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Adsorption of Iron Ions by Biocharcoal from Areca Nut Shells and Fruit Clusters

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Abstract

This study aims to identify the adsorption of iron ions by biochar produced from palm nut shells and palm fruit bunches. The method used in this study was a laboratory experiment employing palm nut shell biochar and palm fruit bunch biochar as adsorbents for Fe ions. The results showed that the optimum contact time for palm nut shell biochar was 150 minutes, with an iron ion adsorption percentage of 99.87%. In contrast, for palm fruit cluster biochar, the optimum contact time was 120 minutes, with an iron ion adsorption percentage of 99.83%. The optimal adsorption of iron ions by areca nut shell biochar occurred at a dose of 20 mg, with an adsorption percentage of 99.70%. In contrast, for areca fruit bunch biochar, it occurred at a dose of 40 mg, with an adsorption percentage of 99.80%. The optimal concentration obtained for both biochar types was the same, namely 60 ppm, with an iron ion adsorption percentage of 99.5% for areca nut shells and 98.85% for areca fruit bunches. The maximum adsorption capacity of areca nut shell biochar was 121.9512 mg/g, and that of areca fruit cluster biochar was 58.1395 mg/g, calculated using the Langmuir isotherm equation. Meanwhile, the maximum adsorption capacity of palm shell biochar was 123.0915 mg/g, and that of palm fruit bunches was 62.1871 mg/g using the Freundlich isotherm equation.

Keywords: Adsorption, areca nut clusters, areca nut shells, biochar, iron

Introduction

The areca palm (Arenga pinnata Merr) is a species of palm native to the Indonesian archipelago, known to some communities since the Dutch colonial era because it produces palm sap, which is used as a raw material for making palm sugar and alcoholic beverages that were quite popular at that time (Suhendra et al., 2023). In terms of its uses, the areca palm is multifunctional, as all parts of the plant can be utilized by the community (Gani, 2009; Kameubun et al., 2020).

The areca palm is a large, perennial plant, growing as a solitary tree up to 12 m tall, with a diameter at breast height (DBH) of up to 60 cm (Hamu et al., 2019). It can reach a height of 15 m with a trunk diameter of up to 65 cm, and in some cases even 20 m, with a canopy of leaves towering above the trunk. When the tree is young, the trunk is not visible because the bases of the leaf sheaths cover it; once the lowest leaves have fallen, the trunk becomes visible. The trunk's surface is covered by black coir fibers originating from the bases of the leaf stalks (Lempang, 2012).

The areca palm (Arenga pinnata) is a tree that has long been known to produce industrial materials. Nearly all parts or products of this plant can be utilized and have economic value. Every part of the areca palm can be put to good use, ranging from the physical parts of the tree to its various products. Almost all of the physical parts of this tree can be utilized, such as the roots (for traditional medicine), the trunk (for various tools and construction materials), and the young leaves or janur (used as wrappers or as a substitute for cigarette paper, known as kawung). The areca palm also produces nira, which has high economic value. Nira is a natural beverage that tastes sweet because it contains glucose. In addition to being processed into sugar, nira can also be processed into bioethanol, saguer, or vinegar through fermentation (Mastiani et al., 2018).

The sugar palm is a local resource with significant potential that deserves to be developed. This is evidenced by the fact that farmers utilize these wild-growing sugar palms as a source of supplemental income beyond their primary income from their main crops (Pulungan et al., 2023). This plant is unique because it holds promising economic value from its roots to its fronds and has indirectly played a vital, generational role in the lives of the local communities that cultivate it. The growth of the aren palm still depends on nature's bounty for aren farmers, as farmers have not yet implemented

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any specific management practices for these palms. Furthermore, there are no systematic development initiatives in place to support aren farming communities while simultaneously conserving the genetic resources of the aren palm (Rahmi, 2006; Qaim et al., 2020).

HCl-activated areca nut shells (Arenga pinnata) have a moisture content of 9.59%, ash content of 17.96%, volatile matter content of 44.32%, and carbon content of 28.18%. In application tests using real samples with the spike method, HCl-activated arenga palm husk activated carbon was able to adsorb Cd^{2+} ions in mineral water by 94.05%, in well water by 97.74%, and in river water by 97.63% (Mandasari & Purnomo, 2016). Palm fruit bunches contain the following chemical components: 68.11% holocellulose, 33.79% α-cellulose, 27.74% lignin, 11.10% moisture, and 1.80% extractives. Organic materials containing lignin, hemicellulose, and cellulose can be used as raw materials for the production of activated charcoal (Nurhidayah, 2017).

The symbol for iron is Fe, with an atomic number of 26 and a mass number of 55.877. In the periodic table, iron is located in Group VIII of Period 4. Iron is a heavy metal, or transition metal, that is widely distributed throughout living systems. Iron is an essential element for the survival of animals and plants; however, excessive accumulation of iron can be harmful to health, particularly to the circulatory system, as it can interfere with the binding of hemoglobin to oxygen. Furthermore, the accumulation of iron in the bone marrow can lead to nervous system disorders (Nurafriyanti et al., 2017).

Adsorption is one method for reducing heavy metals, particularly Cr^{6+}, in batik wastewater using adsorbents (Qisti et al., 2021). This method is highly effective and economical for treating wastewater containing heavy metals. Many materials can be used as adsorbents. One such material is organic waste. Organic waste has been proven effective in reducing heavy metal concentrations in wastewater (Purbawati, 2021).

Divalent iron (Fe) and manganese (Mn) ions are commonly found together in groundwater. Fe and Mn in water can cause turbidity, corrosion, and hardness. Fe and Mn also cause a yellowish tint in laundry and plumbing fixtures. Technologies commonly used to remove Fe and Mn include membrane technology, adsorption, ion exchange, and precipitation. Adsorption is an effective water treatment process that is frequently used to remove heavy metals (Rosman et al., 2019). Consequently, this research seeks to determine how biochar created from palm nut shells and palm fruit bunches can attract and hold iron ions.

Methods

This study will be conducted at the Chemistry Laboratory of the Faculty of Teacher Training and Education at Tadulako University.

The equipment used includes an analytical balance, a 100-ml measuring cylinder, a funnel, a 100 mL Erlenmeyer flask, a beaker, a blender (Waring Commercial), a 200 mesh sieve, a pH meter, an atomic absorption spectrophotometer (AAS), a furnace, a shaker, a spray bottle, aluminum foil, volumetric flasks, 10 mL and 25 mL volumetric pipettes, and a dropper pipette. The materials used include biochar made from palm fruit shells and palm fruit stems, a standard iron(II) solution, distilled water, HNO_3 (Smart Lab), NH_4OH (Merck), and Whatman No. 41 filter paper.

Production of biochar from areca nut shells and areca fruit clusters

Areca nut shells and fruit clusters are collected from plantations and then cleaned to remove any attached debris. They are then dried in the sun for approximately 5 days until their moisture content decreases. Samples of the dried palm fruit shells and bunches are placed in a furnace and pyrolyzed at a temperature of 350 °C. Once turned into charcoal, they are cooled, and the biocharcoal is ground in a blender and sieved using a 200-mesh sieve. The samples are then analyzed using infrared (IR) spectroscopy to determine the differences between the two samples.

Effect of biocharcoal contact time

60 mg of biocharcoal was mixed with 25 mL of a 52.5 ppm iron standard solution at pH 4 in 5 separate 100 mL Erlenmeyer flasks; HNO_3 and NH_4OH solutions were then added to adjust the pH of the solution. Each Erlenmeyer flask was sealed with aluminum foil and shaken using a shaker for varying durations of 30, 60, 90, 120, and 150 minutes, after which the mixtures were allowed to stand for 24 hours. The filtrate and residue were separated by filtration using Whatman No. 41 filter paper. The absorbance of the resulting solutions was measured using atomic absorption spectrophotometry (AAS).

Effect of biocharcoal weight

Biocharcoal weighing 20, 40, 60, 80, and 100 mg was mixed, respectively, with 25 mL of a 52.5 ppm iron standard solution at pH 4 to which HNO_3 and NH_4OH solutions had been added in a 100 mL Erlenmeyer flask. The Erlenmeyer flasks were sealed with aluminum foil and shaken using a shaker for the optimal shaking time determined for each biocharcoal weight, then allowed to stand for 24 hours. Subsequently, the filtrate and residue were separated by filtration using Whatman No. 41 filter paper. The absorbance of the resulting solutions was measured using atomic absorption spectrophotometry (AAS).

Effect of Fe solution concentration

25 mL of a 52.5 ppm iron metal standard solution was diluted in 5 Erlenmeyer flasks to concentrations of 20, 40, 60, 80, and 100 ppm, respectively, at a pH of 4, after adding HNO_3 and NH_4OH solutions. The initial concentrations of

these solutions were then measured using atomic absorption spectrophotometry (AAS). Each iron solution was transferred to a 100 mL Erlenmeyer flask and mixed with the optimal weight of biochar obtained in a previous experiment. The Erlenmeyer flasks were sealed with aluminum foil and then shaken using a shaker for the optimal duration determined in a previous experiment, after which they were allowed to stand for 24 hours. The filtrate and residue were separated by filtration using Whatman No. 41 filter paper. The absorbance of the resulting solutions was measured using atomic absorption spectrophotometry (AAS).

Results and Discussion

Testing using Fourier Transform Infrared (FTIR) aims to identify the functional groups present in palm bunch and palm shell biochar. In addition to FTIR analysis, biochar generally contains hemicellulose, cellulose, and lignin. Lignin is characterized by the presence of hydroxyl (-OH), carboxyl (-COOH), and methoxyl ($-OCH_3$) functional groups; when degraded by a base, it may form benzene derivatives (Setiati et al., 2016).

This study represents an effort to separate metals that can pollute the environment. Metal separation can be achieved using adsorption methods that utilize organic materials derived from waste, such as sago palm fruit bunches and sago palm shells, which can be converted into biochar to adsorb iron. The sago palm fruit bunches and sago palm shells were cleaned of impurities using tap water and then split into small pieces so they could be easily placed into crucibles. Afterward, they were cleaned again with tap water and dried in the sun for 5 days.

The analysis results shown in **Figure 1** and **Figure 2** indicate the presence of phenolic hydroxyl (O-H) groups in areca nut cluster biochar, as evidenced by a wavenumber of 3410.26 cm^{-1}, and in areca nut shells at a wavenumber of 3427.62 cm^{-1}. These results are nearly identical to those reported in (Setiawan et al., 2018), which confirmed the presence of O-H functional groups supported by an absorption band at 3389.04 cm^{-1}. Furthermore, carbonyl (C-O) groups were observed at a wavenumber of 1103.32 cm^{-1} for palm fruit cluster biochar and 1058.96 cm^{-1} for palm shell biochar. This is not significantly different from the findings in the study (Syauqiah et al., 2011), which also identified C-O functional groups in the wavenumber range of 1118.71–1257.59 cm^{-1}. Alkene C–H bonds were observed at a wavenumber of 875.71 cm^{-1} for palm fruit cluster biochar and at a wavenumber of 883.43 cm^{-1} for palm shell biochar.

Data obtained from experiments varying the contact time of biocharcoal on iron ion adsorption showed that palm fruit cluster biocharcoal reached its optimum at a contact time of 120 minutes, while palm shell biocharcoal reached its optimum at a contact time of 90 minutes. At a contact time of 60 minutes, there was an increase in adsorption for palm fruit stem biochar of 99.17%, followed by a decrease to 99.17% at 90 minutes and to 99.68% at 150 minutes. This decrease was caused by an excessively long contact time, which resulted in the re-release of Fe into the sample solution. Palm fruit shell biochar showed a decrease at a contact time of 60 minutes (99.48%) and also at 120 minutes (98.92%).

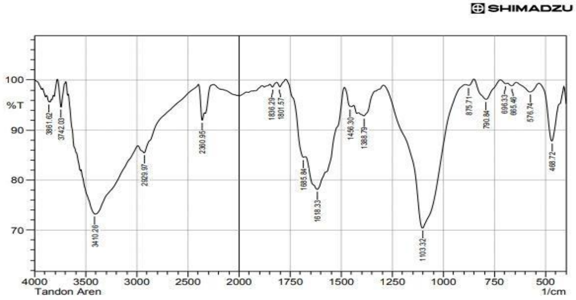

Figure 1. FTIR test results for areca nut clusters

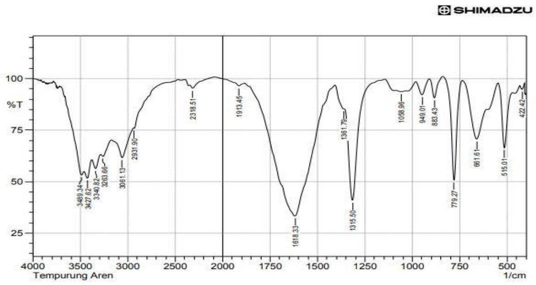

Figure 2. FTIR test results for areca nut shells

The results of the study indicate that the optimal weight for palm fruit cluster biochar is 40 mg and for palm shell biochar is 20 mg. The adsorption of palm fruit cluster biochar at a weight of 20 mg was 98.247%, then increased to 99.80% at a weight of 40 mg. The adsorption capacity of areca nut shell biochar at 20 mg was very high at 99.70%, after which it decreased from 40 mg to 100 mg, reaching 97.51%. This decrease was due to the system having reached its optimal weight. This decrease in adsorption capacity is due to the surface being saturated or nearly saturated with the adsorbate. It is likely that multilayer adsorption occurred, meaning that a second and subsequent adsorption layers formed on top of the adsorbate already attached to the surface (Wahyuni et al., 2020).

The results show that the adsorption efficiency of the sago palm fruit cluster adsorbent increased from 93.72% at 20 ppm to 98.85% at 60 ppm. After a decrease to 96.26% at a concentration of 80 ppm, it rose again to 98.68% at a concentration of 100 ppm. The adsorption capacity of the areca nut shell adsorbent followed a similar pattern to that of the areca fruit cluster adsorbent, showing an increase from 20 ppm (99.10%), followed by a decrease at 40 ppm (98.11%), and then an increase again at 60 ppm (99.54%). Subsequently, the adsorption decreased at a concentration of 80 ppm to 97.04%. It then increased again at a concentration of 100 ppm to

98.94%. The optimum condition for the palm shell adsorbent occurred at a concentration of 60 ppm. The increase in adsorption is due to the increasing concentration of the solution; as the solution concentration increases, the adsorption also increases until it reaches a certain concentration limit. Once the optimum concentration is reached, the adsorption is likely to decrease because the solution has become saturated (Mohamad et al., 2020).

Conclusions

The conclusions of this study are as follows: the characterization of biochar produced from sago palm fruit bunches and sago palm shells yielded a yield of 75.33% for the fruit bunches and 69.27% for the shells. The moisture content of the biochar from sago palm fruit bunches was 5.72%, while that of the sago palm shells was 1.37%. Meanwhile, the ash content of the sago palm fruit bunches was 30%, and that of the sago palm shells was 47%. The identification of functional groups in the biochar from sago palm fruit bunches and sago palm shells was conducted using infrared spectroscopy, revealing the presence of alcohol, alkene, ether, and phenol groups. Meanwhile, more functional groups were identified in the areca nut shell biochar, namely alkenes, alcohols, ethers, and aliphatic compounds (Machová et al., 2021). The optimal contact time determined for palm fruit bunch biochar was 120 minutes, with an adsorption efficiency of 99.83%, and for palm shell biochar, it was 150 minutes, with an adsorption efficiency of 99.87%. For the optimal weight variation, an optimal weight of 40 mg was obtained, capable of adsorbing 99.80% for areca nut cluster biochar, and 20 mg with an adsorption rate of 99.70% for areca nut shell biochar. The optimal concentration obtained for both biochars was the same.

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