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Utilization of Oil Palm Shell Waste (*Elaeis guineensis* Jacq) into Activated Charcoal

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A B S T R A C T

Oil palm shells are solid waste generated from the palm oil industry. The processing of oil palm shells into activated charcoal has not yet been optimized, despite the high demand for activated charcoal in various industries, such as desulfurization in gas purification and LNG processing, as well as filtration processes. Therefore, the quality of activated charcoal depends on the carbonization and activation process. This study aims to determine whether oil palm shells can be converted into activated charcoal using H_3PO_4 as an activating agent at concentrations of 8%, 9%, and 10%, and soaking times of 20, 22, and 24 hours, by the Indonesian National Standard (SNI) for activated charcoal. This study employs a pre-experimental, one-shot case study design. The treatment applied includes the independent variables of H_3PO_4 concentrations (8%, 9%, 10%) and soaking durations (20, 22, 24 hours). The carbonization temperature for all samples was 450–500°C for 0.5 hours. The dependent variable is the resulting activated charcoal powder that meets SNI standards. Activated charcoal with an 8% H_3PO_4 concentration and a 20-hour soaking time yielded the following results: a moisture content of 10.64%, an ash content of 2.66%, and a calorific value of 3,678.43 cal/g. With 9% H_3PO_4 and 20-hour soaking: 9.88% moisture, 2.95% ash, and 4,955.1 cal/g. With 10% H_3PO_4 and 20-hour soaking: 8.21% moisture, 3.53% ash, and 6,190.58 cal/g. The best result, according to SNI 1683-2021 "Wood Charcoal", was achieved at 24 hours of soaking and a 10% H_3PO_4 activator concentration, with the following values: 8.21% moisture, 3.53% ash, and 6,190.58 cal/g calorific value. It is therefore recommended for activated charcoal production.

Cangkang kelapa sawit, merupakan limbah padat yang dihasilkan dari pengolahan industri minyak kelapa sawit. Pengolahan cangkang kelapa sawit sebagai arang aktif belum dilakukan secara maksimal. Sedangkan penggunaan arang aktif dalam bidang industri sangat tinggi, diantaranya sebagai desulfurisasi pada pemurnian gas dan pengolahan LNG, bahan pembantu proses penyaringan dan lain-lain. Oleh sebab itu kualitas arang aktif tergantung pada proses karbonisasi dan proses aktivasi. Penelitian bertujuan mengetahui cangkang kelapa sawit dijadikan arang aktif dengan menggunakan bahan aktivator H_3PO_4 dengan konsetrasi aktivator 8%, 9%, 10% dan waktu perendamannya selama 20, 22, 24 jam sesuai dengan SNI arang aktif. Penelitian ini bersifat Pra-Ekperimental dengan desain *The One Shot Case Study,* penelitian diberi treatment (perlakuan) dengan variabel independen yaitu dengan aktivator H_3PO_4 sebesar: 8%, 9%, 10% dan waktu perendaman 20, 22, 24 jam. Dan suhu karbonisasi untuk semua variabel independen sebesar 450°C-500°C selama 0,5 jam dan variabel dependen yang diharapkan serbuk arang aktif yang sesuai dengan SNI arang aktif. Berdasarkan penelitian yang telah dilakukan Arang aktif pada konsentrasi 8% aktivator H_3PO_4 dengan waktu perendaman 20 jam mengahasilkan kadar air; 10,64%, kadar abu; 2,66%, Nilai Kalor;3,678.43 kal/g. Arang aktif pada konsentrasi 9% aktivator H_3PO_4 dengan waktu perendaman 20 jam mengahasilkan kadar air; 9,88%, kadar abu; 2,95%, Nilai Kalor;4,955.1 kal/g. Arang aktif pada konsentrasi 10% aktivator H_3PO_4 dengan waktu perendaman 20 jam mengahasilkan kadar air; 8,21%, kadar abu; 3,53%, Nilai Kalor;6,190.58 kal/g. Hasil terbaik sesuai dengan SNI 1683-2021 "Arang Kayu" yaitu pada waktu perendaman 24 jam dengan konsentrasi aktifator 10% larutan kimia H3PO4 dengan hasil: Kadar air : 8,21 % , Kadar abu : 3,53 %, Nilai Kalor : 6,190.58 kal/g. Maka dapat direkomendasikan untuk pembuatan arang aktif.

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1. Introduction

The growth of industry is increasing in line with advances in science and technology, making industry one of the key sectors that support the national economy. The palm oil industry holds promising prospects for the future. Field observations show that for every 1 ton of fresh fruit bunches, about 21–23% crude palm oil (CPO) and 5% kernel (palm shell) are obtained. However, the utilization of palm shells remains limited to uses such as fuel, activated carbon, liquid smoke, phenol, and charcoal briquettes. One emerging industry worth exploring is the activated carbon industry, which provides an alternative adsorbent material used in the food and beverage industry, as well as for adsorbing industrial waste (Yessy Meisrilestari, 2013).

Palm shells are a solid waste byproduct of palm oil processing. According to Hutahaean (2007), palm shell ash contains valuable elements. Inefficient utilization of palm shell waste can lead to unused residues and negative environmental impacts. Therefore, it is necessary to find ways to convert this waste into economically valuable materials. Oil palm shells can be processed into activated charcoal, which is produced through carbonization at 550°C for approximately three hours. The charcoal exhibits high activity, as evidenced by its iodine adsorption value of 28.9%.

The shell is the innermost and most challenging part of the oil palm fruit. Due to its hard texture, the shell cannot be processed into oil and is therefore discarded as factory waste. However, due to its high carbon content, it has excellent potential as a fuel. Further processing into charcoal briquettes could increase its usability and efficiency as an alternative fuel.

In Indonesia, domestic production of activated charcoal remains insufficient to meet demand. For high-quality activated charcoal, the country still imports around 2,000 tons per year. Activated charcoal is a form of carbon that has been activated to open its pores, resulting in higher absorption capacity than regular charcoal. It is widely used as an adsorbent to capture toxic liquids, poisonous gases, foul odors, and as a component in water purifiers, pulp refining, drinking water filtration, oil purification, and catalysts, among other applications (Akhmad B et al., 2012). Activated charcoal can be made from any carbon-containing material, whether organic or inorganic, as long as it has a porous structure.

The Indonesian National Standard (SNI) 1683–2021 for wood charcoal specifies that high-quality powdered activated charcoal should have a maximum moisture content of 10%, a volatile matter content not exceeding 25%, an ash content of no more than 4%, and a calorific value of 6,000–6,500 cal/g.

Biomass energy is considered an alternative to fossil fuels (such as petroleum) due to its renewable nature and eco-friendly characteristics—it contains relatively no sulfur, thus reducing air pollution and increasing the efficiency of forest and agricultural resource utilization. One example of biomass energy is charcoal briquettes, which can be made from oil palm shell waste. With the large number of palm oil mills in Sumatra, the amount of palm shell waste produced is also significant.

Research involving activated charcoal made from palm shells has been widely conducted. Other carbon-rich materials that can be used include coconut shells, sugarcane bagasse, rice husks, and more. Based on previous research by Yessy Meisrilestari (2013), titled "Production of Activated Charcoal from Palm Shells Using Physical, Chemical, and Physico-Chemical Activation," physical activation was conducted at 750°C for 3 hours using a furnace. Chemical activation was performed using $ZnCl_2$ and 24 hours of soaking, resulting in an ash content of 0.8824%, which did not meet the requirements of SNI 06–3730–1995.

Elly Kurniati (2008) conducted a study on utilizing palm shells for activated charcoal using H_3PO_4 as the activating agent at concentrations of 1%, 3%, 5%, 7%, and 9%, with soaking times of 16, 18, 20, 22, and 24 hours. The best results were obtained with a carbonization temperature of 400°C for 0.5 hours, a soaking time of 22 hours, and a 9% activator concentration, resulting in the following values: moisture content of 7.36%, ash content of 2.77%, volatile matter of 8.21%, and iodine adsorption of 19.80%. However, this still did not fully meet SNI 06–3730–1995 standards.

Yessy Meisrilestari (2013) also used physical activation at 750°C for 3 hours and chemical activation with $ZnCl_2$ for 24 hours, but the result (ash content of 0.8824%) again did not meet the

standards. In another study, Elly Kurniati (2008) used H_3PO_4 at concentrations of 1%, 3%, 5%, 7%, and 9%, with carbonization at 400°C for 0.5 hours. These results also failed to meet the SNI standard. One factor was the lower quality of charcoal produced with lower activator concentrations and shorter soaking times. Kurniati recommended increasing the activator concentration and soaking time, as the quality of activated charcoal depends heavily on the carbonization and activation processes.

Based on this, the current researcher aims to develop previous studies by using H_3PO_4 (phosphoric acid) at increased concentrations of 8%, 9%, and 10%, and soaking times of 20, 22, and 24 hours. Carbonization will be conducted at 450°C for 0.5 hours. The choice of 8%, 9%, and 10% was made to expand on earlier research that only went up to 9%. It is expected that higher concentrations and longer soaking durations will yield higher-quality activated charcoal.

2. Methods

This study is classified as pre-experimental research, similar to common experimental research designs but without the use of a control group (Sugiyono, 2007: 73). The design used in this study is the "One Shot Case Study," where treatment is given and then observations are made; the treatment acts as the independent variable, and the outcomes as the dependent variable. This research was developed using H_3PO_4 (phosphoric acid) as the activating agent at concentrations of 8%, 9%, and 10%, with immersion times of 20, 22, and 24 hours. The carbonization process was carried out at 450°C–500°C for 0.5 hours. The choice of 8%, 9%, and 10% concentrations was based on previous studies that used lower concentrations (1%, 3%, 5%, 7%, and 9%). Therefore, this study aimed to explore higher concentrations and longer soaking durations to maximize the yield of high-quality activated charcoal powder, as specified by the Indonesian National Standard (SNI) for activated charcoal.

The population in this study consisted of oil palm shell waste obtained from PT. Perkebunan Nusantara VII, Bekri Unit, Central Lampung, also served as the sample collection site. These palm shells were used to produce activated charcoal, which was then tested for quality at the Laboratory of Politeknik Negeri Lampung. The study was conducted with four treatment groups: 8%, 9%, and 10% H_3PO_4 concentrations, and one blank using phosphoric acid solution. The number of samples in each treatment group was determined using the Federer formula.

4.1. Carbonization of oil palm shells

The carbonization process was carried out at a temperature of 450°C–500°C using a furnace for 0.5 hours. At this temperature, it is assumed that the moisture content and other volatile compounds have evaporated, which allows the carbon pores to open. This process results in the formation of pores, although still relatively few, along with changes in shape and color. The higher the carbonization temperature, the more carbon pores will be opened.

4.2. Activation and quality testing of activated charcoal

The next stage is the activation process, which was carried out chemically. The activation was performed by soaking the charcoal in a chemical solution of H_3PO_4 (phosphoric acid) with activator concentrations of 8%, 9%, and 10%. Each sample was soaked for 20 hours, 22 hours, and 24 hours, respectively.

Table 1. Soaking treatments of activated charcoal

Sample	Activated Charcoal Soaking	
	Activator Concentration	Soaking Duration
Treatment A	8%	20 hours
Treatment B	9%	22 hours
Treatment C	10%	24 hours

4.3. Research Procedure

A total of 15 oil palm shells were used (including one blank and three treatment groups). The first treatment involved soaking three palm shells in 8% H_3PO_4 solution for 20 hours. The second treatment involved soaking three palm shells in 9% H_3PO_4 solution for 22 hours. The third treatment involved soaking three palm shells in 10% H_3PO_4 solution for 24 hours. After completing the three treatments, tests were conducted on the samples to measure moisture content, ash content, and calorific value at the Laboratory of Politeknik Negeri Lampung. The data on moisture content, ash content, and calorific value of the activated charcoal were analyzed using descriptive methods.

3. Results

The results of laboratory testing conducted to evaluate the quality of activated charcoal, specifically its moisture content, ash content, and calorific value, are presented as follows:

4.1. Moisture Content

Table 2 shows that the activated charcoal sample with the highest moisture content was the one soaked for 20 hours in an 8% H_3PO_4 (phosphoric acid) solution, while the sample with the lowest moisture content was the one soaked for 24 hours in a 10% H_3PO_4 solution.

Table 2. Moisture content quality test results of activated charcoal

No.	Sample	Result (%)	SNI 1683 : 2021	Meets Standard
1.	Blank	1.95	≤10	YES
2.	Sample 8% (20 hours)	10.64	≤10	NO
3.	Sample 9% (22 hours)	9.88	≤10	YES
4.	Sample 10% (24 hours)	8.21	≤10	YES

4.2. Ash Content

Table 3 shows that the activated charcoal sample with the highest ash content was the one soaked for 24 hours in a 10% H_3PO_4 (phosphoric acid) solution, while the sample with the lowest ash content was the one soaked for 20 hours in an 8% H_3PO_4 solution.

Table 3. Ash content quality test results of activated charcoal

No.	Sample	Result (%)	SNI 1683 : 2021	Meets Standard
1.	Blank	1.34	≤4	YES
2.	Sample 8% (20 hours)	2.66	≤4	YES
3.	Sample 9% (22 hours)	2.95	≤4	YES
4.	Sample 10% (24 hours)	3.53	≤4	YES

4.3. Calorific Value

Table 4 shows that the activated charcoal sample with the highest calorific value was the one soaked for 24 hours in a 10% H_3PO_4 (phosphoric acid) solution, while the sample with the lowest calorific value was the one soaked for 20 hours in an 8% H_3PO_4 solution.

Table 4. Calorific value quality test results of activated charcoal

No.	Sample	Result (Kal/g)	SNI 1683 : 2021	Meets Standard
1.	Blank	5313.10	6000 – 6500 kal/g	NO
2.	Sample 8% (20 hours)	3678.43	6000 – 6500 kal/g	NO
3.	Sample 9% (22 hours)	4955.1	6000 – 6500 kal/g	NO
4.	Sample 10% (24 hours)	6190.58	6000 – 6500 kal/g	YES

4. Discussion

The activated charcoal was processed using a furnace through two main stages: carbonization and activation. In the carbonization stage, oil palm shells were converted into charcoal at a temperature of 450°C–500°C for 0.5 hours. Then, chemical activation was performed by soaking the charcoal in phosphoric acid (H_3PO_4) solutions with concentrations of 8%, 9%, and 10%, for durations of 20, 22, and 24 hours, respectively.

Based on the quality tests of activated charcoal, Table 2 shows the moisture content, Table 3 the ash content, and Table 4 the calorific value. The quality of activated charcoal treated by immersion in H_3PO_4 depends on these three parameters. High-quality activated charcoal has a low moisture content, as moisture affects its calorific value. The best charcoal has a low ash content because lower residue results in higher flame output when burned. Moisture and ash levels are directly correlated with the calorific value of the charcoal.

The raw biomass material also influences the quality of the charcoal. Some biomass can be used directly as fuel (e.g., firewood), while others require processing before use, such as palm shells. Although dry, palm shells are small and not easily burned, hence the need to process them into activated charcoal.

From the laboratory results on moisture content (Table 2), Sample 1 (8% H_3PO_4, 20 hours) had 10.64% moisture; Sample 2 (9% H_3PO_4, 22 hours) had 9.88%; and Sample 3 (10% H_3PO_4, 24 hours) had 8.21%. These results indicate that longer soaking durations generally reduce moisture, particularly at higher activator concentrations. Most of the samples meet SNI standards, except for the 8% concentration at 20 hours, which slightly exceeded the 10% maximum threshold.

Regarding ash content (Table 3), longer soaking generally resulted in higher ash levels, although an increased activator concentration helped reduce ash. All samples, including the control, met the SNI requirement of ≤4%. However, the control sample had the lowest ash content.

For calorific value (Table 4), longer soaking times and higher activator concentrations resulted in higher energy values. According to SNI, the required calorific value is 6000–6500 cal/g. Only the sample treated with 10% H_3PO_4 for 24 hours met this standard (6190.58 cal/g).

Previous research by Elly Kurniati (2008) using H_3PO_4 at concentrations of 1%–9% and soaking times of 16–24 hours showed that even at 9% concentration and 22 hours of soaking, the resulting charcoal had 7.36% moisture, 2.77% ash, 8.21% volatile matter, and 19.80% iodine number, but still did not meet SNI standards. The researcher recommended increasing both activator concentration and soaking time.

In the current study, using H_3PO_4 concentrations of 8%, 9%, and 10%, and soaking durations of 20, 22, and 24 hours, the best quality was achieved at a 10% concentration and a 24-hour soaking duration. The resulting charcoal had 8.21% moisture, 3.53% ash, and a calorific value of 6190.58 cal/g, meeting the requirements of SNI 1683–2021 for wood charcoal.

5. Conclusions

Based on the study on utilizing oil palm shell waste to produce activated charcoal, it can be concluded that activated charcoal made from oil palm shells through a carbonization process at 450°C–500°C for 0.5 hours yielded promising results, characterized by a shiny black appearance. Activated charcoal with an 8% H_3PO_4 activator concentration and 20-hour soaking time produced: moisture content of 10.64%, ash content of 2.66%, and calorific value of 3,678.43 cal/g. At a 9% activator concentration with a 22-hour soaking time, the values were: moisture content of 9.88%, ash content of 2.95%, and calorific value of 4,955.1 cal/g. At a 10% activator concentration and a 24-hour soaking time, the results were: a moisture content of 8.21%, an ash content of 3.53%, and a calorific value of 6,190.58 cal/g.

The best results, as reported by SNI 1683–2021 "Wood Charcoal," were achieved with a 10% H_3PO_4 activator concentration and a 24-hour soaking duration, resulting in a moisture content of 8.21%, an ash content of 3.53%, and a calorific value of 6,190.58 cal/g. Therefore, this method is recommended for the production of activated charcoal.

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