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CHARACTERISTICS OF ACTIVATED CARBON FROM OIL PALM FRONDS USING DIFFERENT TYPES OF ACTIVATORS AT OPTIMUM CONCENTRATIONS

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ABSTRACT

Oil palm fronds are one of the plantation wastes that could be utilized as raw material for producing activated carbon. Activated carbon was produced through carbonization and activation processes. This study aimed to obtain the best type of activator in the production of activated carbon from oil palm fronds. The study was conducted experimentally using a Completely Randomized Design (CRD) with five treatments and three replications. The treatments in this study were P_1 (NaOH 2.5%), P_2 (KOH 15%), P_3 (H_3PO_4 9%), P_4 (H_2SO_4 10%), and P_5 (HCl 15%). The observed parameters consisted of moisture content, ash content, volatile matter content, fixed carbon content, and iodine adsorption capacity. The data were analyzed statistically using analysis of variance (ANOVA); if F-count ≥ F-table, the treatment had a significant effect, and the analysis continued with Duncan's Multiple Range Test (DMRT) at the 5% significance level. The results showed that the type of activator significantly affected all observation parameters. Activated carbon with the best treatment was found on P_4 treatment (H_2SO_4 10%) with a moisture content of 0.49%, ash content of 1.10%, volatile matter content of 2.10%, fixed carbon content of 96.31%, and iodine adsorption capacity of 854.46 mg/g.

Keywords: activated carbon, chemical activation, type of activator, oil palm fronds

INTRODUCTION

Indonesia, as a tropical country, has many plantation commodities, one of which is oil palm. Oil palm (*Elaeis guineensis* Jacq.) is one of the most important plantation commodities in Indonesia and contributes the largest foreign exchange earnings in the non-oil and gas sector, in addition to rubber and coffee. In 2023, Indonesia had an oil palm plantation area of 15,435,700 ha, with Riau Province, as one of the major oil palm-producing regions, accounting for 2,537,257 ha of the total plantation area (Badan Pusat Statistik, 2024). On average, each hectare of oil palm plantation is planted with approximately 130 oil palm trees and produces approximately 167 m^3 of biomass per hectare in the form of fronds and leaves that are pruned during the replanting period and simultaneously with the harvesting of fresh fruit bunches from the plantation. Oil palm fronds contain lignocellulosic material with a chemical composition consisting of 25.08% cellulose, 24.06% hemicellulose, and 18.46% lignin (Muhdarina et al., 2020). The lignocellulosic content indicates that oil palm fronds have the potential to be used as a raw material for the production of activated carbon.

Activated carbon is an amorphous form of carbon with a high adsorption capacity. Activated carbon has excellent adsorption capability for anions, cations, as well as molecules in both liquid and gaseous forms. It is generally applied in solution purification, decolorization, water purification, gas purification, and wastewater treatment processes. Activated carbon is produced through carbonization and activation processes. Carbonization is the process of converting raw materials into charcoal under limited oxygen conditions, while activation is required to transform the carbonized product into an adsorbent with a large

surfacahmede area. The carbonization process produces charcoal with relatively low adsorption capacity; therefore, an activation process is necessary to enlarge the surface area of the charcoal and improve its adsorption capability.

Activation is a stage in the production of activated carbon that aims to enlarge the pores of the charcoal by breaking hydrocarbon bonds or oxidizing surface molecules, thereby causing chemical and physical changes, including an increase in surface area that enhances its adsorption capacity. The activation process can be carried out using three methods: physical activation, chemical activation, and a combination of physical and chemical activation. Physical activation is performed using heat, steam, CO_2 gas, or N_2 gas, whereas chemical activation is carried out using chemical substances as activating agents. Chemical activation has advantages over physical activation because it produces a higher carbon yield, requires a shorter activation time, and operates at a lower activation temperature. Chemical activation can be performed using acidic activating agents (HCl, H_3PO_4, H_2SO_4), alkaline activating agents (KOH and NaOH), and salt-based activating agents ($ZnCl_2$ and NaCl).

Based on a previous study by Krismayanti et al. (2019) on the production of activated carbon from bamboo stem waste activated using 2.5% NaOH, the best treatment resulted in a moisture content of 1%, ash content of 6%, volatile matter content of 10.1%, and iodine adsorption capacity of 825.88 mg/g. Novitasari et al., (2024), in their study on the production of activated carbon from rubber fruit shells using various KOH concentrations, reported that activated carbon treated with 15% KOH was the best treatment, yielding a moisture content of 1.58%, ash content of 3.38%, and volatile matter content of 38.54%. Patandung (2017), in a study on the production of activated carbon from candlenut shells activated using H_3PO_4, found that 9% H_3PO_4 was the best activating agent concentration, resulting in a moisture content of 10.24%, ash content of 6.22%, volatile matter content of 20.22%, and iodine adsorption capacity of 764.48 mg/g. Amirudin et al. (2020), in their study on the production of activated carbon using H_2SO_4 as the activating agent, reported that activated carbon produced from tobacco stems using 10% H_2SO_4 resulted in a moisture content of 0.04%, ash content of 0.03%, volatile matter content of 0.87%, fixed carbon content of 99.08%, and iodine adsorption capacity of 994.05 mg/g.

Uhum et al. (2017), in their study on the production of activated carbon from coconut pulp using various HCl concentrations, showed that activated carbon treated with 15% HCl was the best treatment, resulting in a moisture content of 6.67% and an ash content of 0.52%. Several previous studies have utilized oil palm fronds as a raw material for activated carbon production. However, comparative studies on various types of chemical activating agents at their optimum concentrations for the characteristics of activated carbon produced from oil palm fronds are still limited. Therefore, this study was conducted to determine the most effective type of activating agent for producing high-quality activated carbon. This study aims to identify the selected activating agent capable of producing activated carbon from oil palm fronds with characteristics that comply with Indonesian National Standard (SNI) No. 06-3730-1995 (Badan Standardisasi Nasional, 1995).

METHODS

Materials

The materials used in this study were oil palm fronds obtained from pruning during harvesting, which had been dried beforehand, and were collected from the oil palm plantation of PT SAI Simp. Panta, Km 6, Ujung Batu District, Rokan Hulu Regency. Other materials used included 2.5% sodium hydroxide (NaOH), 15% potassium hydroxide (KOH), 9% phosphoric acid (H_3PO_4), 10% sulfuric acid (H_2SO_4), 15% hydrochloric acid (HCl), 0.1 N iodine (I_2) solution, 1% starch solution, 0.1 N sodium thiosulfate ($Na_2S_2O_3$), and distilled water.

The equipment used in this study included a metal drum, mortar and pestle, blender, oven, analytical balance, basin, filter paper, desiccator, pH meter, 100-mesh sieve, Erlenmeyer flask, dropper pipette,

graduated cylinder, spatula, porcelain crucible, aluminum foil, burette, retort stand, labeling paper, glass jars, stationery, and a smartphone camera for documentation.

Research Design

The study was conducted experimentally using a Completely Randomized Design (CRD) consisting of five treatments and three replications, resulting in a total of 15 experimental units. The treatments in this study were based on the best treatment conditions reported in previous studies conducted by Krismayanti et al. (2019), Novitasari et al. (2024), Patandung (2017), Amirudin et al. (2020), and Uhum et al. (2017), with the following activator concentrations:

P1 = 2.5% NaOH concentration
P2 = 15% KOH concentration
P3 = 9% H_3PO_4 concentration
P4 = 10% H_2SO_4 concentration
P5 = 15% HCl concentration

Research Implementation

Preparation of raw materials

The oil palm fronds used in this study were collected after harvesting and had been dried prior to use. The raw material preparation procedure followed Meilianti (2017). The oil palm fronds were cut into small pieces and cleaned of impurities, then sun-dried for 3 days.

Carbonization of oil palm fronds

The carbonization process of the oil palm fronds was carried out according to Bema et al. (2021). The dried oil palm fronds were carbonized using a metal drum made of tin or galvanized steel. Kerosene was used as a fire starter to initiate the carbonization process. Subsequently, the oil palm fronds were carbonized in the drum under limited oxygen supply for 1 hour until charcoal was formed and the smoke emitted from the drum became thin. The resulting charcoal was ground using a blender and then sieved through a 100-mesh sieve. The moisture content, ash content, and volatile matter content of the charcoal were determined before the activation process.

Activation of oil palm frond charcoal

The activation process of the oil palm frond charcoal followed the method of Refianti (2018). The carbonized charcoal that had been sieved was weighed at 10 g for each experimental unit, placed into a beaker, and soaked in 100 mL of the activating solution according to the treatment, namely 2.5% NaOH, 15% KOH, 9% H_3PO_4, 10% H_2SO_4, and 15% HCl. The soaking process was carried out for 24 hours, after which the charcoal was filtered using filter paper. The activated charcoal was then washed with distilled water until a neutral pH was reached. Finally, the charcoal was dried in an oven at 105°C for 1 hour.

Moisture content

The moisture content determination in this study followed the method of Zulfadhli & Iriany (2017). A porcelain crucible was first dried in an oven at 105°C for 15 minutes and then cooled. Approximately 2 g of the sample was weighed and placed into the pre-weighed porcelain crucible. The crucible containing the sample was dried in an oven at 105°C for 3 hours under constant conditions, then cooled in a desiccator for 15 minutes and weighed. The sample and crucible were returned to the oven and heated again at 105°C for 1 hour, cooled in a desiccator for 15 minutes, and weighed. This procedure was repeated until a constant weight was obtained (the difference between two consecutive weighings was 0.0002 g). The moisture content of the activated carbon was then calculated as a percentage using the following equation:

$$\text{Moisture content (\%)} = \frac{\text{Initial sample weight (g)} - \text{Final sample weight (g)}}{\text{Initial sample weight (g)}} \times 100$$

Ash content

The ash content determination followed the method of Zulfadhli & Iriany (2017). The crucible was first dried in an oven at 105°C for 15 minutes and cooled in a desiccator for 10 minutes. Approximately 2 g of the sample was weighed and placed into a porcelain crucible with a known dry weight. The crucible containing the sample was then placed in a muffle furnace at 600°C for 3 hours until whitish ash was obtained, cooled in a desiccator for 30 minutes, and weighed. The ash content was calculated using the following equation:

$$\text{Ash content (\%)} = \frac{\text{Ash weight (g)}}{\text{Sample weight (g)}} \times 100$$

Volatile matter content

The determination of volatile matter content followed the method of the Indonesian National Standard (1995). Approximately 2 g of the sample was weighed and placed into a crucible of known weight, then heated in a muffle furnace at 950°C for 7 minutes. The porcelain crucible was cooled in a desiccator and weighed until a constant weight was obtained. The volatile matter content was calculated using the following equation:

$$\text{Volatile matter content (\%)} = \frac{\text{Difference in sample weight (g)}}{\text{Oven-dried sample weight (g)}} \times 100$$

Fixed carbon content

The determination of fixed carbon content was conducted to determine the amount of pure carbon present in the activated carbon after carbonization and activation. The determination of fixed carbon content followed the Indonesian National Standard (1995). The fixed carbon content was calculated by subtracting the percentages of moisture content, ash content, and volatile matter content using the following equation:

$$\text{Fixed Carbon (\%)} = 100 - (\text{Moisture content} + \text{Ash content} + \text{Volatile matter content})$$

Iodine adsorption capacity

The determination of iodine adsorption capacity followed the Indonesian National Standard (1995). Approximately 0.25 g of oven-dried sample was weighed and placed into an Erlenmeyer flask. Subsequently, 50 mL of 0.1 N iodine (I_2) solution was added, and the mixture was stirred using a magnetic stirrer for approximately 15 minutes. The mixture was filtered using filter paper, and 10 mL of the filtrate was collected. The filtrate was then titrated with 0.1 N sodium thiosulfate ($Na_2S_2O_3$) solution until a pale yellow color appeared. Subsequently, 1 mL of 1% starch indicator was added, and the titration was continued until the solution became colorless. The volume of titrant used was recorded. The iodine adsorption capacity of the activated carbon was calculated using the following equation:

$$\text{Iodine adsorption capacity (mg/g)} = \frac{\left(A - \frac{B \times N(\mathrm{Na_2S_2O_3})}{N(\mathrm{I_2})}\right) \times 12.69 \times 5}{\alpha}$$

where:
A = Volume of iodine solution (mL)
B = Volume of $Na_2S_2O_3$ solution used (mL)
5 = Dilution factor
α = Weight of activated carbon (g)
N ($Na_2S_2O_3$) = Concentration of $Na_2S_2O_3$ solution (N)
N (I_2) = Concentration of iodine solution (N)
12.69 = Amount of iodine equivalent to 1 mL of 0.1 N $Na_2S_2O_3$ solution

Data Analysis

The research data were analyzed statistically using Analysis of Variance (ANOVA) in IBM SPSS Statistics software version 25. If F-count ≥ F-table, further analysis will be carried out using Duncan's Multiple Range Test (DMRT) at the 5% significance level.

RESULTS AND DISCUSSION

Moisture Content

ANOVA showed that the type of activating agent significantly affected the average moisture content of activated carbon produced from oil palm fronds. The average moisture content of the activated carbon is presented in Table 1.

Table 1. Average moisture content of activated carbon produced from oil palm fronds

Treatment	Moisture Content (%)
P1 = 2.5% NaOH concentration	1.15[b]
P2 = 15% KOH concentration	1.62[c]
P3 = 9% H_3PO_4 concentration	9.54[e]
P4 = 10% H_2SO_4 concentration	0.49[a]
P5 = 15% HCl concentration	6.56[d]

Note: Values followed by different lowercase letters indicate significant differences according to Duncan's Multiple Range Test (DMRT) at the 5% significance level.

Based on Table 1, the moisture content of activated carbon differed significantly among treatments, ranging from 0.49% in P4 (10% H_2SO_4) to 9.54% in P3 (9% H_3PO_4). These results indicate that the activating agent directly influenced the moisture content of the activated carbon. The alkaline activators (NaOH and KOH) produced relatively low moisture contents (1.15% and 1.62%, respectively), whereas the acidic activators exhibited greater variation. H_2SO_4 produced the lowest moisture content (0.49%), while H_3PO_4 and HCl resulted in higher values of 9.54% and 6.56%, respectively. This finding suggests that moisture content is influenced not only by the acidic or alkaline nature of the activating agent but also by its interaction with the lignocellulosic structure during activation.

The low moisture content obtained with H_2SO_4 was likely due to its strong dehydrating ability. Sulfuric acid promotes dehydration by interacting with hydroxyl (–OH) groups in lignocellulose, facilitating water removal and forming a more stable carbon structure, thereby reducing the tendency of activated carbon to absorb moisture (Chew et al., 2023). A similar result was reported by Rusli et al. (2025), who found that H_2SO_4-treated coconut coir produced activated carbon with lower moisture content than NaOH treatment because of more intensive dehydration.

In contrast, the highest moisture content observed with H_3PO_4 was attributed to the hygroscopic nature of phosphoric acid, which leaves polar functional groups on the carbon surface and increases its affinity for atmospheric moisture. Although H_3PO_4 effectively develops pores and increases the surface area of

activated carbon, its hygroscopic properties contribute to a higher final moisture content. All treatments satisfied the Indonesian National Standard for powdered technical activated carbon (SNI No. 06-3730-1995), which specifies a maximum moisture content of 15%.

Ash Content

ANOVA showed that the type of activating agent significantly affected the ash content of activated carbon produced from oil palm fronds. The average ash content is presented in Table 2.

Table 2. Average ash content of activated carbon produced from oil palm fronds

Treatment	Ash Content (%)
P1 = 2.5% NaOH concentration	5.77[d]
P2 = 15% KOH concentration	4.27[c]
P3 = 9% H_3PO_4 concentration	8.75[e]
P4 = 10% H_2SO_4 concentration	1.10[a]
P5 = 15% HCl concentration	1.71[b]

Note: Values followed by different lowercase letters indicate significant differences according to Duncan's Multiple Range Test (DMRT) at the 5% significance level.

Based on Table 2, the ash content of activated carbon differed significantly among treatments, ranging from 1.10% in P4 (10% H_2SO_4) to 8.75% in P3 (9% H_3PO_4). These results indicate that the type of activating agent influenced the removal of inorganic minerals during the activation process. The ash content ranged from 1.10% (P4, 10% H_2SO_4) to 8.75% (P3, 9% H_3PO_4), indicating that the activating agent strongly influenced the removal of inorganic minerals during activation. H_2SO_4 produced the lowest ash content because it promotes dehydration while converting minerals such as Ca^{2+}, K^+, and Mg^{2+} into soluble sulfate salts that are removed during washing, resulting in a more stable carbon structure (Chew et al., 2023). Similarly, HCl effectively dissolved alkali and alkaline-earth minerals into soluble chloride salts, leading to a low ash content (Uhum et al., 2017). These findings agree with Amirudin et al. (2020), who reported that H_2SO_4 activation reduced the ash content of tobacco stem activated carbon to below 2%.

In contrast, H_3PO_4 produced the highest ash content because phosphate residues remained trapped within the carbon matrix after activation. Similar results were reported by et al. (2024), who found higher ash content in H_3PO_4-activated lontar frond carbon than in alkali-activated carbon. NaOH and KOH resulted in intermediate ash contents (5.77% and 4.27%, respectively), possibly due to residual alkali salts remaining after washing (Budianto et al., 2021).

Overall, the differences in ash content demonstrate that each activating agent has a different capacity to remove inorganic minerals from oil palm fronds. Acidic activators, particularly H_2SO_4 and HCl, were more effective than alkaline activators, whereas H_3PO_4 tended to leave phosphate residues that increased the ash content. Nevertheless, all treatments complied with the Indonesian National Standard (SNI No. 06-3730-1995), which specifies a maximum ash content of 10%.

Volatile Matter Content

ANOVA showed that the type of activating agent significantly affected the volatile matter content of activated carbon produced from oil palm fronds. The average volatile matter content is presented in Table 3. Based on Table 3, the volatile matter content of activated carbon from oil palm fronds differed significantly among treatments. The highest volatile matter content was obtained in P3 (9% H_3PO_4) at 18.40%, while the lowest was observed in P4 (10% H_2SO_4) at 2.10%, indicating that the activating agent influenced the removal of volatile compounds and the stabilization of the carbon structure. H_2SO_4 produced the lowest volatile matter content because its strong dehydrating action promoted the decomposition of

hemicellulose and lignin, resulting in a more stable carbon structure. Amirudin et al. (2020) reported that H_2SO_4 significantly reduced volatile matter through intensive thermal degradation.

Table 3. Average volatile matter content of activated carbon produced from oil palm fronds

Treatment	Volatile Matter (%)
P1 = 2.5% NaOH concentration	8.15[b]
P2 = 15% KOH concentration	12.35[c]
P3 = 9% H_3PO_4 concentration	18.40[e]
P4 = 10% H_2SO_4 concentration	2.10[a]
P5 = 15% HCl concentration	15.41[d]

Note: Values followed by different lowercase letters indicate significant differences according to Duncan's Multiple Range Test (DMRT) at the 5% significance level.

NaOH produced lower volatile matter than KOH, H_3PO_4, and HCl because it effectively degraded unstable lignocellulosic compounds. Nandi et al. (2023) explained that NaOH breaks ether and ester bonds during activation. Lano et al. (2020) reported that NaOH reduced volatile matter by decomposing unstable organic compounds. Budianto et al. (2021) also found that NaOH accelerates hemicellulose decomposition, resulting in lower volatile matter content. In contrast, KOH produced higher volatile matter because residual potassium compounds remained in the carbon matrix after activation. Bakhtiar et al. (2019) reported that these residues are difficult to remove during washing.

H_3PO_4 resulted in the highest volatile matter content because phosphate residues retained volatile compounds within the carbon pores. Rini et al. (2024) reported that phosphate compounds increase volatile matter content. Chew et al. (2023) further explained that the mesoporous structure formed by H_3PO_4 activation enhances the retention of heavier volatile compounds. HCl also produced relatively high volatile matter because it mainly removes inorganic minerals rather than degrading volatile organic compounds. Uhum et al. (2017) reported that HCl effectively reduces ash content but has limited effect on volatile matter. All treatments satisfied the quality requirement of SNI No. 06-3730-1995, which specifies a maximum volatile matter content of 25%.

Fixed Carbon Content

ANOVA showed that the type of activating agent significantly affected the fixed carbon content of activated carbon produced from oil palm fronds. The average fixed carbon content is presented in Table 4. Based on Table 4, the fixed carbon content ranged from 63.31% in P3 (9% H_3PO_4) to 96.31% in P4 (10% H_2SO_4), indicating that the activating agent significantly influenced carbon retention during activation. H_2SO_4 produced the highest fixed carbon content because its strong dehydrating effect promoted the removal of moisture and volatile compounds, leaving a stable carbon matrix. Amirudin et al. (2020) reported that H_2SO_4 activation increased fixed carbon by effectively removing volatile substances. Mishra et al. (2024) further explained that H_2SO_4 promotes aromatic condensation reactions, producing a highly stable carbon structure. NaOH produced a relatively high fixed carbon content (84.93%) by degrading unstable lignocellulosic compounds and increasing the proportion of solid carbon. Lano et al. (2020) reported that NaOH activation increases fixed carbon through the decomposition of volatile compounds. Budianto et al. (2021) also found that NaOH enhances fixed carbon as volatile matter decreases. H_3PO_4 resulted in the lowest fixed carbon content (63.31%) because phosphate esterification and polycondensation reactions formed thermally stable organophosphate compounds that reduced the proportion of pure carbon. Rini et al. (2024) reported that residual phosphate compounds also contribute to lower fixed carbon content.

KOH produced a lower fixed carbon content than NaOH because residual potassium compounds remained within the carbon matrix after activation. Bakhtiar et al. (2019) reported that these residues reduce fixed carbon despite improving porosity. HCl also produced relatively low fixed carbon (76.32%) because it mainly removes inorganic minerals rather than promoting the decomposition of volatile compounds. Uhum et al. (2017) reported that HCl effectively reduces ash content but has limited ability to increase fixed carbon. Except for P3 (63.31%), all treatments met the quality requirement of SNI No. 06-3730-1995, which specifies a minimum fixed carbon content of 65%.

Table 4. Average fixed carbon content of activated carbon produced from oil palm fronds

Treatment	Fixed Carbon Content (%)
P1 = 2.5% NaOH concentration	84.93[d]
P2 = 15% KOH concentration	81.76[c]
P3 = 9% H_3PO_4 concentration	63.31[a]
P4 = 10% H_2SO_4 concentration	96.31[e]
P5 = 15% HCl concentration	76.32[b]

Note: Values followed by different lowercase letters indicate significant differences according to Duncan's Multiple Range Test (DMRT) at the 5% significance level.

Iodine Adsorption Capacity

ANOVA showed that the type of activating agent significantly affected the iodine adsorption capacity of activated carbon produced from oil palm fronds. The average iodine adsorption capacity is presented in Table 5.

Table 5. Average iodine adsorption capacity of activated carbon produced from oil palm fronds

Treatment	Iodine Adsorption Capacity (mg/g)
P1 = 2.5% NaOH concentration	647.19[c]
P2 = 15% KOH concentration	524.52[a]
P3 = 9% H_3PO_4 concentration	765.63[d]
P4 = 10% H_2SO_4 concentration	854.46[e]
P5 = 15% HCl concentration	579.51[b]

Note: Values followed by different lowercase letters indicate significant differences according to Duncan's Multiple Range Test (DMRT) at the 5% significance level.

Based on Table 5, the iodine adsorption capacity ranged from 524.52 mg/g in P2 (15% KOH) to 854.46 mg/g in P4 (10% H_2SO_4), indicating that the activating agent significantly influenced the adsorption performance of the activated carbon. H_2SO_4 produced the highest iodine adsorption capacity because its strong dehydrating action effectively removed volatile compounds and impurities, resulting in higher fixed carbon content and better-developed pore structures. Amirudin et al. (2020) reported that H_2SO_4 activation increased iodine adsorption by improving the porosity of activated carbon.

H_3PO_4 also produced a high iodine adsorption capacity (765.63 mg/g) because phosphate activation effectively removed impurities and enlarged pore structures, thereby enhancing adsorption performance. Sahara et al. (2017) reported that H_3PO_4 activation improves iodine adsorption by cleaning and enlarging the pores of activated carbon.

NaOH resulted in an iodine adsorption capacity of 647.19 mg/g by removing residual tar and opening micropores, thereby increasing the available adsorption surface. NaOH promotes the removal of tar residues from carbon pores. Lano et al. (2020) also found that NaOH activation increases the surface area of activated carbon, leading to improved iodine adsorption.

HCl produced a moderate iodine adsorption capacity (579.51 mg/g) because it mainly acts as a demineralizing agent, improving carbon purity but having limited ability to develop new pores. Uhum et al. (2017) reported that HCl activation reduces ash content but provides lower iodine adsorption capacity than other chemical activators.

KOH produced the lowest iodine adsorption capacity (524.52 mg/g), which was attributed to residual potassium compounds and remaining volatile matter that reduced adsorption efficiency. Bakhtiar et al. (2019) reported that potassium residues remaining after KOH activation can reduce iodine adsorption despite increasing porosity. According to SNI No. 06-3730-1995, activated carbon should have a minimum iodine adsorption capacity of 750 mg/g. Only P3 and P4 met this requirement, whereas P1, P2, and P5 did not.

CONCLUSION

Based on the results of this study, it can be concluded that the type of activating agent significantly affected the moisture content, ash content, volatile matter content, and fixed carbon content, and iodine adsorption capacity of activated carbon produced from oil palm fronds. Among the activating agents evaluated, 10% H_2SO_4 (P4) was identified as the most effective treatment, producing activated carbon with the best characteristics, including a moisture content of 0.49%, ash content of 1.10%, volatile matter content of 2.10%, fixed carbon content of 96.31%, and an iodine adsorption capacity of 854.46 mg/g. The activated carbon produced under this treatment met the quality requirements for powdered activated carbon specified in SNI No. 06-3730-1995.

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