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Application of activated carbon from durian peel activated with potassium hydroxide and microwave as an adsorbent for the purification of used cooking oil

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ABSTRACT

Durian (*Durio zibethinus*) is a seasonal fruit widely consumed in Indonesia. This high consumption results in a large amount of durian peel waste, which is often unused and underutilized. Durian peel, which contains lignocellulosic components, can be used as a precursor for adsorbents or activated carbon in the purification of used cooking oil. This study aims to enhance the adsorption capacity of activated carbon derived from durian peel by combining chemical activation using potassium hydroxide (KOH) with subsequent physical activation using microwaves. The experimental procedure consisted of several stages, including carbonization of durian peel, chemical activation using KOH, followed by microwave-assisted physical activation, and analysis of the purified oil. The variables investigated were the carbon-to-KOH ratio (w/v) (1:5, 1:10, 1:15, and 1:20) and the adsorbent concentration (5%, 10%, 15%, and 20%). Microwave activation was carried out at a power of 560 W for 10 min, followed by oven drying of the activated carbon. The adsorbent particle size was 150–200 mesh, with an adsorption time of 120 min and a stirring speed of 250 rpm. The results indicate that a carbon-to-activator ratio (w/v) of 1:20 produced the best activated carbon from durian peel, with a moisture content of 4.07%, ash content of 4.91%, carbon content (C) of 67.56%, and a surface area of 400.68 $m^2\ g^{-1}$. Under optimal conditions, the free fatty acid (FFA) content decreased by 92.84%, while the peroxide value decreased by 53.01%.

Keywords: durian peel, used cooking oil, adsorbent, adsorption, microwave.

INTRODUCTION

Cooking oil is an essential commodity widely used in households, restaurants, and the food industry. During frying, repeated heating causes physical and chemical degradation of the oil through oxidation, polymerization, and hydrolysis, generating toxic compounds such as aldehydes, fatty acids, and peroxides, which are associated with cancer and cardiovascular diseases (Bazina et al., 2025; Panadare, 2015). These changes also reduce nutritional quality, alter color, and impair food aroma (Miskah et al., 2019).

Adsorption using activated carbon is one of the most practical and cost-effective methods for refining used cooking oil due to its simplicity and ease of operation (Miskah et al., 2019). The effectiveness of activated carbon largely depends on its pore structure and surface area, which are influenced by the choice of raw material and activation method.

Durian peel is a promising precursor for activated carbon production. As the largest fraction of the fruit (60–75%), durian peel is abundantly generated as waste and is typically discarded (Tambun et al., 2024). It contains a high

cellulose content (50–60%) and lignocellulosic components, which are favorable for producing high-quality activated carbon (Aminah et al., 2022; Yuliusman et al., 2020). Activation further enhances its adsorption capacity by enlarging pores and increasing surface area through the breaking of hydrocarbon bonds and oxidation of surface molecules (Said et al., 2023).

Several biomass-derived activated carbons have been explored for used cooking oil refining. Activated carbon from snake fruit seeds, activated with H_2SO_4, effectively reduced free fatty acid (FFA), peroxide, and acid values at an optimal adsorption time of 120 minutes (Al Qory et al., 2021). Coconut shell charcoal activated with HCl at varying concentrations reduced the peroxide value by up to 60.11%, with particle size also playing a significant role (Fathurrahmaniah et al., 2022). While conventional activation methods, such as acid-treated snake fruit seed and coconut shell adsorbents, show notable reductions in FFA and peroxide values, their performance is often limited by insufficient pore development and longer processing times. In contrast, microwave-assisted alkali pretreatment of palm kernel shell (PKS) significantly enhances adsorption capacity within shorter processing durations, indicating a more efficient modification pathway (Alhusnah et al., 2024).

Despite these advances, several gaps remain. Previous studies have predominantly employed acidic activators (H_2SO_4 and HCl), while KOH, a strong base known to produce well-developed micro- and mesoporous structures with higher surface areas, remains underexplored. Moreover, durian peel, despite its high lignocellulosic content, has rarely been investigated as a raw material for activated carbon. The use of microwave activation also remains limited, despite its advantages in energy efficiency, reduced processing time, and more uniform pore formation.

To address these gaps, this study investigates the preparation of activated carbon from durian peel using KOH activation combined with microwave treatment and evaluates its performance in refining used cooking oil. This work offers a novel combination of an underutilized biomass precursor, a base activator, and a microwave-assisted activation strategy, contributing to the development of more effective and environmentally friendly adsorbents for used cooking oil purification.

MATERIALS AND METHOD

In this study, the raw materials used were durian peel, used cooking oil (UCO), potassium hydroxide (KOH), sodium hydroxide (NaOH), 96% (v/v) ethanol, phenolphthalein ($C_{20}H_{14}O_4$) indicator, potassium iodide (KI), glacial acetic acid (CH_3COOH), chloroform ($CHCl_3$), sodium thiosulfate ($Na_2S_2O_3$), and starch indicator. All chemicals were of analytical grade unless otherwise stated. The equipment used in this study included a muffle furnace, microwave oven, laboratory oven, Brunauer - Emmett - Teller (BET) surface area analyzer, gas chromatography (GC) instrument, and scanning electron microscopy coupled with energy-dispersive X-ray spectroscopy (SEM-EDX).

Carbonization of durian peel

Durian peel was washed with distilled water to remove surface impurities, cut into small pieces (approximately 1–2 cm), and dried under sunlight until a constant weight was achieved. The dried durian peel (approximately 100 g) was placed in a porcelain crucible and carbonized in a muffle furnace at 300 °C for 2 hours. After carbonization, the sample was cooled to room temperature in a desiccator. The resulting biochar was ground and sieved through a 150–200 mesh sieve. The carbonization yield was calculated gravimetrically as the ratio of the mass of carbon obtained to the mass of the dried durian peel, expressed as a percentage.

Chemical activation of carbon

The carbon was immersed in a solution of KOH with 0.1 N at carbon-to-activator ratios (w/v) of 1:5, 1:10, 1:15, and 1:20. The mixture was homogenized using a magnetic stirrer and allowed to soak for 24 hours at room temperature. The chemically activated carbon was then filtered and washed repeatedly with distilled water until the filtrate reached a neutral pH (pH 7), as measured using a pH meter. The sample was subsequently dried for three hours at 105 °C in the oven.

Physical activation of carbon

The carbon that was chemically activated was subjected to microwave activation using a microwave oven at a power of 560 W for 10 minutes. After

activation, the sample was filtered using Whatman No. 42 filter paper and washed with distilled water until the filtrate reached pH 7. The activated carbon was then dried in an oven at 105 °C for 3 hours and stored in a desiccator until further use.

Adsorption of used cooking oil

The adsorption process was carried out by mixing UCO with durian peel activated carbon at predetermined adsorbent-to-oil ratios (w/w: 1, 3, 5, 7, and 10 wt%) in a beaker. For two hours, the mixture was agitated at 250 rpm with a magnetic stirrer at room temperature. After adsorption, the mixture was filtered through Whatman No. 42 filter paper to separate the adsorbent from the purified oil.

Free fatty acid analysis

The free fatty acid (FFA) content of the purified UCO was determined by acid–base titration. Approximately 5 g of purified UCO was weighed into a 250 mL Erlenmeyer flask. Then, 50 mL of 96% (v/v) ethanol was added, and the mixture was heated at 40 °C for 15 minutes to facilitate dissolution. The solution was cooled to room temperature, and three Phenolphthalein indicator dots were applied. The solution was then used 0.1 M NaOH for titration until persistent pink colored appeared (endpoint). Equation 1 was used to determine the FFA content.

$$\%FFA = \frac{V_{NaOH} \times M_{NaOH} \times MW_{fatty\ acid}}{Sample\ weight\ (\mathrm{g})} \times 100 \quad (1)$$

Peroxide value analysis

The peroxide value (PV) of the purified UCO was determined using iodometric titration method. Purified UCO of 5 g was weighed into a 250 mL Erlenmeyer flask. A mixture of glacial acetic acid and chloroform (3:2, v/v) totaling 30 mL was added and swirled until the oil was completely dissolved. Then, 1 mL of saturated KI solution was added, and the flask was gently agitated about 1 minute in the dark to allow reaction with peroxides. Subsequently, 75 mL of distilled water was added. The solution was titrated with 0.01 N $Na_2S_2O_3$ until the yellow-brown iodine color faded to pale yellow. Then, 1 mL of 1% (w/v) starch indicator solution was added, and titration was continued until the blue color completely disappeared. A blank titration was conducted under identical conditions. The peroxide value was calculated using Equation 2.

$$Peroxide\ value = \frac{V_{Na_2S_2O_3} \times N_{Na_2S_2O_3} \times 1000}{Sample\ weight\ (\mathrm{g})} \times 100 \quad (2)$$

RESULTS AND DISCUSSION

Characteristics of the produced activated carbon

Results of water and ash content analysis

The water content (4.07%) and ash content (4.91%) of the durian peel activated carbon comply with the SNI 06-3730-1995 requirements (maximum 15% and 10%, respectively) (Table 1). The low water content reflects the effectiveness of microwave treatment in removing residual moisture from the pore structure, as microwave energy generates internal heat that drives water out of the carbon matrix more uniformly than conventional drying (Legiso et al., 2020). The low ash content indicates minimal residual mineral impurities, which is important because mineral deposits can block active adsorption sites and reduce the overall adsorption capacity (Kristianto, 2017). Together, these results confirm that KOH–microwave activation successfully produced an adsorbent with a clean and accessible pore structure suitable for oil purification.

Results of scanning electron microscope-energy dispersive x-ray (SEM-EDX) analysis

SEM analysis (Figure 1) reveals a well-developed porous morphology resulting from carbonization and KOH–microwave activation. KOH acts as a chemical activating agent by reacting with the carbon matrix to generate K_2CO_3 and CO_2 during activation. Subsequent microwave irradiation intensifies this reaction by rapidly generating localized heat, causing volatile by-products to escape and leaving behind an expanded and interconnected pore network (Ajithkumar and Arivoli, 2021; Akhila and Rao, 2023). This combination explains the pronounced pore development observed in Figure 1, which is essential for effective adsorption.

EDX analysis (Table 2) confirms that carbon (C) is the dominant element at 67.56 wt% (65.28 at%), satisfying the SNI 06-3730-1995 minimum carbon requirement of 65%. The presence of potassium (K) at 2.18 wt% is consistent with

Table 1. Water and ash content of durian peel activated carbon compared with SNI 06-3730-1995

Parameter	Activated carbon quality requirements (SNI 06-3730-1995)	Test results (%)
Water content	Max. 15%	4.07
Ash content	Max. 10%	4.91

residual KOH activating agent embedded within the carbon structure, which may introduce surface functional groups that enhance the affinity of the adsorbent toward polar compounds such as free fatty acids and peroxides (Ajithkumar and Arivoli, 2021). Oxygen (O) at 28.10 wt% indicates the presence of oxygenated surface functional groups (e.g., hydroxyl and carboxyl), which contribute to the polar nature of the adsorbent surface and facilitate interactions with FFA and peroxide molecules during adsorption.

Brunauer-Emmett-Teller (BET) analysis results

BET analysis showed a specific surface area of 400.68 m^2/g (Figure 2). This high surface area is a direct result of the combined KOH–microwave activation mechanism, in which KOH etches the carbon framework to create micropores, while microwave irradiation accelerates volatile release and pore expansion, producing a hierarchical pore structure with high surface accessibility (Usman and Wahyuningsih, 2022). A larger surface area provides more available adsorption sites per unit mass, thereby enhancing adsorption of FFA and peroxide compounds from used cooking oil. This structural advantage underpins the adsorption performance discussed in subsequent sections.

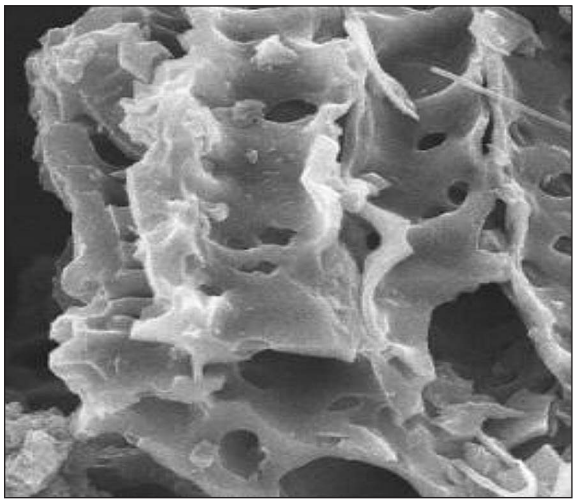

Figure 1. SEM results of durian peel activated carbon after KOH activation and microwave treatment

Characteristics of used cooking oil

Results of GC-MS analysis of used cooking oil

GC-MS analysis identified palmitic acid and oleic acid as the dominant fatty acid compounds in used cooking oil before and after purification. The untreated oil showed elevated FFA and peroxide levels of 2.961% and 16.6 meq O_2/kg, respectively, indicating significant hydrolytic and oxidative degradation. These degradation processes can generate potentially harmful compounds upon prolonged consumption (Woodhouse and Kelton, 2023). These baseline values highlight the need for effective purification and serve as a reference for evaluating the performance of the adsorbent.

The effect of adsorbent content on the percentage of free fatty acid (FFA) in used cooking oil after purification

Figure 3 shows that the FFA content decreased progressively with increasing adsorbent dosage across all carbon-to-activator ratios. This trend can be explained by the greater number of active surface sites available at higher adsorbent concentrations, which enhances interactions between FFA molecules and the polar functional groups on the activated carbon surface (Miskah et al., 2019). The oxygenated surface groups identified by EDX play a key role by facilitating hydrogen bonding and electrostatic interactions with the carboxyl groups of free fatty acids.

Among all conditions, the carbon-to-activator ratio of 1:20 with 20 wt% adsorbent produced the lowest FFA content of 0.21%, corresponding to a reduction of 92.84% from the initial value of 2.96%. This result meets the SNI 7709:2012 limit of ≤0.3%. The superior performance at the 1:20 ratio is attributed to the higher degree of activation, which leads to better pore development and higher surface area, as confirmed by BET analysis. In contrast, conditions with FFA values above 0.3% did not meet the SNI standard, indicating that both sufficient activator ratio and adsorbent dosage are required to achieve acceptable oil quality.

Table 2. Elemental composition of durian peel activated carbon determined by EDX

Element	Weight (wt%)	Atomic percent
C	67.56	65.28
O	28.10	32.29
K	2.18	1.12
Si	2.16	1.31

The effect of adsorbent content on peroxide value in used cooking oil after purification

The peroxide value decreased consistently with increasing adsorbent dosage (Figure 4), from an initial value of 16.6 meq O_2/kg to 7.8 meq O_2/kg at the 1:20 ratio with 20 wt% adsorbent, representing a reduction of 53.01%. This trend reflects the affinity of polar peroxide compounds for the activated carbon surface, where adsorption is driven by interactions with oxygen-containing functional groups (Yang, 2019). The adsorption process was conducted without heating, as higher temperatures can accelerate lipid oxidation and promote peroxide formation, counteracting the purification process (Miskah et al., 2019).

Several conditions met the SNI requirement of ≤10 meq O_2/kg, including the 1:10 ratio at 20 wt%, the 1:15 ratio at 15 wt% and 20 wt%, and the 1:20 ratio at 15 wt% and 20 wt%. The improvement with higher activator ratios is consistent with the FFA results and confirms that enhanced KOH–microwave activation increases adsorption capacity. Notably, achieving SNI compliance for peroxide value required a lower adsorbent dosage than for FFA, suggesting that peroxide compounds are more readily adsorbed under the tested conditions.

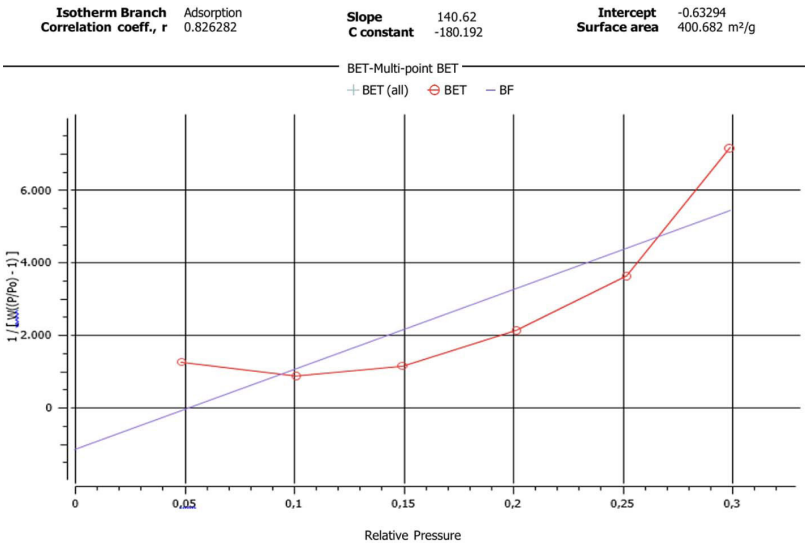

Figure 2. BET results of durian peel activated carbon after KOH activation and microwave treatment

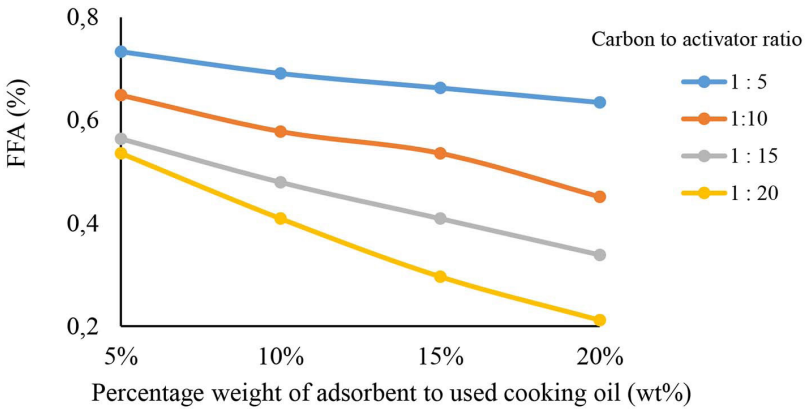

Figure 3. Effect of percentage weight of adsorbent and carbon to activator ratios on free fatty acid content in used cooking oil

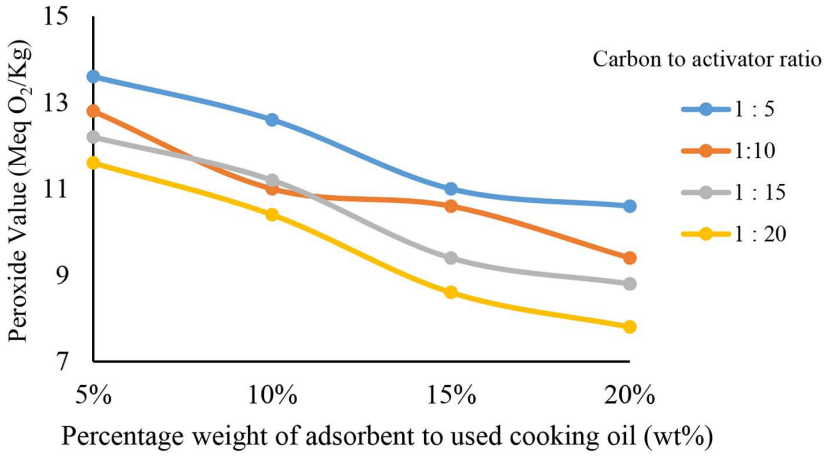

Figure 4. Effect of percentage weight of adsorbent and carbon to activator ratios on peroxide value in used cooking oil

Comparison with previous studies

Several studies have investigated the use of bio-based adsorbents derived from agricultural and plantation waste for purifying used cooking oil, as summarized in Table 3.

Based on Table 3, Alhusnah et al. (2024) reported that microwave-alkali-delignified palm kernel shell improved FFA adsorption up to 55%, highlighting the importance of pretreatment in enhancing porosity (Alhusnah et al., 2024). Fathurrahmaniah et al. (2022) showed that HCl-activated coconut shell achieved up to 60.11% peroxide reduction, emphasizing the influence of particle size and activator concentration (Fathurrahmaniah et al., 2022). Meanwhile, Al Qory et al. (2021) demonstrated that snake fruit seed-based activated carbon effectively reduced FFA and peroxide values, with contact time identified as a critical parameter (Al Qory et al., 2021).

In contrast, this study utilizes durian peel as a novel precursor and applies a combined chemical (KOH) and microwave-assisted physical activation approach. The optimal carbon-to-KOH ratio (1:20) resulted in a high surface area (400.68 m²/g) and achieved 92.84% FFA reduction and 53.01% peroxide reduction, outperforming previous studies in terms of FFA removal. This improved performance is attributed to the dual activation strategy, which enhances pore development more effectively than conventional single-step methods. These findings

Table 3. Comparison of previous studies on the purification of used cooking oil using bio-based adsorbents

No.	Reff	Adsorbent raw material	Preparation method	Activator	Research variables	Best result
1	(Alhusnah et al., 2024)	Palm kernel shell (PKS)	Microwave-alkali delignification + carbonization (400 °C, 2 h)	NaOH (10%, 20%, 30%)	NaOH concentration, delignification temperature (70–90 °C), delignification duration (30–40 min)	FFA adsorption capacity of 55% (NaOH 30%, 90 °C, 35 min); without delignification only 32%
2	(Fathurrahmaniah et al., 2022)	Coconut shell	Chemical activation (HCl), sieved to 80 and 100 mesh	HCl (0.5 M; 1 M; 1.5 M)	Charcoal powder size (80 and 100 mesh), HCl concentration	Peroxide value reduction up to 60.11% (80 mesh, HCl 1.5 M)
3	(Al Qory et al., 2021)	Snake fruit seed	Furnace carbonization (350 °C, 1.5 h) + chemical activation	H_2SO_4 0.1 N	Activated carbon mass (10–30 g), adsorbent size (80 and 100 mesh), adsorption time (30–120 min)	FFA 0.108%; AV of 0.244 mg KOH/g; moisture 0.062%; PV of 2.5 meq O_2/kg (30 g, 100 mesh, 90 min)
4	This study	Durian peel	Carbonization + chemical activation (KOH) + physical activation (microwave, 560 W, 10 min)	KOH (C:KOH ratio = 1:5; 1:10; 1:15; 1:20)	Carbon:KOH ratio (w/v), adsorbent concentration (5%, 10%, 15%, 20%), size 150/200 mesh, contact time 120 min, stirring speed 250 rpm	FFA reduction 92.84%; peroxide value reduction 53.01%; surface area 400.68 m²/g; moisture 4.07%; ash content 4.91% (C:KOH = 1:20)

demonstrate the strong potential of durian peel as a sustainable and high-performance adsorbent for used cooking oil purification.

CONCLUSIONS

This study demonstrates that the variety of chemical and microwave activation is an effective approach for manufacturing superior activated carbon from durian peel waste. The optimized carbon-to-activator ratio (1:20, w/v) generated a surface area of activated carbon of 400.682 m²/g, which successfully reduced FFA and peroxide values of UCO by 92.84% and 53.01%, respectively. Beyond its technical performance, this study highlights the dual benefit of valorizing agricultural waste while providing a sustainable and efficient alternative for used cooking oil purification, thereby contributing to green chemistry and improved waste management practices.

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