

Characterization of Activated Charcoal from Pyrolysis of Human Hair Cuttings and Its Utilization as an Adsorbent

Dewa AARS Adnyani^{a*}, I Dewe K. Anom^a, John Z. Lombok^a

^aChemistry, Universitas Negeri Manado, Tondano, 95618, Indonesia

INFO ARTICLE

Received 11 May 2025

Accepted 19 June 2025

Keywords:

Activated Charcoal

Human Hair

Characterization

Adsorbent

*e-mail:

agungrakaadnyani707@gmail.com

*Tel: 082187576463

ABSTRACT

This study aims to determine the characteristics of activated carbon from human hair cutting waste and to determine its ability to adsorb metals contained in water. This study uses an experimental method that is preceded by the activation of charcoal with KOH activator. Then continued with characterization using Fourier Transform Infra - Red (FTIR), X-Ray Diffraction (XRD), Scanning Electron Microscope Energy Dispersive X-Ray (SEM-EDS) and Atomic Absorption Spectrophotometer (AAS). The results of the study showed that the FTIR spectrum showed the presence of a group OH, CH, C=C and CO. The results of SEM analysis of activated carbon show the morphology of the pores of unactivated carbon, namely the surface looks smooth and dense with small particles evenly distributed and there are no large pores or significant cracks. Activated carbon from activation with KOH has a surface structure that looks more porous than before activation. The results of EDS analysis show the elemental composition of unactivated carbon and after activation using KOH only the C element is produced. XRD analysis of unactivated activated carbon shows one wide and not sharp diffraction peak. This characteristic indicates that the material has an amorphous structure, which means that the atoms in the material are not arranged crystalline but randomly. The relatively low diffraction intensity and high background strengthen the amorphous character of this pyrolysis carbon. After activation using KOH, the diffraction pattern still shows a wide peak at the same 2θ , but with higher intensity and a more defined peak shape. The results of AAS analysis show that activation with KOH provides high adsorption efficiency of 26.82%.

Introduction

Modern life produces waste in huge amounts, and one of the organic wastes that is often not utilized is human hair. Every day, there must be pieces of human hair produced as waste from beauty salons, households to the personal care industry. Although human hair is classified as organic waste, human hair has properties that are difficult to decompose naturally. When disposed of carelessly, it takes a long time to degrade and causes adverse environmental impacts [1].

Waste human hair cuttings, especially Papuan hair that is considered useless will be thrown away or burned. However, it is not realized that waste human hair cuttings contain

various organic compounds that are potentially harmful to the environment if not managed properly. Disposal and burning of waste human hair cuttings can disrupt environmental sustainability, both water and land. Heating waste human hair cuttings in open spaces can produce foul-smelling gases, and directly or indirectly these gases can disrupt human health and the environment [2].

Human hair has a unique chemical composition, namely rich in keratin, a protein containing carbon. This makes human hair one of the potential materials to be used as an alternative carbon source in charcoal making. Processing human hair into charcoal not only reduces organic waste, but also provides

additional benefits as an absorbent material that has wide applications in various industrial sectors, especially in water and air treatment [3].

Human hair waste management requires systematic thinking because of the importance of protecting the environment and human health, especially the potential for processing human hair waste so that it can be used for the benefit of humans and the environment or can be converted into useful and economically valuable waste products. In the field of developing new materials and technologies, there are several socio-cultural and economic aspects related to it, which often determine the adaptation of such use.

The pyrolysis method is one of the alternatives for processing urban solid waste and is thought to have good potential for development [4]. The working mechanism is simple and the pyrolysis process does not produce new waste that can pollute the environment, pyrolysis is one way to process solid waste, especially human hair waste [5]. Another advantage of pyrolysis is that solid waste will have products with a high ratio and high energy content. Pyrolysis techniques for processing solid waste, especially human hair waste, must continue to be developed in order to obtain a good and efficient working system. Pyrolysis itself is a reaction of decomposition of substances at high temperatures in limited oxygen conditions, through several stages starting from decomposition, gas formation, condensation and the final stage or termination. Pyrolysis of solid waste will produce products in the form of liquids, gases and the rest in the form of solids or charcoal. About the kinetics of gas and liquid smoke from the catalytic pyrolysis of human hair waste and its characterization.

Absorbents or absorbent materials function to capture and remove hazardous substances from the environment, such as pollutants, heavy metals, or organic compounds. The use of activated charcoal as an absorbent has long been known to be effective, especially because of its large surface area and pore structure that can trap various types of contaminants. Most of the activated charcoal available on the market is produced from natural materials such as wood, coconut shells,

and coal. However, with the increasing need for activated charcoal in industry and awareness of the importance of sustainability, there is a need to explore alternative sources that are more environmentally friendly and easily accessible, one of which is human hair clippings [6].

The use of human hair charcoal as an adsorbent has several significant advantages. First, human hair is an abundant resource and is discarded as waste. By processing it into charcoal, not only can the waste problem be reduced, but also create a product with economic value. Second, human hair has a high carbon content, so the potential to be processed into activated charcoal with good absorbent capacity is very large. Third, human hair has a unique fiber structure, which allows the formation of small pores during the carbonization process, which can then increase the absorption capacity of charcoal against pollutants and hazardous substances.

KOH (potassium hydroxide) is often used in charcoal activation because of its unique chemical properties. KOH is a strong base that can help break down organic matter in human hair during pyrolysis, resulting in the formation of pore structures [7]. KOH was chosen as a solution in characterizing charcoal because it is a chemical activator commonly used in the charcoal activation process.

KOH is a strong base. KOH can help break down organic matter in human hair during pyrolysis, resulting in the formation of pore structures. KOH can also react with carbon at high temperatures to form carbonate salts, which are then removed during the washing process, leaving pores in the charcoal.

Materials and Methods

The materials to be used are Papuan hair charcoal as raw material, a number of distilled water and Potassium Hydroxide (KOH) activator. This research is a quantitative research that uses experimental methods to characterize charcoal from pyrolysis of human hair waste activated using KOH activator. The pyrolysis hair charcoal is then ground and sieved using a 150 mesh sieve. Then activated using KOH. The activation results are then analyzed using the Fourier Transform Infra Red (FTIR), SEM (Scanning Electron Microscope)

and EDS (Energy Dispersive X-Ray), X-Ray Diffraction (XRD) and Atomic Absorption Spectrofometry (AAS) instruments.

Results and Discussion

Table 1. Average water content test

Treatment	Water content
Without Activation	10.45%
Activation using KOH 3 M	3.13%

The test results showed that the water content in human hair charcoal before activation and after activation using KOH activator tended to be different. The quality of activated charcoal water content based on SNI 06-3730-1995 is a maximum of 4.5%. The activated charcoal of Papuan hair produced in this study had a water content after activation with KOH of 3.13%. This shows that the water content in this study meets the standards. The water in the sample has evaporated effectively during the heating process. Where according to Gonjoo et al, 2023 shows that the water content in ash is highly dependent on the processing method and heating conditions.

Table1- Ash content test results

Treatment	Ash Content
Without Activation	2.36%
Activation using KOH 3 M	2.29%

The test results show that the ash content of activated carbon before activation and after activation is different. Ash content can be used to determine the quality of good charcoal, The lower the ash content, the better the quality of the charcoal. The ash content of Papuan hair activated charcoal meets the standards set by SNI 06-3730-1995, which is lower than the threshold for the quality of activated charcoal, which is usually a maximum of 2.5%. Where according to Priprem et al, 2018 [8] shows that chemical treatments such as KOH can affect the characteristics of ash from biological materials. For example, research on the use of eucalyptus ash to change the structure

of hair proteins shows that treatment with alkalis such as KOH can change the morphology and physical properties of hair, including its tensile strength. In addition, research on the characterization of charcoal ash and wood ash in Africa found that the pH, electrical conductivity, and nutrient content of ash can vary greatly depending on the source of the material and the processing method [9].

FTIR Analysis

Samples before and after activation will show the type of bond through functional group analysis using an instrument for Fourier Transform Infra Red (FTIR) characterization testing.

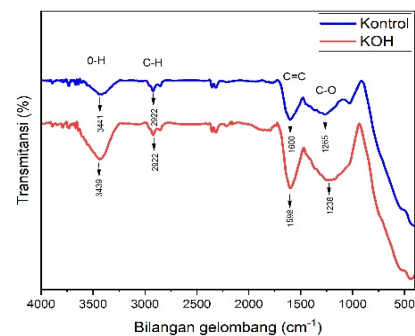


Figure 1. FTIR spectrum of human hair charcoal before activation and after activation with KOH.

Spectrogram identified in the FTIR spectrum shows various functional groups in the human hair charcoal samples before activation and after activation using KOH activator.

Table 3. FTIR Spectrogram Analysis of Human Hair Charcoal before and after activation

Group	Wavelength	Information
OH (hydroxyl) group	3441 cm ⁻¹ 3439 cm ⁻¹	This peak indicates the presence of a hydroxyl group (-OH) which is usually found in water or alcohol molecule.
CH group (alkanes and aromatics)	2922 cm ⁻¹ 2922 cm ⁻¹	This peak indicates the presence of a C-H bond which is usually found in aliphatic or aromatic

compounds.
hydrocarbon chain.

C=C group (aromatic or alkene)	1600 cm ⁻¹	This peak indicates the presence of a carbon-carbon double bond (C=C) which is commonly found in aromatic compounds or alkene structure.
	1598 cm ⁻¹	
CO group (alcohol, ester, or ether)	1265 cm ⁻¹	This peak indicates the presence of a CO bond which is usually found in alcohols, esters or ether.
	1238 cm ⁻¹	

In an FTIR spectrum, the high or low absorption peaks (intensities) reflect the relative amounts of a particular functional group present in the sample. High and sharp peaks indicate the presence of a large number of functional groups or the strong interaction of the vibrations of the molecule with infrared radiation. Conversely, weak or low peaks may indicate a small number of functional groups, or that the groups are less infrared active.

SEM-EDS analysis

Scanning Electron Microscopy – Energy Dispersive X-ray Spectroscopy (SEM-EDS) was used to observe the physical morphology of the sample surface and analyze the elemental composition including visible light elements such as carbon, nitrogen and oxygen. SEM testing was carried out at a magnification of 1000x, where the results are seen in Figure 2 and Figure 3. Figure 2 shows that the surface of the activated carbon looks smooth and dense with small particles evenly distributed and there are no large pores or significant cracks. The activated carbon from activation with 3 M KOH has a surface structure that appears more porous than before activation, there is an increase in roughness and a more even distribution of small particles and this indicates the formation of micro or mesopores.

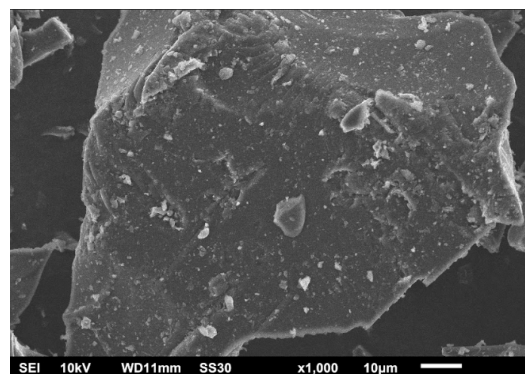


Figure 2. Results of SEM analysis without activation

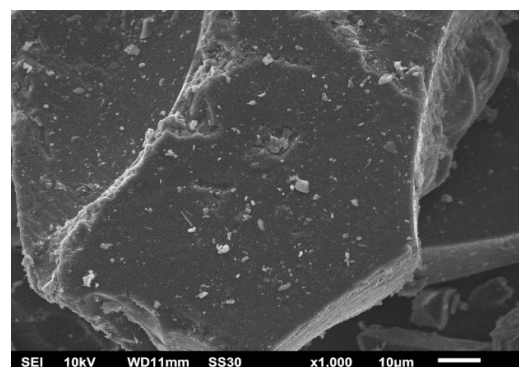


Figure 3. Results of SEM analysis activated using KOH activator

The image explains that activation can make the pores in the carbon open. It is assumed that the bound water content and impurities such as tar have been lost which causes some of the pores to open. With the high concentration of activator, the surface area of the activated carbon sample becomes larger so that its contact power capacity is also greater [10].

Apart from being able to see the pores that form, you can also find out the elemental content contained in the activated charcoal samples of human hair which are tested using the EDS instrument.

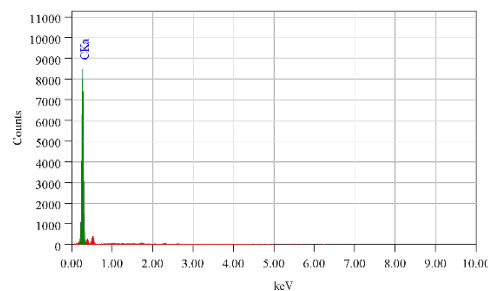


Figure 4. EDS spectrum without activation

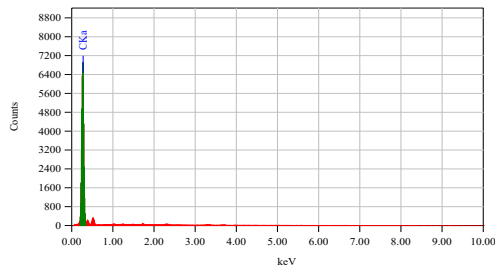


Figure 5. EDS spectrum of KOH activation

The results of EDS analysis showed that both carbon samples before and after activation with KOH only contained carbon elements, without detecting other elements such as potassium (K) or oxygen (O). This indicates that the post-activation washing process was effective, so that residual compounds such as KOH, K_2CO_3 , or K_2O were successfully removed from the carbon surface. In addition, the presence of other elements in very small amounts or those trapped in the pore structure is likely not detected. In a study reported by Guo and Wang (2022) [11] in a study of the preparation and characterization of carbon using KOH activation, where KOH activator residues were not detected after thorough washing. They stated that at high activation temperatures, potassium compounds can decompose and become volatile, so they do not remain in the carbon structure. Therefore, these results indicate that chemical activation with KOH successfully improves the carbon structure without leaving significant foreign element contaminants, making this material suitable for adsorption applications.

XRD Analysis

Sample characterization using X-Ray Diffraction (XRD) to determine the crystal structure or information on the presence of crystal and amorphous phases of the basic materials that have been synthesized, either in the form of element content or in the form of compounds. The crystal phase is characterized by the presence of a sharp peak while the amorphous phase is characterized by the formation of a wide peak or (hump) with low intensity [12]. XRD analysis using Shimadzu, Ms. Excel and Origin software.

XRD characterization in Figure 6 shows the X-ray diffraction profile of human hair

activated carbon before activation and after activation with KOH. The X-ray diffraction results show carbon with an amorphous structure, so it is impossible to determine the crystal phase of the carbon formed [13]. Similar results were also reported by Sun & Webley, 2010 [14] with corn cob as the basic material. According to (Tongpoothorn et al., 2011) [15] activated carbon samples with broad peaks and the absence of sharp peaks indicating a dominant amorphous structure are beneficial properties for well-defined adsorbents.

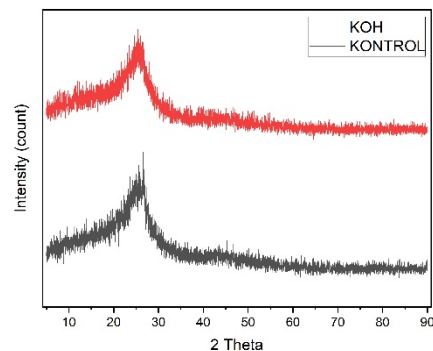


Figure 6. XRD diffraction pattern of activated charcoal without activation and after activation with KOH.

The results of the XRD analysis before activation showed amorphous structure with small crystallite size ($14 \text{ \AA}$) the result of manual calculation using Scherrer formula. The wide peak confirms that carbon has a low degree of crystallinity.

The XRD spectrum after activation with KOH shows the characteristics of the activated carbon structure that has undergone chemical activation using KOH solution. A broad peak is seen at the position $2\theta = 26.38^\circ$, which indicates the amorphous nature of the carbon material. The large FWHM value indicates a small crystallite size, which is around $17 \text{ \AA}$. This is consistent with the characteristics of activated carbon, which tends to have low crystallinity.

Application of activated charcoal to iron (Fe) metal solution

Testing was carried out using the Atomic Absorption Spectroscopy (AAS) method to determine the ability of activated charcoal to absorb iron (Fe) ions from water.

Table 4- AAS test results

Activator	Final Concentration of Fe (mg/L)	Adsorption Efficiency (%)
Without activation	1.6919	15,405
KOH	1.4636	26.82

Adsorption efficiency is an important parameter to assess the ability of an adsorbent to bind metal ions from a solution. The calculation of this efficiency is done by comparing the concentration of metal ions in the solution before and after the adsorption process. In this study, the solution used to soak the charcoal contained Fe ions with a concentration of 2 ppm, so this value is used as the initial concentration (C_0) in calculating efficiency. According to Yuliasri et al. (2021) [16], the initial concentration in the adsorption process is determined from the level of metal solution used when soaking the adsorbent, and is the main reference in evaluating adsorption efficiency. Based on the measurement results using AAS, the concentration of Fe ions after adsorption by charcoal without activation was 1.6919 mg/L, while charcoal activated with KOH produced a final concentration of 1.4636 mg/L. Therefore, the adsorption efficiency is calculated using the adsorption efficiency formula.

The calculation results show that unactivated charcoal has an adsorption efficiency of 15.41%, while charcoal activated with KOH showed a higher efficiency of 26.82%. This shows that the chemical activation process with KOH can increase the adsorption capacity of charcoal against Fe ions, which is thought to be caused by the increase in surface area and the number of adsorption centers on the charcoal. Similar research by Afifah et al. (2022) [17] also reported that charcoal activation with KOH can increase the adsorption efficiency of heavy metals, on the grounds that alkali activators can open pores and introduce polar functional groups that increase interactions with metal ions. Thus, the use of 2 ppm as the initial concentration can be scientifically justified, because it represents the actual conditions of the amount of metal available for the adsorption process.

Conclusions

Characterization of activated carbon from human hair before and after activation using KOH solution showed that the activation process successfully improved the quality of the material in terms of chemical structure, morphology, and crystal properties. FTIR results showed that the main functional groups such as hydroxyl ($-OH$), methyl/alkane ($C-H$), double bonds ($C=C$), and ether or alcohol groups ($C-O$) remained identified both before and after activation, indicating the stability of functional groups that support adsorption capacity. SEM-EDS characterization showed that the surface of activated carbon after activation became rougher and more porous, with a more even distribution of small particles, indicating the formation of micro or mesopores due to KOH treatment.

The elemental composition based on EDS only showed the presence of carbon, without detecting any KOH residue or other elements, indicating that the post-activation washing process was effective. In addition, XRD characterization showed an amorphous structure in both samples, with broad peaks and small crystallite sizes (14 Å before activation and 17 Å after activation), which are typical of high-quality and porous activated carbon. In addition, the adsorption efficiency of Fe ions increased from 15.41% (without activation) to 26.82% (after activation with KOH), indicating that chemical activation was able to increase the adsorption capacity of the charcoal. Thus, the activation process using KOH was proven to be able to improve the physicochemical characteristics of carbon from human hair, making it a feasible and potential material as an adsorbent for environmental applications.

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