.

This process occurs through an adsorption mechanism, where activated carbon with its large and porous surface absorbs dissolved molecules. The variation of activated carbon concentration had a significant effect on the effectiveness of the filtration process. Activated carbon with a higher concentration (0.8 % b/v) has a greater adsorption capacity, so it can attract more dissolved particles compared to the lower concentration (0.4 % b/v). The greater reduction in TDS at higher concentrations is in line with the results of previous studies which showed that increasing the dose of activated carbon can increase the effectiveness of dissolved solids removal in water.

Although the TDS reduction recorded was significant, the TDS value after filtration was still above the limit considered ideal for drinking water according to WHO and SNI standards, which is around 500 mg/L. Therefore, although activated carbon can reduce TDS, further treatment may be required to achieve more stringent drinking water standards, especially if it is used for human consumption applications.



**Figure 9.** TSS value of water before and after activated carbon filtration

The TSS test results showed a significant decrease after the water was filtered using activated carbon from teak wood powder. Before filtration, the TSS value was around 50 mg/L, indicating the presence of suspended particles in the water. After the filtration process using activated carbon activated with 5 % NaOH and 5 % ZnCl<sub>2</sub>, the TSS value decreased to between 40 and 10 mg/L. This decrease indicates that the activated carbon can reduce the amounts of particles mixed in the water, which contributes to improved water quality.

The use of activated carbon with different concentrations, 0.4 % b/v and 0.8 % b/v of water volume, also affected the filtration effectiveness. At the higher concentration (0.8 % b/v), activated carbon can adsorb more suspended particles, resulting in a greater reduction in TSS compared to the lower concentration (0.4 % b/v). These results show that activated carbon is not only effective in adsorbing dissolved chemicals, but can also reduce solid particles suspended in water, making it a more complete solution in water purification[29].

From the pH, TDS, and TSS test results, it can be concluded that activated carbon made from teak wood powder and activated with 5 % NaOH and 5 % ZnCl<sub>2</sub> proved effective in improving water quality. After filtration, the pH of the water increased from 7.75 to between 8.06 to 8.39, indicating an increase in water basicity. TDS values also decreased significantly from 650 mg/L to 590-440 mg/L, while TSS dropped from 50 mg/L to 40-10 mg/L. The decrease in both parameters

shows that activated carbon can reduce the amount of dissolved and suspended solids in water, making it an effective solution for improving overall water quality [30].

#### 4. Conclusion

Activated carbon resulting from chemical activation using  $\text{ZnCl}_2$  and NaOH showed high adsorption performance, indicated by the iodine absorbency which is proportional to the specific surface area and pore structure formed. Activation with  $\text{ZnCl}_2$  was most effective at 320 °C, while NaOH gave optimal results at 380 °C. Both activators significantly improved the physicochemical qualities of the activated carbon, including increased pH, decreased TDS and TSS values, and the formation of surface functional groups as evidenced through SEM and FTIR analyses. These results indicate that activated carbon from teak wood powder activated with  $\text{ZnCl}_2$  or NaOH has high potential as a water filtration material that meets national water quality standards and is suitable for water purification and efficient pollutant removal applications.

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