Adsorption Performance of Coffee Husk-Activated Carbon for Reducing Free Fatty Acid (FFA) of Used Palm Cooking Oil

Performa Adsorpsi Karbon Aktif dari Kulit Kopi untuk Menurunkan Asam Lemak Bebas (FFA) pada Minyak Jelantah

Eka Nur'azmi Yunira [1*)], Tamam Athallah Rhely Putra[2)], Borneo Satria Pratama[3)], Jatmiko Eko Witoyo[4)], Martasari Beti Pangestuti[5)]

[1)2)4)5)] Department of Agricultural Industrial Technology, Faculty of Industrial Technology, Institut Teknologi Sumatera, Lampung 35365, Indonesia

[3)] Department of Agricultural Technology, Politeknik Negeri Pontianak, Kalimantan Barat 78124, Indonesia

*E-mail: *eka.yunira@tip.itera.ac.id*

Abstract

Coffee husk-activated carbon is a promising biomass for use as an adsorbent due to its composition and abundance. This study aimed to analyze the performance of coffee husk-activated carbon in reducing the free fatty acid (FFA) content of used palm cooking oil. The study examined the effects of potassium hydroxide (KOH) concentration, adsorption time, and the mass of activated carbon. The activated carbon was produced through carbonization at a temperature of 300−400°C, followed by activation used 0 M, 1 M, and 2 M of KOH solutions. The results showed that the reductions in FFA levels at various adsorption times (2, 4, and 6 hours) were 24.219%, 33.828%, and 46.016%, respectively. The longer the adsorption time, the greater the reduction in FFA levels. In mass variations (0.1, 0.3, and 0.5 g) for 100 ml of used palm cooking oil, the reductions in FFA levels for 0 M, 1 M, and 2 M KOH-activated carbon were 40.234%, 47.968%, and 50.781%, respectively. The study found that increasing adsorption time and the mass of coffee husk-activated carbon resulted in lower FFA levels in used palm cooking oil. The highest percentage reduction in FFA levels, 50.781%, was achieved used 2 M KOH-activated carbon with a mass of 0.5 grams used and 6 hours for adsorption time. These findings suggested that coffee husk-activated carbon was a viable and sustainable adsorbent for improving the quality of used palm cooking oil, potentially reducing its environmental impact and enhancing its reuse potential in various applications.

Keywords: Activated carbon; Coffee husk; FFA; KOH; Used palm cooking oil

Abstrak

Karbon aktif dari kulit kopi merupakan biomassa yang menjanjikan sebagai adsorben karena komposisinya dan ketersediaannya yang melimpah. Penelitian ini bertujuan untuk menganalisis kinerja karbon aktif dari kulit kopi dalam menurunkan kadar asam lemak bebas (FFA) pada minyak goreng sawit bekas (minyak jelantah). Penelitian ini mengkaji pengaruh konsentrasi kalium hidroksida (KOH), waktu adsorpsi, dan massa karbon aktif. Karbon aktif diproduksi melalui proses karbonisasi pada suhu 300–400ºC, kemudian diaktifkan menggunakan larutan KOH dengan konsentrasi 0 M, 1 M, dan 2 M. Hasil penelitian menunjukkan bahwa penurunan kadar FFA pada karbon aktif pada berbagai waktu adsorpsi (2, 4, dan 6 jam) masing-masing sebesar 24,219%, 33,828%, dan 46,016%. Semakin lama waktu adsorpsi, semakin besar penurunan kadar FFA. Pada variasi massa karbon aktif (0,1, 0,3, dan 0,5 g) dalam 100 ml minyak goreng sawit bekas, penurunan kadar FFA untuk karbon aktif yang diaktifkan dengan 0 M, 1 M, dan 2 M KOH berturut-turut adalah 40,234%, 47,968%, dan 50,781%. Studi ini *menemukan bahwa peningkatan waktu adsorpsi dan massa karbon aktif dari kulit kopi menghasilkan penurunan kadar FFA yang lebih signifikan dalam minyak goreng sawit bekas. Persentase penurunan kadar FFA tertinggi, yaitu 50,781%, dicapai dengan menggunakan karbon aktif yang diaktifkan dengan 2 M KOH dan massa 0,5 gram selama 6 jam waktu adsorpsi. Temuan ini menunjukkan bahwa karbon aktif dari kulit kopi merupakan adsorben yang berkelanjutan dan berpotensi meningkatkan kualitas minyak goreng sawit bekas, sekaligus mengurangi dampak lingkungan serta meningkatkan potensi penggunaannya kembali dalam berbagai aplikasi.*

Kata Kunci: *FFA, Karbon aktif, KOH, Kulit kopi, Minyak Jelantah*

INTRODUCTION

Environmental problems are becoming increasingly complex, particularly concerning palm cooking oil waste. Indonesian people commonly use palm cooking oil for frying and other production processes, resulting in a high level of consumption. According to data from Badan Pusat Statistik (2024), palm cooking oil consumption in Indonesia increased by 12.04% between 2018 and 2022, reaching 20.9 million tons in 2022. The high consumption of palm cooking oil generates residues in the form of used palm cooking oil waste, which falls into the domestic waste category, amounting to approximately 3.8 million tons annually (Lopiani & Fikri, 2025). The physical and chemical properties of used palm cooking oil change during frying due to thermolytic, hydrolytic, and oxidative reactions (Yahya et al., 2019). Used palm cooking oil contains hazardous compounds such as free fatty acids (FFA), aldehydes, acrolein, and polymerization compounds, which can pollute the environment if not managed properly (Hidyus et al., 2024). Consequently, many researchers were eager to develop innovative solutions for its purification.

One effective method for absorbing hazardous compounds in used palm cooking oil is adsorption by activated carbon. Activated carbon consists of approximately 70% carbon and has physical characteristics such as black color, fine-grained texture, high surface area, lightweight nature, and high porosity, making it capable of absorbing various pollutants, including free fatty acids (FFA) (Siregar & Anwar, 2022). The activation process can be conducted by potassium hydroxide (KOH) (Yuliastuti et al., 2018). Conventional activated carbon production often relies on non-renewable raw materials, highlighting the need for alternative, more sustainable raw materials.

A potential raw material for producing activated carbon is coffee husk. Coffee husks are a type of biomass waste generated during coffee production through dry processing at the peeling stage. In the dry processing method, approximately 1 kg of coffee husk is produced for every 1 kg of coffee beans (Cangussu et al., 2021). Furthermore, Lampung Province was the second-largest coffee producer in Indonesia, with a total production of 118.1 thousand tons in 2022 (Badan Pusat Statistik Provinsi Lampung, 2023). Consequently, the amount of coffee husk waste was abundant. In addition, coffee husks contain 59.32% lignocellulose, primarily composed of cellulose, followed by 7.62% hemicellulose and 3.39% lignin (Dione et al., 2025). Given this composition, the high lignocellulose content in coffee husks presents a promising carbon source for producing activated carbon.

Ultimately, this research aimed to analyze the performance of activated carbon derived from coffee husk, activated with KOH, in the adsorption of FFA from used palm cooking oil. By utilizing coffee husk waste as a raw material for activated carbon, this study was expected to contribute significantly to the development of an environmentally friendly and sustainable treatment for used palm cooking oil. The findings of this study were anticipated to serve as a reference for both the community and industry in managing used palm cooking oil more effectively while mitigating its negative impacts on the environment and human health.

RESEARCH METHODOLOGY

Materials and Tools

The research was conducted at the Agricultural Industrial Technology Laboratory, Sumatera Institute of Technology. The material was coffee husks from Lampung coffee beans harvested via a dry method that dried under sunlight and then through a peeling process. The used palm cooking oil was from the households around the university. The chemicals were potassium hydroxide (KOH), sodium hydroxide (NaOH), distilled water, ethanol, phenolphthalein (PP) indicator, and pH paper. These reagents were pro-analysis grade and were purchased from a chemical supplier. While, the tools used in this research were crucibles, an oven (Memmert type: UN30), a muffle furnace (Thermo Scientific FB1310M-33), 200 ml bottles, Erlenmeyer flasks, digital scales, a sieved 40 mesh, a grinder, a centrifuge, pipette, filter clothes, tongs, desiccators, glasswares, pH meter, and thermometer.

Research Procedures

The research procedures were, firstly, the pretreatment of coffee husk. A 100-gram of coffee husk was reduced in size by grinding. The raw materials were dried in the oven at 105°C until the constant weight. Subsequently, the pretreated coffee husk was subjected to carbonization. The dried coffee husk was placed in a muffle furnace at 300-400°C for one hour. The resulting raw carbon from the coffee husk was then sieved to a 40-mesh size before activation.

The second stage was the activation process. The raw carbon of coffee husk with a 1:2 w/v ratio was soaked in 0 M, 1 M, and 2 M KOH solutions for 24 hours to produce activated carbon. The activated carbon was then filtered by filter clothes and washed with distilled water until the pH became neutral. Afterward, it was dried in an oven at 105°C until a constant weight was achieved.

This research involved a pretreatment stage for used palm cooking oil which were filtration and heating processes. The used palm cooking oil was filtered by a filter cloth and then heated at 105°C for 30 minutes to reduce its water content. Subsequently, 10 grams of the treated oil was placed in an Erlenmeyer flask for Free Fatty Acid (FFA) content analysis, followed by an adsorption process with specific treatment variations.

Treated-used palm cooking oil was placed in a bottle at a volume of 100 mL and then added activated carbon for the adsorption. The process was carried out in two variations. The first involved time variations of 2, 4, and 6 hours with 0.1 g of activated carbon treated with 0 M, 1 M, and 2 M KOH. The second involved mass variations of activated carbon (0.1 g, 0.3 g, and 0.5 g) treated with 0 M, 1 M, and 2 M KOH, an adsorption time of 6 hours. After the adsorption process, the used palm cooking oil was separated by centrifuge. The oil was then subjected to FFA testing according to Indonesian SNI 04-7182:2015 standards.

The procedure of FFA testing was a total of 10 grams of used palm cooking oil sample put into an Erlenmeyer flask. Then 50 mL of 95% ethanol was added and stirred until homogeneous. The solution was added 2 drops of phenolphthalein (PP) indicator and titrated with 0.1 N NaOH solution until the color of the solution changed to pink for 30 seconds. Free fatty acids were calculated by the following formula:

$$\%FFA = \frac{N\ NaOH\ x\ v\ NaOH\ x\ Mr\ FFA}{g}\ x\ 100\%$$

Description:

N NaOH : NaOH concentration

v NaOH : Volume of NaOH

Mr FFA : FFA molecular weight (palmitic acid = 256 g/mol)

g : Used cooking oil sample weight

RESULT AND DISCUSSION

FFA Content of Adsorption Time Variation

The initial FFA content of used palm cooking oil in this research was 1.28%. After adsorption of coffee husk-activated carbon with contact time variations, the FFA content produced a range value of 0.691 - 1.044%. The lowest FFA content was 0.691% in KOH 2 M activation and the adsorption time of 6 hours. Meanwhile, the value of FFA content still high (1.044%) was obtained from 0 M KOH-activated with 2 hours of adsorption time. The FFA content data at adsorption time variations can be seen in Figure 1 below:

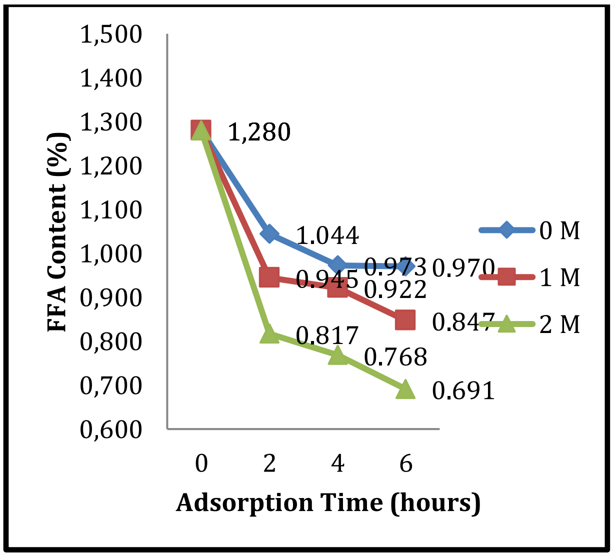

Figure 1. The FFA content data at adsorption time variations

The value of FFA content tended to decrease along with the increase in contact time of coffee husk-activated carbon during adsorption. The percentage decrease in FFA levels produced by 0 M, 1 M, and 2 M KOH-activated at various adsorption times were 24.219%, 33.828%, and 46.016%, respectively. Figure 1 shows that the value of FFA content was influenced by the duration time of the adsorption process. The longer the contact time of coffee husk-activated carbon with used cooking oil, the more FFA contents were adsorbed. That was in line with the research of Miskah et al. (2019), who used activated carbon from durian peel with a chemical activation method to purify the used cooking oil. Their study used contact time variations of 30, 60, 90, 120, and 150 minutes. The FFA levels decreased along with the increase in contact time, producing a range value of 0.1513 - 0.0637%.

The longer the contact time, the more FFA content was decreased. These results were obtained because the length of contact time would affect the amount of adsorbate that adsorbed by activated carbon (Fajrianti et al., 2016). The number of molecules adsorbed in the pores of activated carbon would cause the saturation point of activated carbon to be reached. As well as would occur the equilibrium (Mohamad et al., 2020).

Figure 1 also showed a decrease in the value of FFA content along with the increase in KOH concentration used. This occurred due to the characteristics of coffee husk-activated carbon after the chemical activation process with KOH. The ash content and volatile substances could affect the surface area of activated carbon. This characteristic would also impact the adsorption ability. High ash content and volatile substances could generate the filling of activated carbon pores. The number of filled and still empty pores would influence the surface area of activated carbon (Agustina et al., 2018). The greater number of pores indicates a wider activated carbon surface. Hence the adsorption performance becomes higher (Pratama et al., 2018). This situation might result in more FFA molecules being adsorbed by activated carbon.

FFA Content of Coffee Husk-Activated Carbon Mass Variation

After adsorption with coffee husk-activated carbon mass variation, the FFA content of used cooking oil resulted in a range value of 0.630 - 0.970%. The initial FFA content of used cooking oil was 1.28%. The lowest FFA content was 0.630% from 2 M KOH-activation and 0.5 grams of coffee husk-activated carbon mass. The FFA content data at coffee husk-activated carbon mass variations can be seen in Figure 2 below:

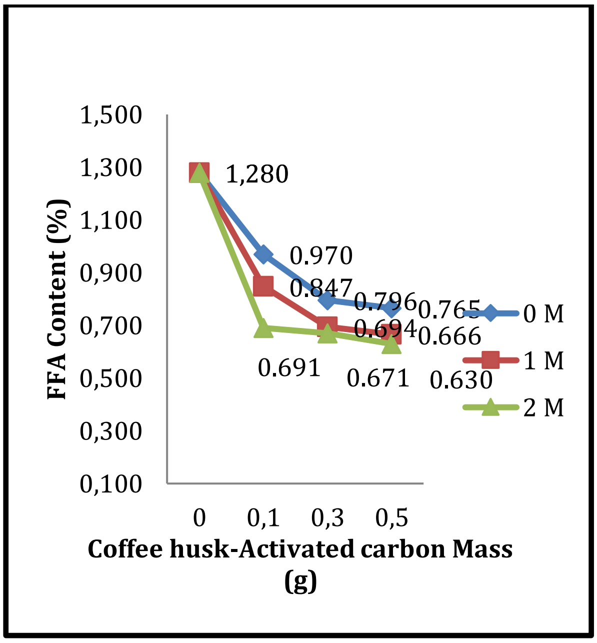

Figure 2. The FFA content data at adsorbent mass variations

According to Figure 2, the value of FFA content was inclined to decrease along with the increase in coffee husk-activated carbon mass variations. The percentage decrease in FFA content produced by 0 M, 1 M, and 2 M KOH-activated was 40.234%, 47.968%, and 50.781%, respectively. The highest FFA content value occurred in the process condition without activation (0 M KOH) with a weight of 0.1 gram which was 0.970%. The 2 M KOH-activated process condition with a weight of 0.5 grams obtained the lowest FFA content value of 0.630%. Furthermore, based on Figure 2, the value of FFA content was related to the mass of coffee husk-activated carbon used during the adsorption process. The increasing mass of adsorbent would affect the amount of adsorbate that was successfully absorbed by activated carbon (Zarkasi et al., 2018). These results were in line with the research of Miskah et al., (2018), which used activated carbon from durian peel with mass variations of 2, 3, 4, 5, and 6 grams.

The study resulted in a decrease in FFA levels along with an increase in activated carbon mass, namely 0.1514 - 0.0515%.

The coffee husk-activated carbon mass variation also showed a decrease in FFA content as the KOH concentration used increased. It was related to the characteristics of activated carbon that affect the number of pores. The more pores of activated carbon indicate the wider surface of activated carbon, thus causing more free fatty acid molecules to be adsorbed.

CONCLUSION

This study successfully analyzed the performance of activated carbon from coffee husk as influenced by KOH activator concentration, adsorption time, and adsorbent mass. The higher the KOH concentration, the lower the FFA content of used cooking oil. The longer the adsorption time, the lower the FFA content of used palm cooking oil. The more mass of coffee husk-activated carbon used, the lower the FFA content of used palm cooking oil. The results showed that activation of 2 M KOH in coffee husk-activated carbon with a mass of 0.5 grams produced the highest percentage reduction in FFA content of 50.781%.

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