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Characterization of Coconut Shell Charcoal Activated with Aren Palm Vinegar – HNO_3 and Its Adsorption Kinetics

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ABSTRACT

Among the numerous plants that contribute significantly to Indonesia's economy is the multipurpose coconut. Coconut shells, a byproduct of the copra industry in North Sulawesi, are an economically valuable component of the coconut. Coconut shell charcoal's functional groups, elemental composition, and adsorption kinetics are the targets of this investigation This study includes the stages of pyrolysis, charcoal activation, Energy Dispersive Spectroscopy (EDS) analysis and adsorption kinetics. In the EDS test, coconut shell charcoal modified with nitric acid has a carbon element composition of 76.7%. In the analysis of the adsorption kinetics of coconut shell charcoal activated using palm sap acid follows the first order equation with a value of $R^2 = 0.9186$.

Introduction

Indonesia, a tropical country rich in natural resources, is home to numerous plant species that serve various purposes but also produce waste that can be utilized. One of these resources is the coconut tree (*Cocos nucifera L.*), a versatile plant whose parts can be used optimally [1]. In addition to the coconut meat and water, waste products such as coconut shells from harvesting are often discarded or burned, even though they hold great potential as raw materials for activated charcoal.

[2] According to research by Rampe et al. (2013), coconut processing yields many valuable products, including flour, briquettes, and activated carbon, all derived from coconuts. Coconut is a type of hardwood with a moisture content of approximately 9–10% based on dry mass estimates; its shell functions as a protective layer for the fruit inside. The pyrolysis process of coconut shells is a common method used to produce activated charcoal from biomass. One part of the coconut plant that has not been optimally utilized is the coconut shell, which often becomes waste from coconut processing industries—such as the coconut oil industry. When processed, coconut shells can gain high economic value, such as through the production of coconut shell charcoal via heating or pyrolysis, resulting in a high-value product [3].

In this process, coconut shells are heated under limited oxygen conditions, resulting in the thermochemical decomposition of organic material and the production of charcoal, liquid smoke, and gas. The resulting charcoal possesses a microporous structure and a high surface area, making it highly effective in absorbing various contaminants in air and liquids [4]. Activated charcoal can be used to adsorb heavy metal ions, hazardous organic compounds, and toxic gases, making it highly valuable in water and air purification applications [5].

The purification of charcoal through chemical activation aims to obtain pure charcoal free from metal impurities bound to it. This purification process is intended to remove contaminants [6], and in this study, aren sap acid was used, with analyses conducted on moisture content, ash content, EDS, and adsorption kinetics.

[7] According to research by Harti et al. (2014), the addition of nitric acid (HNO_3) to previously activated carbon can introduce functional groups on the activated carbon and enhance the adsorption of iron (Fe) and copper (Cu) metals. This reactivation of activated charcoal is expected to yield improved results in filtration and purification applications. Adsorption kinetics is a critical element in activated carbon research. It describes how the adsorption process progresses over time, as well as the factors that influence the rate of adsorption, such as the initial concentration of the adsorbate, temperature, and pH [8]. Understanding the kinetics of adsorption can aid in designing more efficient and effective purification systems, and provides insight into how activated charcoal can be applied in real-world situations—considering the importance of water and air treatment as essential steps in protecting environmental and public health.

This study aims to determine the elemental composition and adsorption kinetics of activated coconut shell charcoal. The research includes the stages of pyrolysis, charcoal activation, Energy Dispersive Spectroscopy (EDS) analysis, and adsorption kinetics evaluation.

Materials and Methods

This study employed a set of instruments including a pyrolysis apparatus, 250 mL Erlenmeyer flasks, a 100-mesh sieve, an analytical balance, 250 mL beakers, a mortar and pestle, stirring rods, a spray bottle, porcelain crucibles, aluminum foil, tweezers, and a funnel.

The materials used in this research included coconut shells sourced from the Tondano market, aren sap acid, nitric acid (HNO_3), sodium hydroxide (NaOH), filter paper, universal indicator, and distilled water (aquadest).

Coconut Shell Preparation

Six kilograms of coconut shells, used as the raw material, were randomly purchased from the Tondano Market. The samples were prepared by removing residual fibers and dirt from the shells using a knife. The cleaned shells were then sun-dried for ten days. Subsequently, the coconut shells were broken into smaller pieces using a hammer.

Carbonization

A tightly sealed pyrolysis reactor was used to heat the dried coconut shell samples, ensuring that no oxygen could enter the system. Charcoal flakes were produced from the coconut shells through a pyrolysis process conducted at 350°C for 5 hours, followed by a cooling period of 1 hour. The resulting charcoal was then ground using a mortar and pestle to produce coconut shell charcoal powder. The next step was to standardize the particle size by passing the powder through a 100-mesh sieve, allowing only particles that passed through the mesh to be collected for further use.

Activation Process

Five grams of sieved charcoal powder were soaked in 250 milliliters of aren sap acid for twenty-four hours. The soaked charcoal was then filtered using Whatman No. 24 filter paper and rinsed with distilled water until the pH of the rinse water reached a neutral level. After purification, the charcoal powder was dried in an oven at 120°C for three hours.

Combination Activation Process

The combination activation process involves the use of nitric acid (HNO_3). The charcoal powder, which has already been activated using aren sap acid, is further activated using nitric acid. Five grams of the activated charcoal powder are heated until boiling for 3.5 hours, then rinsed with distilled water until the wash water reaches a neutral pH.

Adsorption Kinetics

The charcoal powder that has been activated with aren sap acid and HNO_3 was then divided into three samples, each weighing 2 grams, which were further activated using aren sap acid. The samples were then soaked in acetic acid for varying durations of 30 minutes, 60 minutes, and 90 minutes. After soaking, the samples were filtered, and the filtrate was collected in 10 mL portions, which were then titrated with NaOH.

Results and Discussion

The activated charcoal was analyzed for several parameters, including moisture content, ash content, EDS, and adsorption kinetics.

Moisture Content Analysis

The moisture content of the coconut shell charcoal, which had been heated in an oven at 105°C, was analyzed to determine the water content in the charcoal resulting from soaking in acetic acid and aren sap acid. According to research by Fajri et al. (2024) [9], the hygroscopic quality of activated carbon is determined through moisture content analysis, with superior results found for lower moisture content. Since activated charcoal has hygroscopic properties, its absorption capacity can be influenced by the amount of water bound to it. This is because the pores of the charcoal will narrow, and its absorption capacity will decrease as the moisture content increases.

The moisture content test results of this study showed that the coconut shell activated charcoal has very good quality and its moisture content meets the standards of SNI 06-3730-1995, which states that powdered activated charcoal should not contain more than 15% moisture.

Low moisture content in activated charcoal is crucial because it enhances its absorption capacity. For optimal pollutant absorption, it is important to use activated charcoal with low moisture content [10].

Ash Content Analysis

Ash content is the amount of inorganic material remaining after a substance is heated to high temperatures. A low ash content indicates more effective activated carbon with fewer contaminants. The higher the ash content, the lower the quality and effectiveness of the activated charcoal [11]. In this study, the ash content test results showed a value of 2.79%. This result indicates that the coconut shell activated charcoal meets quality standards and complies with the ash content criteria set by SNI 06-3730-1995, which establishes a maximum ash content limit of 15% for powdered activated charcoal.

Energy Dispersive Spectroscopy (EDS)

Analysis Energy Dispersive Spectroscopy (EDS) is an analytical method that measures the energy of X-rays emitted by elements when exposed to radiation to determine the elemental composition of a material. After the adsorption process, EDS is used to identify the components of activated carbon, showing that carbon is the primary component [12].

The results of the Energy Dispersive Spectroscopy analysis before activation, after activation with aren sap acid, and after combined activation with nitric acid are presented in Figures 1, 2, and 3.

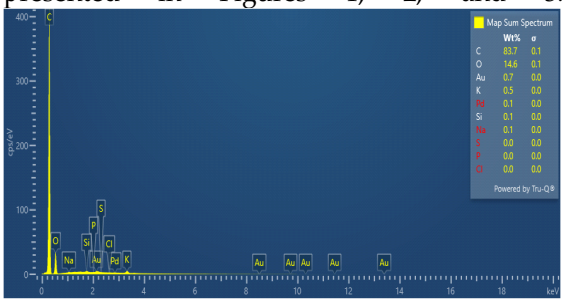


Figure 1. Elemental Composition of EDS from Coconut Shell Pyrolysis

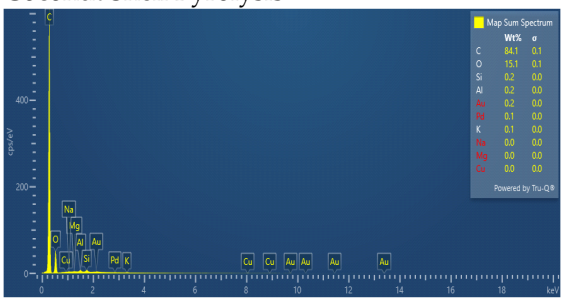


Figure 2. Elemental Composition of EDS from Activation with Acetic Acid

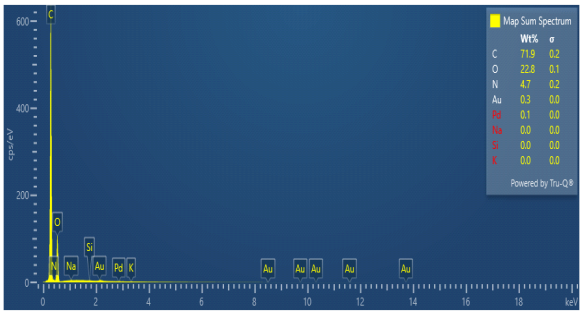


Figure 3. Elemental Composition of EDS from Modification with Nitric Acid

Table 1. EDS Composition Results of Coconut Shell Charcoal from Pyrolysis, Activation with

Aren Sap Acid, and Combined Activation with Nitric Acid.

Element	Composition Pyrolysis result (%)	Activation Result (%)	Combined Activation Result (%)
Carbon	83,7	84,1	76,7
Oxygen	14,6	15,1	18,8
Potassium	0,5	0,1	0,1
Sodium	0,1		
Palladium	0,1	0,1	0,1
Silica	0,1	0,2	0,2
Gold	0,7	0,2	0,3
Nitrogen			3,8
Aluminium		0,2	

The elemental composition of coconut shell charcoal powder after pyrolysis, activation with aren sap acid, and modification with nitric acid (HNO_3) based on Energy Dispersive Spectroscopy (EDS) testing is presented in Table 1, which shows the composition of the charcoal depicted in Figures 1, 2, and 3. The carbon (C) content in the pyrolysis result is 83.7%, while the activation with aren sap acid solvent contains 84.1% carbon. The modification with nitric acid resulted in 76.7% carbon. The impurities listed in Table 1 are likely to come from mineral additives in the charcoal process and the activating compounds used.

Adsorption Kinetics

The adsorption kinetics test of coconut shell charcoal was conducted using acetic acid (CH_3COOH) 1 N. The activated coconut shell charcoal acts as the adsorbent, while acetic acid (CH_3COOH) 1 N serves as the adsorbate. Adsorption kinetics analysis is an important factor in determining the effectiveness of absorption [13].

Siahaan (2000) [14] stated that the reaction rate for different orders is directly proportional to the concentration of reactants and can be represented graphically against time. For first-order reactions, the graph is linear with concentration; for second-order reactions, the graph is a square of the concentration (or the concentration squared of the reactants); and for third-order reactions, the graph corresponds to the cube of the concentration or a combination of all three, with the graph showing a relationship between $1/C^2$ and time

.

According to Aprilianti et al. (2024) [15], this is due to the interaction between metal ions bound to the atom particles and the surface of activated carbon, where the metal ions approach the activated carbon surface. The attractive forces at the atomic level cause the ions to be adsorbed. The adsorption kinetics results for charcoal activated with aren sap acid are presented in Table 3 and Figures 9, 10, and 11.

Table 3. Adsorption Kinetics of Coconut Shell Activated Charcoal with Aren Sap Acid

Time	Concentration	In C	1/C	$1/C^2$
30	1,53N	0,425	0,653	0,427
60	0,89 N	-0,116	1,123	1,262
90	0,75 N	-0,028	1,333	1,777

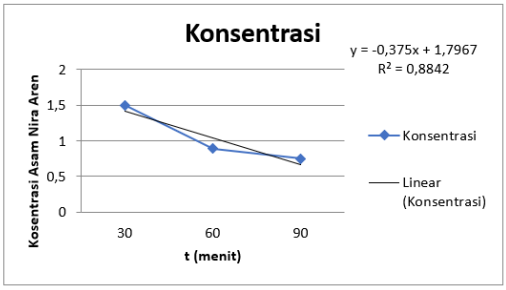


Figure 4. Effect of Time on Concentration Decrease

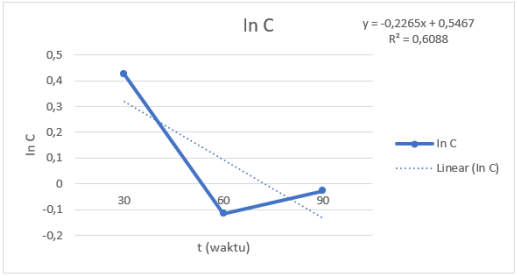


Figure 5. Graph of the Relationship Between In C and Time

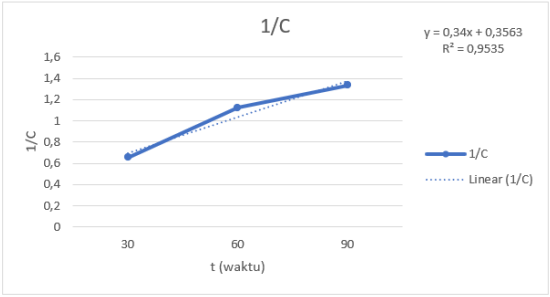


Figure 6. Graph of the Relationship Between 1/C and Time

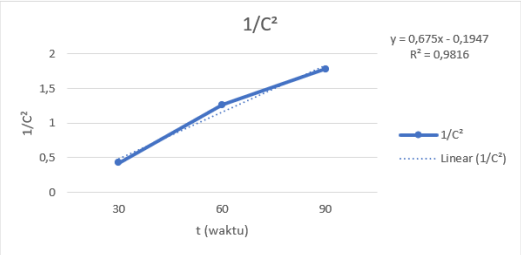


Figure 7. Graph of the Relationship Between 1/C² and Time

Based on the graph results obtained from the adsorption kinetics analysis of modified coconut shell charcoal with CH_3COOH 1N, the regression values are as follows: for the first order, R^2 = 0.6088; for the second order, R^2 = 0.9535; and for the third order, R^2 = 0.9816. From the regression values, it can be concluded that the adsorption kinetics of modified coconut shell charcoal with CH_3COOH 1N in this study follows a third-order reaction, as the regression value and the third-order graph are closest to 1. In a third-order reaction, the reaction rate (adsorption rate) depends on the concentration of the adsorbate raised to the third power, meaning that as the concentration of the adsorbate increases, the reaction rate will increase much more quickly.

Author Contribution

Lusiana Rajaguguk contributed to the conceptualization of the study, implementation of the study, data collection, data processing and curation, formal analysis, interpretation of the results, and preparation of the initial draft of the manuscript. Meytij Rampe contributed to the conceptualization and design of the research methodology, research supervision, interpretation of the results, and critical review and editing of the manuscript. Jeane Tuerah contributed to the supervision, evaluation of the research results, critical review, editing, and refinement of the substance of the manuscript before publication. All authors have reviewed and approved the final version of the manuscript and declare responsibility for all the contents of the published research.

Conclusion

The testing results of coconut shell charcoal indicate that the Energy Dispersive Spectroscopy (EDS) analysis of modified coconut shell charcoal shows the following carbon (C) content: 83.7% in the pyrolysis result, 84.1% in the activation using aren sap acid, and 76.7% in the modification with aren sap acid. The adsorption kinetics analysis of acetic acid (CH_3COOH) 1 N on modified coconut shell charcoal activated with aren sap acid follows a third-order reaction.

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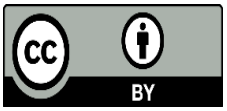
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