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Characterization of Indonesian Bamboo Charcoal for Enhanced Adsorption Capabilities

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Abstract

Bamboo charcoal from four types of Indonesian bamboo species had been successfully prepared and characterized. The yield was 19.67%; 30.86%; 33,16% and 27,34 respectively for Apus bamboo, Javanese bamboo, Ori bamboo and Yellow bamboo. The activation of bamboo charcoal was carried out chemically using KOH and H_3PO_4. Activated bamboo charcoal was characterized for the content of water, volatile substance, total ash, and carbon, as well as iodine absorption capacity based on the technical standard of activated carbon SNI 06-3730-1995. The activated bamboo charcoal was also characterized using Fourier Transform Infrared (FTIR) to determine the functional groups, SEM to determine morphology and nitrogen adsorption desorption to determine the surface area. The activation process was able to reduce water, ash, volatile substance content; thereby increasing carbon content which has the potential to be used for adsorption, and this is evidenced by the increase in the value of iodine absorption. From the FTIR data activated bamboo charcoal shows the presence of a C=O at 1500-1600 cm^{-1}, O-H at 3400-3500 cm^{-1} and CO at 1300-1400 cm^{-1} which has the potential to contribute the active site for adsorption-process. Based on SEM data the morphology of activated bamboo charcoal was porous. Enhance quantity of pores would increase the surface area and the adsorption ability. From the results of the surface area data, it was found that the 4 types of activated bamboo charcoal produced a higher surface area, and activation using KOH was more effective than H_3PO_4 in increasing the surface area of activated bamboo charcoal.

Keyword: *Bamboo charcoal; activated carbon; adsorbents*

Introduction

Due to its numerous potential applications, activated charcoal has become a common part of our daily lives. It is known for its ability to adsorb heavy metal ions and remove dye waste(Yuvaraj, 2021), purify water (Chien and Fujimoto, 2017), clean used cooking oil (Suryandari and Kusuma, 2021), and cater to our daily needs such as facial wash and toothpaste (Rattanawut, 2018; Megalobrama *et al.*, 2021). Along with industrial development, the need for activated charcoal is also increasing, both for export and domestic. The production of activated carbon in Indonesia has reached a significant level of development. In 1998, the production amounted to 24,903 tons, which increased to 29,610 tons in 1999. In the year 2000, production remained at 24,903 tons, and during that period, approximately 6,576 tons were exported. In 2001, the production of activated carbon reached 30,161 tons per year, while the export volume amounted to 11,834 tons. Large countries such as the United States have a per capita demand of 0.4 kg per year, while in Japan, it ranges from 0.2 kg per year(Suryandari and Kusuma, 2021)

Activated charcoal can be obtained from various sources, for example from coconut shells(Akinlabi *et al.*, 2017), coconut husk, coal(Kumar *et al.*, 2021), bamboo (Chien and Fujimoto, 2017; Lin and Lin, 2018), rice husks (Van, Thuy and Thi, 2014), plant seeds (Ogungbenro *et al.*, 2017) and others. Recently, activated charcoal in general is used around 300.000 tons/year. Of the many uses, only about 10% of activated carbon comes from coconut shells, while the rest comes from other sources. From this data, there are still many opportunities to make activated charcoal from various natural materials, such as wood, bamboo and others.

Bamboo is found in many types and quantities and easily available in Indonesia. The use of activated carbon in all types of industries, such as the food industry, medicine, beverage, water treatment and others(Nurdin, Harahap and Fahmi, 2022). Thus, the aim of this research is to synthesize and characterize activated bamboo charcoal from 4 types of bamboo in Indonesia Javanese, Apus, Yellow and Ori bamboo to determine their potential as an adsorbent.

Methods

This research method includes tools and materials used and research procedures

Tools and Materials

The materials used in this study were 4 types of bamboo namely Java bamboo, Apus, Ori and Kuning bamboo, the activators used were H_3PO_4, and KOH. The instrumentation used for characterization was the Fourier Transform Infra-Red Spectrophotometer (FTIR) to determine functional groups, scanning electron microscope (SEM) to determine morphology and BET to determine the surface area of the adsorbent.

Experiment

The experiment of this research is divided by 2 stages:

The first stage is synthesis and activation bamboo charcoal

Bamboo charcoal was synthesized from 4 types of Bamboo, Javanese, Apus, Yellow and Ori bamboo by heating process and carried using 2 methods, ordinary charcoal and pyrolysis(Liu *et al.*, 2010; Smith *et al.*, 2019). The each bamboo were cut into tiny size and heated in a furnace with temperatures as 400^{o}C for 2 hours. The next process is chemical activation using H_3PO_4 (phosphoric acid) and KOH (potassium hydroxide)(Wang, 2006; Sutapa *et al.*, 2021).

The second stage is characterization

Bamboo charcoal and activated bamboo charcoal was characterized physical properties based on the SNI (Indonesian National Standard) regarding to technical activated charcoal. These characteristics are water content, volatile matter content, total ash content, carbon content, and iodine absorption capacity. The charcoal was characterized using FTIR to determine its functional groups, using SEM to determine the morphology and surface area using Nitrogen Adsorption Desorption.(Arang *et al.*, 2020; Hu *et al.*, 2021; Surata, 2021)

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Result and Discussion

This section discussed the results of the synthesis and activation of bamboo charcoal and its characterization, namely physical characteristics which include moisture content, ash content, volatile matter content, carbon content, characterization using FTIR to determine the effect of activation on the functional groups of the adsorbent, morphological characteristics obtained from SEM data, and adsorbent surface area from BET analysis results

Synthesis and activation Bamboo charcoal

The bamboo charcoal synthesis was carried out through three step process, dehydration, carbonization and activation process by heating process for 2 hours using heating at 400°C giving yield as shown in Table 1 for the four types of bamboo and 2 types of process heating (ordinary charcoal and pyrolysis system). Bamboo charcoal and activated bamboo charcoal from each of the bamboos gave almost the same results. Visually, it has a black and according to research (Hardyanti *et al.*, 2017).

Based on the information provided in Table 1, it could be observed that the bamboo charcoal production using a closed container resulted in higher yields compared to the open container method. This is attributed to the closed container effectively reducing air contact, which in turn optimizes the charcoal production process and minimizes the formation of ash. These findings were consistent across all four types of bamboo, namely Apus, Javanese, Ori, and Yellow bamboo. Notably, the Ori Bamboo demonstrated the highest yields among the four types.

Characterization

Characterization was carried out to determine that the bamboo charcoal produced complies with technical activated carbon standard(Badan Standardisasi, no date), which included water, ash, volatile substance, carbon, and iodine absorption capacity. The results obtained can be seen in **Table 2.**

Table 1. The Yields result from ordinary charcoal and pyrolysis system

No	Types of Bamboo	Yield (%)	
		Ordinary charcoal	Pyrolysis
1	Apus	18.64	29.67
2	Javanese	20.43	30.86
3	Ori	21.76	33.16
4	Yellow	14.32	27.34

Table 2. Physical characteristics of bamboo charcoal (BC) and activated bamboo charcoal (ABC)

Types of Bamboo	characteristics	water content (%)	ash content (%)	volatile substance content (%)	carbon content (%)	iodine absorption (mg/g)
Apus	BC	6.76	6.23	10.23	76.78	582.28
	ABC (H_3PO_4)	6.24	4.63	8.63	80.50	1082.51
	ABC (KOH)	5.25	2.34	6.34	86.07	982.51
Javanese	BC	4.49	4.84	8.84	81.83	646.12
	ABC (H_3PO_4)	4.36	1.28	5.28	89.08	1146.35
	ABC (KOH)	3.52	0.14	3.86	92.76	1046.28
Ori	BC	8.25	5.23	9.23	77.29	526.18
	ABC (H_3PO_4)	8.02	4.94	8.94	78.08	1026,41
	ABC (KOH)	7.22	3.65	7.65	81.48	926.22
Yellow	BC	7.38	7.82	11.82	72.98	482.37
	ABC (H_3PO_4)	7.18	7.26	11.26	74.30	982.60
	ABC (KOH)	6.38	5.29	9.29	79.04	882.65
SNI[20]		Max 15	Max 10	Max 25	Min 65	Min 750

Based on the data presented in Table 2, both bamboo charcoal and activated bamboo charcoal exhibit specific physical characteristics. These include a water content of less than 15%, ash content of less than 10%, volatile substance content of less than 25%, carbon content greater than 65%, iodine absorption greater than 750 mg/g, and compliance with the activated carbon standard SNI 06-3730-95

The characteristics and absorption ability of activated carbon are influenced by its water content, with higher water content resulting in lower adsorption ability. The obtained results indicate that both activated bamboo charcoal and bamboo charcoal have water content levels below 15%, which aligns with the standard requirements. Ash content, on the other hand, refers to the mineral residue remaining during the carbonization process. Since the raw materials used are natural and contain not only carbon compounds but also minerals, ash content analysis is necessary to determine the presence of metal oxides. Some minerals are lost during carbonization and activation, while others react with oxygen and remain as ash. The carbon content in bamboo charcoal represents the fraction of carbon that is bound to the charcoal, excluding water, ash, and volatile substances. Volatile substances are lost during heating up to 950 °C due to the decomposition of active carbon constituents in the carbonization process. Minimizing volatile substances could be achieved by increasing the carbonization temperature or employing pyrolysis techniques. Insufficient temperature and suboptimal pyrolysis and decomposition processes can lead to higher levels of volatile substances. The temperature and duration of carbonization are crucial factors influencing the volatile substance content.

The absorption capacity of bamboo charcoal, particularly for odors, can generally be assessed through its iodine absorption capacity. The type and concentration of the activator employed influence the absorption ability of iodine. The concentration of the activator impacts the surface area, where higher concentrations result in the formation of more pores. This facilitates the entry of absorbed compounds into the pores, leading to increased absorption, particularly of iodine. The surface area is a critical parameter that determines the quality and efficacy of activated carbon during the adsorption process

The analysis of FTIR spectra revealed an increase in absorption intensity within the wave number range of 3500-2700 cm^{-1}, which corresponds to the hydroxyl group absorption region. Notably, activated bamboo charcoal exhibited the highest intensity in this region. The augmented absorption intensity at the wave number range of 3000-2700 cm^{-1} indicates the formation of aromatic compounds. Additionally, vibrations observed at 1500-1600 cm^{-1} correspond to C=O bonds, while the hydroxyl groups bonded to O-H (3400-3500 cm^{-1}) and C-O (1300-1400 cm^{-1}) were also evident, as presented in Table 3.

Table 3. FTIR data for activated bamboo charcoal and bamboo charcoal

Types of Bamboo		Functional Group	O-H	C=O	C-O
Wave Number (cm^{-1})	Apus	BC	3432.65	1591.78	
		ABC (H_3PO_4)	3429.78	1599.78	1165.02
		ABC (KOH)	3429.88	1595.58	1433.98
	Javanese	BC	3426.94	1584.4	1380.45
		ABC (H_3PO_4)	3432.29	1597.81	1168.,14
		ABC (KOH)	3428.12	1592.74	1165.44
	Ori	BC	343.025	1585.36	1382.28
		ABC (H_3PO_4)	3433.97	1604.27	1238.23
		ABC (KOH)	3435.38	1584.55	1380.29
	Yellow	BC	3431.9	1576.95	1173.67
		ABC (H_3PO_4)	3426.35	1606.14	1112.66
		ABC (KOH)	3433.72	1594.55	1109.89

Based on the data provided in Table 3, it can be concluded that the activation process does not eliminate functional groups within the activated bamboo charcoal. These functional groups aligned with the standard functional groups of activated carbon, serving as active sites in the adsorption process. This finding was consistent with previous research (smith, *et al.*, 2019).

The activated bamboo charcoal has morphology which more porous than bamboo charcoal shows as shown from the SEM data with a magnification of 5000 times in **Figure** 1. SEM analysis was conducted to assess the morphological characteristics of bamboo charcoal before and after activation, aiming to determine any changes. The SEM results indicate that the pores in bamboo charcoal are initially closed. However, after activation, it becomes evident that the pores begin to open up further. This effect is observed regardless of whether Potassium Hydroxide or phosphoric acid is used as the activator.

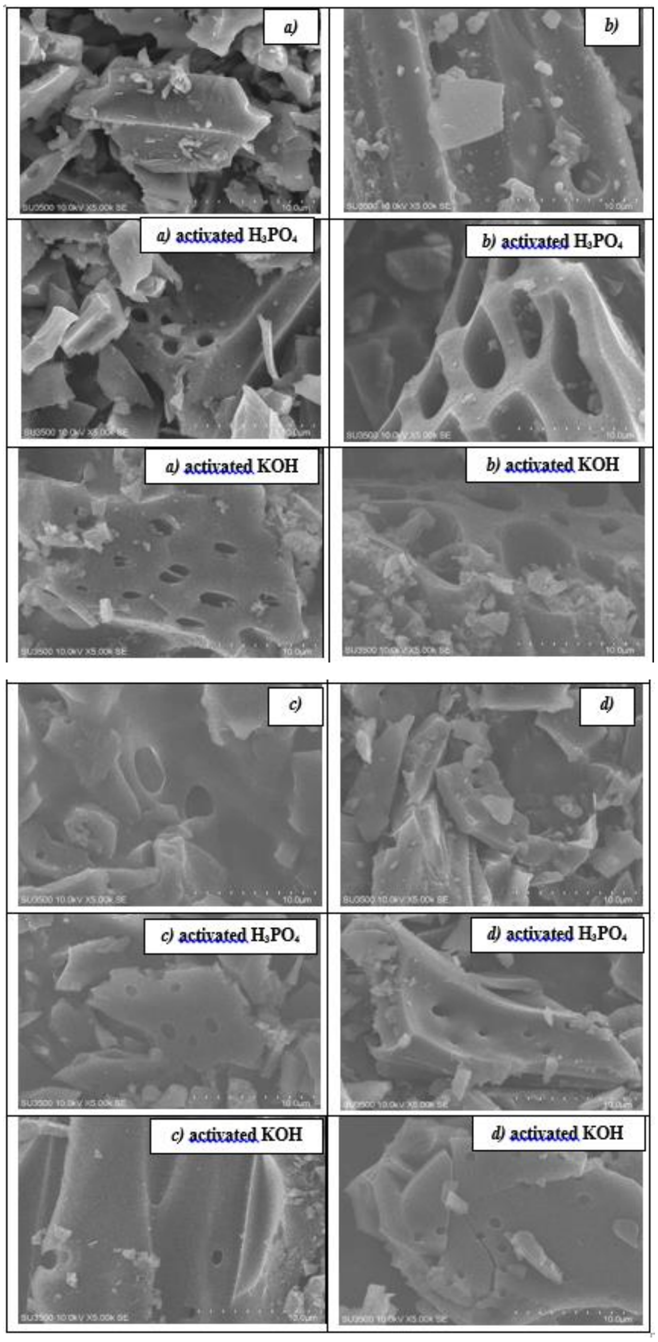

Figure 1. SEM image of bamboo charcoal and activated bamboo charcoal for (a) Apus Bamboo (b) Javanese Bamboo, (c) Ori Bamboo and (d) Yellow Bamboo

The activation process leads to the formation of numerous and larger pores. These findings are consistent across all four types of bamboo examined, indicating that activation enhances the number and size of pores uniformly. The increased presence of open pores on the surface of activated bamboo charcoal has a direct impact on its surface area. Consequently, a higher surface area enhances the adsorption capacity of activated bamboo charcoal during the adsorption process.

SEM analysis allows for the observation of morphological characteristics such as the shape, size, and arrangement of particles. In the case of activated bamboo charcoal, SEM images reveal a more uniform distribution of pores compared to bamboo charcoal. This is attributed to the activation process, which leads to the formation of a higher number of pores, thereby increasing the surface area of the charcoal. These findings align with the research conducted (Surata, 2021).

Based on the SEM data at a magnification of 5000 times, Figure 1 illustrates the contrasting morphologies of activated bamboo charcoal and bamboo charcoal. Activated bamboo charcoal exhibits a more porous structure, with a regular and well-distributed pore arrangement. This morphology is achieved through the activation process, which stimulates the formation of additional pores. As a result, the adsorption capacity of activated bamboo charcoal is significantly enhanced. These observations are consistent with previous research (Yuvaraj, 2021)

The activation process can be carried out through physical or chemical means. In this study, chemical activation was employed by introducing chemicals to enlarge the pores, either by breaking hydrocarbon bonds or oxidizing surface molecules. This modification leads to changes in the physical and chemical properties of charcoal, particularly in terms of the surface area.

Table 4. Surface Area for Bamboo (BC) and Activated Bamboo Charcoal (ABC) in various types of bamboos

Types of Bamboo	Surface Area (m^2/g)		
	BC	ABC (H_3PO_4)	ABC (KOH)
Apus	6,94	133.861	425.042
Javanese	6,463	389.957	430.093
Ori	3.153	513.536	363.486
Yellow	260.785	405.124	467.136

The objective of the activation process is two-fold: to eliminate impurities and increase pore volume. This involves enlarging the diameter of existing pores and creating new ones. During activation, the carbon content in the sample is oxidized, resulting in the removal of impurities and volatile substances. This oxidation process increases the volume and number of pores, thereby expanding the surface area.

The chemical activation process is highly dependent on the concentration and type of activator utilized. Stronger concentrations of activators facilitate their penetration into the carbon structure, resulting in pore expansion, impurity removal, and the creation of new pores (Liu and Xiao, 2018; Farma, Wahyuni and Awitdrus, 2019). The use of H_3PO_4 and KOH as activators yields varying data on surface area and pore size for the four types of bamboo, as presented in Table 4.
The activation process using KOH was more effective than H_3PO_4 in increasing the surface area of activated bamboo charcoal.

Conclusion

Both activated bamboo charcoal and bamboo charcoal exhibit physical properties that align with the standards set for activated carbon, specifically SNI 06-3730-95. These properties include water content, ash content, volatile substance content, carbon content, and iodine absorption capacity. Activated bamboo charcoal shows promise as an effective adsorbent due to the activation process, whether it is carried out physically or chemically. This process effectively eliminates impurities, opens up and expands the pores, thereby increasing the surface area and enhancing the adsorption ability of the charcoal. As a result, activated bamboo charcoal has the potential to be utilized as a reliable adsorbent.

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