ISSN 2807-9329 (Print) ISSN 2807-9167 (Online)

Journal of Mathematics, Science and Computer Education (JMSCEdu)

https://ppjp.ulm.ac.id/journals/index.php/jmsc-edu

Green Remediation of Used Cooking Oil Using Sugarcane Bagasse: A Sustainable, Green Chemistry Approach

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Received: 19 November 2024 **Accepted:** 16 December 2024 **Published:** 9 January 2025

DOI: https://doi.org/10.20527/jmscedu.v4i2.14139

Abstract

Environmental pillars are the foundation of sustainable development, emphasizing waste management solutions like used cooking oil purification. This study assesses used cooking oil quality based on color, odor, water content, free fatty acids, and peroxide value after sugarcane bagasse adsorption over 1, 2, and 3 days. Using a one-group pretest-posttest design, the 3-day treatment yielded optimal results: peroxide value (5.603 meq/kg), water content (0.070%), and free fatty acids (0.13%) decreased significantly, with improved color and odor compared to the control. The study integrates green chemistry principles, including waste prevention, energy efficiency, renewable material use, chemical degradation design, and safer chemical applications. This minimizes hazardous material usage, energy consumption, and environmental impact. Spent bagasse can be transformed into valuable products like compost or biofuel, providing sustainable solutions for managing used cooking oil waste, while reducing pollution and greenhouse gas emissions. The research offers an effective strategy aligned with Indonesia's conservation goals and green chemistry principles. It encourages public participation in local waste management, potentially inspiring innovative approaches for handling other waste types, thereby strengthening sustainability efforts.

Keywords: quality; sugarcane bagasse; used cooking oil

How to Cite: Dewi, N. P. P. M. S & Khodizah, A. T. (2024). Green remediation of used cooking oil using sugarcane bagasse: a sustainable, green chemistry approach. *Journal of Mathematics, Science, and Computer Education*, 4(2), 125-135.

INTRODUCTION

The Sustainable Development Goals (SDGs) were officially adopted on September 25, 2015, at the United Nations Headquarters in New York by 193 member countries as part of the Global Development Agenda. The SDGs aim to build upon and refine the Millennium Development Goals (MDGs), which were implemented from 2000 to 2015. Unlike the MDGs, the SDGs emphasize human development, environmentally sustainable economic growth, and environmental conservation. Within the framework of the SDGs, humans are positioned as both key drivers and beneficiaries of development, with a primary focus on promoting human welfare (Alisjahbana & Murniningtyas, 2018).

The SDGs are broken down into 17 measurable goals to facilitate implementation. One of these goals, point number 13, focuses on climate action. Environmental issues are a serious concern that now receives global attention. On a global scale, improving and restoring the environment to achieve sustainable governance has become a top priority in

Journal of Mathematics, Science and Computer Education (JMSCEdu)
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programs that synergize various sectors (Luqmania et al., 2022). The environmental pillar is crucial and serves as the foundation for the transformative spirit of sustainable development, where the environment, nature, and all its contents serve as limits. Therefore, all social and economic goals must not disrupt the sustainability of the environment's functions to support current and future life.

Youth have the potential to shape society through their moral compass, social impact, and innovative ideas. Their ecological literacy allows them to recognize the importance of life's intricate web and environmental stewardship (Hadi Wardhana et al., 2022). Young people's environmental activism has reshaped the political landscape, garnering media attention and influencing government policies (Boulianne et al., 2020). Climate strikes have pioneered innovative online mobilization tactics and redefined citizenship. Governments have responded by committing to ambitious carbon reduction targets and establishing citizen assemblies to address climate and environmental justice issues (Sloam et al., 2022). The study showed that young people offered promising solutions to environmental threats. They prioritized reducing industrial impact and increasing civic engagement. Young people define civic engagement as involvement in school-based activities and community initiatives. They strongly desire to contribute to local solutions by sharing innovative ideas and actively participating in discussions on environmental issues (Brondi et al., 2012). To support the SDGs, young generations can actively participate in proper waste management activities that contribute to climate change mitigation. By implementing integrated waste management practices, we can reduce greenhouse gas emissions, mitigate the effects of global warming, and protect water and soil resources.

One type of waste produced in large quantities by households, restaurants, and the food industry is used cooking oil. Cooking oil is one of the nine essential commodities the Indonesian people need. It serves as a heat conductor, adds flavour, and increases the caloric content of food. Cooking oil consists of around twenty different fatty acids, which are essential for determining its quality, as these fatty acids influence the chemical properties and stability of the oil (Mardiana et al., 2020). However, cooking oil is frequently reused in the community. The reuse rate of cooking oil is quite high, reaching 24% (Hakim et al., 2021). Reused cooking oil is referred to as "used cooking oil" (Hamsyah Adhari & Putri Utami, 2016).

Long-term consumption of used cooking oil can lead to health problems such as high blood pressure, cancer, loss of central nervous system control, or throat irritation (Damayanti et al., 2020). Used cooking oil also poses environmental hazards. It is often discarded without control, leading to water and soil pollution. When absorbed into the soil, used cooking oil can contaminate the land, reducing its fertility and affecting the mineral content of clean water (Damayanti et al., 2020). Used cooking oil waste can be used as raw material for non-food industries, such as biodiesel and solid and liquid soap. Before it can be applied as an industrial raw material, the used cooking oil must first undergo purification. This ensures that the oil and the industrial products meet the Indonesian National Standards (SNI). The adsorption process is one technique to improve the quality of used cooking oil (Hakim et al., 2021).

Adsorption is the process of binding molecules in a fluid, either liquid or gas, to the surface of solid pores. The material used in adsorption is called an adsorbent. Using adsorbents is an effective and relatively inexpensive method because it can utilize by-products or agricultural waste. One such by-product is sugarcane bagasse. According to the Central Statistics Agency (2020), the total area of sugarcane plantations in Indonesia is 419,000 hectares, producing 2.13 million tons in 2020. Sugarcane is cultivated in tropical regions as the main raw material for sugar production. The plant takes approximately one year from planting to harvest. Sugarcane has significant economic value and is crucial as

the primary raw material for the sugar industry, leading to ongoing efforts to increase its production. However, during the milling process, only 35-40% of the sugarcane's weight is reduced, meaning that 0.75-0.85 million tons of sugarcane bagasse have the potential to be utilized as derivative products. In order to process used cooking oil waste, the researchers applied the adsorption method using unused sugarcane bagasse. Sugarcane bagasse contains cellulose and lignin, which help absorb impurities from used cooking oil (Wahyuni & Srimiati, 2018). This study assesses the quality of used cooking oil in terms of colour, odour, water content, free fatty acid content, and peroxide value after undergoing adsorption with sugarcane bagasse waste for 1, 2, and 3 days.

The entire community can contribute to achieving the SDG targets, including within the education sector. Meanwhile, the principles of green chemistry, also known as sustainable chemistry, are essential to integrate into education to give students, as future generations, an early understanding of sustainability. Therefore, it is crucial to explore the connection between sustainable development, green chemistry, and its application in learning—particularly in chemistry education. Green chemistry principles can guide human behaviour and actions towards environmental sustainability. Green education, a form focused on environmental issues, can be crucial in promoting these principles. This aligns with the idea that education is essential for spreading awareness and knowledge about green chemistry (Mitarlis et al., 2023). Integrating green chemistry-based SDGs into chemistry education aims to empower students to become environmentally conscious problem-solvers. By implementing green chemistry principles in curricula and laboratories and promoting problem-based learning and systems thinking, students can develop a deep understanding of chemistry's role in sustainability. This enables them to identify and address chemistry-related environmental challenges (Anggraeni et al., 2024). A comprehensive review of 695 articles led to the selection of 13 for further analysis by Sánchez Morales et al. (2024). The study demonstrates that green chemistry can be a key learning strategy to foster sustainable development and help achieve the SDGs. Based on the background, this study aims to assess the quality of used cooking oil in terms of colour, odour, water content, free fatty acid content, and peroxide value after undergoing adsorption with sugarcane bagasse waste for 1, 2, and 3 days and describe the integration of green chemistry principles in the experiment to support one of the SDGs achievements.

METHOD

This study used a true experimental approach by applying a one-group pretest-posttest design, as shown in the Table 1.

Table 1 Experimental design

Sample	Pretest	Treatment	Posttest
Experiment	O_1	X	O_2

The sugarcane bagasse waste samples were obtained from several sugarcane juice vendors on Sidakarya Street, Denpasar. These samples were then processed into powder. The second sample, which used cooking oil, was collected from several food vendors around SMA Santosa Intercultural School.

The variables used in this study are divided into three categories: (1) Independent variable, deliberately altered in the experiment, in this case, the adsorption time of 1 day, 2 days, and 3 days. (2) Dependent variable results from the treatment of the independent variable, including organoleptic properties, peroxide value, water content, and free fatty acid content. (3) Controlled variable, which is kept constant in the study, namely the amount of sugarcane bagasse waste (2 grams) and the volume of used cooking oil (200 mL).

Preparation of Sugarcane Bagasse Waste

The sugarcane bagasse samples were thoroughly washed, cut into pieces approximately 5 cm in size, and dried. To ensure uniformity, all the samples were stirred evenly with a stirring rod and then ground using a blender. The ground sugarcane bagasse was then sieved using a 100-mesh sieve to obtain particles of uniform size.

Application of Sugarcane Bagasse Waste on Used Cooking Oil

The used cooking oil was obtained from food vendors around SMA Santosa Intercultural School. A total of 2 grams of sugarcane bagasse waste was placed into a glass container, and 200 mL of used cooking oil was added. The mixture was stirred until homogeneous and then sealed tightly. The adsorption process was carried out for 1, 2, and 3 days. After the adsorption process, the samples were filtered using filter paper and their quality was analyzed in terms of odour, colour, water content, free fatty acid content, and peroxide value.

Organoleptic Test

The organoleptic test involved 25 untrained panellists. The selected panellists were food vendors who regularly use cooking oil daily. Before starting the organoleptic test, a school nurse conducted health screenings for the 25 panellists. The organoleptic test, which included evaluations of colour and odour, was conducted in the Chemistry Laboratory of SMA Santosa Intercultural School from 9:00 AM to 11:00 AM. The panellists performed a hedonic (preference) test on the samples and filled out forms based on their opinions. The criteria for the organoleptic test evaluation are presented in Table 2.

Table 2 Criteria for organoleptic test evaluation

Colour	Odor	Scale
Black	Very smelly	1
Dark brown	Smelly	2
Light brown	Average smell	3
Dark yellow	A little smell	4
Light yellow	No smell	5

Colour Test

5 ml of the oil sample is placed into a test tube and observed against a white background. The panellists then evaluate the sample by assigning a score based on Table 2.

Odor Test

5 ml of the oil sample is placed into a test tube, and the panellists smell the sample. They then assign a score based on Table 2.

Determination of Peroxide Value

The determination of the peroxide value was carried out at UPT-Laboratory of Analytical Services, Udayana University. Approximately 5.00±0.05 g of cooking oil was weighed and placed into a sealed 250 ml Erlenmeyer flask. Then, 12 ml of chloroform and 18 ml of glacial acetic acid were added to the flask. The solution was shaken until all components were dissolved. After mixing the solution, 0.5 ml of saturated KI solution was added. The mixture was left to stand for 1 minute while being shaken, followed by adding 30 ml of distilled water. Next, 0.5 ml of 1% starch solution was added, and the mixture was immediately titrated with 0.1000 N $Na_2S_2O_3$ until the solution changed from blue to a point where the blue colour started to fade. The procedure was repeated three times. The peroxide value is expressed in mg-equivalents peroxide per 100 g of the sample (Suroso, 2013).

Determination of Water Content

The determination of water content was conducted at UPT-Laboratory of Analytical Services, Udayana University. A clean porcelain dish was heated in an oven at 105°C for 30 minutes, then cooled in a desiccator and weighed until a constant weight was achieved for the empty, dry dish. Next, 2 grams of the oil sample were weighed into the dish and heated in an oven at 105°C for 4 hours. The sample was then cooled in the desiccator for 15 minutes and weighed again. Drying was repeated until a constant weight was obtained (with a difference of less than 0.2 mg between successive weighings). The weight loss represents the water content in the oil. Water content was determined three times (Suroso, 2013).

Determination of Free Fatty Acid Content

The determination of free fatty acid content was conducted at UPT-Laboratory of Analytical Services, Udayana University. The cooking oil was stirred thoroughly and maintained in a liquid state for easy sampling. A sample of 28.2 ± 0.2 g was weighed and placed into a 250 ml Erlenmeyer flask. Next, 50 ml of hot neutral alcohol and 2 ml of phenolphthalein (PP) indicator were added to the sample, which was immediately titrated with 0.100 N NaOH until a color change from colorless to light pink occurred and remained for 30 seconds (Suroso, 2013).

Data analysis

All the data obtained were clearly described. The next step was to analyze the differences in organoleptic properties, water content, peroxide value, and free fatty acid content between the pretest and posttest experimental groups using the following steps:

a) Data selection, including editing, coding, and tabulation, was performed using SPSS version 25.0 for Windows to determine whether there was an effect between before and after the treatment.
b) The normality of the organoleptic properties, water content, peroxide value, and free fatty acid content for each group was analyzed using the Shapiro-Wilk test (since the sample size was < 30) with a significance level of $\alpha = 0.05$. The data were categorized as normally distributed if sig > 0.05.
c) The Levene test was used to analyze homogeneity of variance between groups. Variance between groups is homogeneous if $p > 0.05$. The prerequisite for ANOVA is that the data must be normally distributed or at least normally distributed.
d) To determine whether the sugarcane bagasse waste had an effect on the organoleptic properties, water content, peroxide value, and free fatty acid content of each treatment group compared to the control group, and to assess the interaction between treatments, a One-Way ANOVA was used with a significance level of $\alpha = 0.05$.

RESULTS AND DISCUSSIONS

Organoleptic Test

Organoleptic testing, also known as sensory evaluation, is a method of assessment that utilizes the human senses to observe the texture, colour, shape, aroma, and taste of food, beverages, or pharmaceuticals. Organoleptic testing plays a crucial role in product development. Sensory evaluation can be used to assess desired or undesired product changes and identify development areas (Ayustaningwarno et al., 2020).

Twenty-five untrained panelists were involved in the organoleptic test. The selected panelists were vendors who regularly use cooking oil. Table 3 shows the average results of the panellists' organoleptic evaluation of the oil samples.

Table 3 Organoleptic test result

Treatment	Colour	Odor
Control	1.32^{a}	1.40^{a}
1 day	3.52^{b}	2.92^{b}
2 days	4.56^{c}	4.36^{c}
3 days	4.60^{c}	4.48^{c}

Description: Different letter notations indicate significant differences ($p<0.05$).

Colour is the first impression that emerges and is evaluated by the panellists. Colour is the earliest organoleptic parameter in presenting food materials (Ege et al., 2023). An attractive colour will entice the panellists to use or taste a product. Based on Table 3, the evaluation of the oil samples with adsorption times of 2 and 3 days did not show significant differences, and the panellists favoured the colour of those samples.

Odor is one of the parameters used to test organoleptic properties using the sense of smell. Odour is a subjective sensation and can be acceptable if the substance has a specific aroma. Changes in the odour of oil can occur after the cooking oil is used for frying food; the oil may smell rancid. This condition is possible because, during the frying process, the oil undergoes decomposition reactions. The hydrolysis of fats occurs when fats are hydrolyzed into free fatty acids and glycerol. The rancid odour is caused by forming free fatty acids (Dwiloka et al., 2021). Based on Table 3, the panellists' evaluation of the oil samples with adsorption times of 2 and 3 days did not show significant differences, and the panellists favoured the odour of those samples.

Peroxide Value

The peroxide value is an index of the amount of fat or oil that has undergone oxidation. The oxidation process is influenced by several factors, including temperature, oxygen, light, and the presence of catalysts during oxidation (Suandi et al., 2017). Peroxides can accelerate the development of undesirable rancid odors in food products. If the peroxide content in oil exceeds quality standards, it may become toxic and unsuitable for consumption. Peroxides can also destroy certain vitamins in fatty food products, such as vitamins A, D, E, and K (Ketaren, 2008).

Based on the research results, the peroxide values in samples with adsorption times of 1, 2, and 3 days have been statistically tested and presented in Table 4.

Table 4 Peroxide value

Adsorption time	Peroxide value (mek/kg)
Control	9.806 ± 0.003^{a}
1 day	8.390 ± 0.008b
2 days	6.085 ± 0.004^{c}
3 days	5.603 ± 0.005^{d}

Description: Different letter notations indicate significant differences ($p<0.05$)

Based on Table 4, the lowest peroxide value is produced after 3 days of adsorption. The cellulose present in sugarcane bagasse can bind peroxide compounds, aldehydes, and ketones, which are oil decomposition products. These molecules have polar groups that can interact with or bind cellulose in the sugarcane bagasse, which is rich in polar hydroxyl (-OH) groups (Rahayu et al., 2014).

Water Content

One of the determinants of oil deterioration is water content. High water content can accelerate the hydrolysis process of oil. The moisture referred to here is the water that is physically bound to the oil; therefore, water can be separated from the oil by drying it in an

oven at 100–105°C (Suroso, 2013). Based on the research results, the water content in samples with adsorption times of 1, 2, and 3 days has been statistically tested and presented in Table 5.

Table 5 Water content

Adsorption time	Water content (%)
Control	0.10 ± 0.000^{a}
1 day	0.082 ± 0.001^{b}
2 days	0.079 ± 0.005^{c}
3 days	0.070 ± 0.005^{d}

Description: Different letter notations indicate significant differences ($p<0.05$).

Based on Table 5, the lowest moisture content is produced after 3 days of adsorption. Sugarcane bagasse, which contains hygroscopic cellulose (Marwanto, 2017), is optimal for absorbing the water in used cooking oil.

Free Fatty Acid Content

Free fatty acids are non-esterified fatty acids that are not bound as triglycerides. They are produced through hydrolysis and oxidation processes. The hydrolysis reaction is accelerated by the presence of water in fried food. The more frequently cooking oil is used, the higher the free fatty acid content becomes. Based on the research results, the free fatty acid content in samples with adsorption times of 1, 2, and 3 days has been statistically tested and presented in Table 6.

Table 6 Free fatty acid content

Adsorption time	Free fatty acid content (%)
Control	0.19 ± 0.005^{a}
1 day	0.15 ± 0.001b
2 days	0.14 ± 0.000^{c}
3 days	0.13 ± 0.002^{d}

Description: Different letter notations indicate significant differences ($p<0.05$).

Based on Table 6, the lowest free fatty acid content is produced after 3 days of adsorption. The sugarcane bagasse contains cellulose with hydroxyl (-OH) functional groups. The absorption band for the hydroxide (-OH) group in sugarcane bagasse is observed at 3282.99 cm^{-1} (Priyanto et al., 2021). The presence of these hydroxyl functional groups will interact with the free fatty acids in used cooking oil (Wulandari & Dewi, 2019).

Green Chemistry Approach

Green Chemistry, also known as sustainable chemistry, was introduced around two decades ago by Anastas & Warner (1998). It outlines twelve principles to design chemical processes that are inherently safer for human health and the environment. Emphasizing sustainability, Green Chemistry encompasses a wide range of applications, including education, research laboratories, and the chemical industry. The twelve principles of Green Chemistry are: (1) prevention, (2) atom economy, (3) using less hazardous chemical synthesis, (4) designing safer chemicals, (5) selecting safer solvents and auxiliaries, (6) energy efficiency, (7) using renewable feedstocks, (8) reducing derivatives, (9) catalysis, (10) design for degradation, (11) real-time pollution prevention analysis, and (12) inherently safer chemistry for accident prevention (Anastas & Warner, 1998; Listyarini et al., 2019).

Green chemistry focuses on minimizing waste production and represents an innovative approach to safeguarding human health and the environment. It has long been acknowledged that energy conservation and consumption significantly influence environmental well-being. Green chemistry has several advantages, such as providing clean

air for breathing, clean water resources, enhanced worker safety in the chemical industry, significantly less harmful and hazardous food products, and reducing the impact of global warming (Ayalew & Jeevan, 2022).

The choice of sugarcane bagasse as an adsorbent in this study aligns with the principles of green chemistry. Firstly, using sugarcane bagasse as an adsorbent is an effort to reduce agricultural waste. Sugarcane bagasse waste, often considered a by-product with no economic value (Mathivanan & Saranathan, 2015), can be further processed into useful materials. Thus, this research contributes to more sustainable waste management. Secondly, the adsorption process carried out at ambient temperature and pressure without using hazardous chemicals demonstrates this research's commitment to the principles of green chemistry (Slootweg, 2024), which prioritizes energy efficiency and pollution prevention. Using natural adsorbents such as sugarcane bagasse also reduces reliance on synthetic chemicals that often negatively impact the environment.

The adsorption process was carried out at ambient temperature and pressure, which are the conditions of the surrounding environment. These conditions were chosen for several reasons. Firstly, ambient temperature and pressure allow the process to occur naturally without significant additional energy input, thus reducing energy consumption. Secondly, these mild reaction conditions minimize the risk of unwanted side reactions, such as thermal degradation or oxidation, which could reduce the quality of the final product (Mane et al., 2023).

The sugarcane bagasse adsorption method offers a more environmentally friendly alternative than conventional methods. The use of sugarcane bagasse as an adsorbent reduces reliance on synthetic chemicals, produces less waste, and is easier to manage. The saturated sugarcane bagasse waste can be further processed into value-added products such as compost or biomass fuel (Hiranobe et al., 2024). This indicates that this method reduces the amount of waste and provides economic value. The integration of green chemistry in the adsorption of use cooking oil by using sugarcane bagasse is shown in Table 7.

Table 7 Integration of green chemistry in the adsorption of used cooking oil by using bagasse waste

Principles of Green Chemistry	Integration in the Adsorption of Used Cooking Oil by using Bagasse Waste
Waste Prevention (GCP 1)	Utilizing sugarcane bagasse, an agricultural by-product (Liu et al., 2024), to remediate used cooking oil helps minimize waste by repurposing materials that might otherwise be discarded.
Design for Energy Efficiency (GCP 6)	Adsorption processes using bagasse do not require high temperatures or pressure, reducing the overall energy demand of the remediation process. By leveraging the natural adsorptive properties of sugarcane bagasse, the process eliminates the need for external energy-intensive steps, thereby conserving resources (Hameed, 2024) and reducing the carbon footprint.
Use of Renewable Feedstocks (GCP 7)	Sugarcane bagasse is a renewable resource (Syahputra et al., 2020), aligning with relying on sustainable and renewable materials instead of non-renewable alternatives.
Design for Degradation (GCP 10)	This principle applies if the process ensures that the by-products or residual materials from the remediation are biodegradable (Khurshid et al., 2023) and environmentally benign.
Safer Chemistry for Accident Prevention (GCP 12)	Using a non-toxic and readily available material like sugarcane bagasse (Syahputra et al., 2020) reduces potential hazards, making the process safer for handling and less risky for the environment.

We maintain environmental quality by reducing the use of raw cooking oil (Okpo & Edafiadhe, 2024). Untreated cooking oil can contaminate soil, water, and air and disrupt ecosystems. In addition, the open burning of used cooking oil also contributes to increased

greenhouse gas emissions. Therefore, reusing used cooking oil through adsorption is the right step to address environmental problems related to used cooking oil waste.

CONCLUSIONS

The conclusions of this study are as follows: the results of the organoleptic tests for colour and odour indicate that the samples with treatments of 2 and 3 days do not show significant differences. The values obtained are 4.56 and 4.60, respectively, indicating that the panellists liked the colour and odour of the two and 3-day samples. The lowest peroxide value is produced after 3 days of adsorption, measuring 5.603 ± 0.005 meq/kg. The lowest moisture content is obtained after 3 days of adsorption, measuring 0.070 ± 0.005%. The lowest free fatty acid content is produced after 3 days of adsorption, measuring 0.13 ± 0.002%. In conclusion, applying green chemistry principles in the remediation of used cooking oil through sugarcane bagasse adsorption showcases a sustainable, eco-friendly approach. Sugarcane bagasse, an agricultural by-product, reduces waste and repurposes a material with minimal economic value, supporting more sustainable waste management. Conducting the adsorption process at ambient temperature and pressure aligns with green chemistry's focus on energy efficiency, minimizing energy input and reducing the risk of undesirable reactions. This approach avoids hazardous chemicals, lessening environmental impact and reliance on synthetic materials. Additionally, the saturated bagasse can be converted into value-added products like compost or biofuel, enhancing its economic potential and reducing waste. This green approach addresses the environmental concerns of untreated used cooking oil, which can contaminate ecosystems and contribute to greenhouse gas emissions if disposed of improperly. Reusing cooking oil via natural adsorption contributes to environmental quality by preventing soil, water, and air pollution. Overall, this research presents a viable solution to manage used cooking oil waste sustainably, aligning with the broader objectives of Green Chemistry and environmental conservation.

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