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Production of an Adsorbent from Chicken Eggshell Waste for the Purification of Used Cooking Oil

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Abstract

This study aimed to develop an adsorbent derived from chicken eggshell waste for the purification of used cooking oil. Repeated consumption of used cooking oil poses potential health risks due to the accumulation of degradation products; therefore, purification is necessary before further utilization. Chicken eggshells were selected as the raw material because of their high calcium carbonate content and porous structure, which contribute to their adsorption capacity. The preparation of the adsorbent involved carbonization followed by chemical activation using 3 M hydrochloric acid (HCl). The study evaluated the optimal adsorption time and adsorbent dosage for the treatment of used cooking oil. The results demonstrated that the optimum adsorption time was 90 minutes, reducing the free fatty acid (FFA) content from 5.12% to 1.02%, while odor and color intensity decreased by 87%. The optimum adsorbent dosage was 1.5 g, which exhibited the highest effectiveness in improving the quality of the used cooking oil. These findings suggest that eggshell-derived adsorbents offer a sustainable and environmentally friendly approach to managing used cooking oil waste while simultaneously valorizing organic eggshell waste as a low-cost adsorbent material.

Keywords: *Chicken Eggshell Waste, Free Fatty Acids, Sustainable Waste Management, Used Cooking Oil, Waste Valorization.*

Introduction

Cooking oil is an essential household commodity widely used in food preparation, particularly for frying. However, repeated use of cooking oil leads to a gradual decline in its quality, resulting in the formation of used cooking oil (UCO), commonly known as waste frying oil. During repeated heating cycles, various harmful compounds are generated, including free fatty acids (FFAs), peroxides, aldehydes, and free radicals [1]. These compounds are recognized for their toxic and potentially carcinogenic properties, making the consumption of repeatedly used oil a significant health concern. Furthermore, improper disposal of used cooking oil can cause environmental pollution, clog drainage systems, and degrade groundwater quality [2].

Various techniques have been developed to regenerate or purify used cooking oil. However, many of these methods are costly, require sophisticated technology, and may generate secondary environmental impacts [3]. As a result, adsorption has emerged as a promising alternative due to its simplicity, cost-effectiveness, and environmental compatibility. Adsorption is a surface phenomenon in which dissolved substances are retained on the surface of a porous adsorbent material with a large specific surface area [4],[5].

Activated carbon is among the most widely used adsorbents because of its high adsorption capacity and effectiveness in removing undesirable odors, colors, and hazardous chemical compounds. In the present study, chicken eggshell waste was selected as the precursor material for adsorbent production. Eggshells are abundantly available organic waste materials that are often discarded without further utilization. They contain approximately 90–95% calcium carbonate ($CaCO_3$), along with smaller amounts of minerals such as magnesium, iron, and sulfur [6]. This composition makes eggshells a promising and environmentally friendly raw material for adsorbent preparation.

Beyond serving as a natural calcium source, eggshells have been extensively investigated for their adsorption potential. Previous studies have demonstrated the effectiveness of eggshell-based adsorbents in reducing acid value, peroxide value, and moisture content in used cooking oil [1],[2]. Furthermore, Niko et al. [7] reported that the purification of used cooking oil using rice husk charcoal, sugarcane bagasse, and eggshell-based adsorbents produced oil that met the quality requirements specified in the Indonesian National Standard (SNI 7709:2019) for cooking oil.

Unlike previous studies, the present research focuses on the development of an eggshell-derived adsorbent activated with hydrochloric acid (HCl). Chemical activation is expected to enhance the adsorbent's surface characteristics by increasing pore volume and adsorption capacity, thereby improving its ability to remove impurities from used cooking oil. The activation process may also facilitate the exposure of additional active sites that contribute to more efficient adsorption.

This approach is expected to provide a more efficient, economical, and environmentally sustainable method for used cooking oil purification while simultaneously supporting the principles of the circular economy and the Sustainable Development Goals (SDGs) [8]. The utilization of organic waste such as eggshells not only helps mitigate environmental pollution associated with used cooking oil but also creates added value and potential economic opportunities for local communities and small and medium-sized enterprises (SMEs). Therefore, this study aims to determine the optimum contact time and adsorbent dosage of HCl-activated chicken eggshell adsorbent for the purification of used cooking oil.

Materials and Methods

A. Research Method

The study was conducted through a systematic experimental procedure consisting of eggshell charcoal preparation, chemical activation, and evaluation of the adsorbent's effectiveness in removing contaminants from used cooking oil. Experimental data obtained from each stage were analyzed quantitatively to generate objective and verifiable conclusions regarding the adsorption performance of the prepared adsorbent. The eggshell-derived activated carbon used as the adsorbent was produced through a series of dehydration, carbonization, and activation processes. Sample preparation activities were carried out in open areas during the dehydration and carbonization stages, while adsorption experiments and analytical measurements were conducted at the Science Laboratory of Universitas Muhammadiyah Maumere.

B. Materials

The materials used in this study included chicken eggshells, which were cleaned and dried prior to use as the raw material for activated carbon production. Used cooking oil collected from street food vendors in Maumere City, primarily originating from the frying of tofu, tempeh, and bananas, was used as the oil sample for purification. Hydrochloric acid (HCl, 3 M) served as the chemical activating agent during adsorbent preparation. Distilled water (aqua dest.) was used as a solvent and rinsing medium throughout the experimental procedures. Additional chemicals included silver nitrate ($AgNO_3$), which was employed for chloride ion testing, phenolphthalein (PP) indicator for titration and free fatty acid analysis, pH indicator paper for pH determination, and 95% ethanol for cleaning and sterilization purposes. Aluminum foil was used to cover reaction vessels and protect samples during thermal treatment. Laboratory tissues were utilized for cleaning laboratory equipment.

C. Equipment

The equipment employed in this study included an analytical balance for accurate mass measurements, a glass stirring rod for manual mixing, and plastic spatulas for handling solid materials. A magnetic stirrer equipped with a hot plate was used for simultaneous heating and agitation of samples. An electric oven was utilized for moisture removal and drying processes. Glassware included 100-mL Erlenmeyer flasks for reaction vessels, 100-mL beakers for sample preparation and testing, 100-mL volumetric flasks for solution preparation and dilution, glass funnels for filtration procedures, and watch glasses for sample weighing and vessel covering. Porcelain mortars and pestles were used to grind eggshell charcoal into fine powder, while a 200-mesh sieve was employed to obtain a uniform particle size. Filter paper (Whatman No. 42 or equivalent) was used to separate solid and liquid phases during filtration. A metal container fabricated from a recycled biscuit tin was used as a simple pyrolysis reactor during the carbonization process for activated carbon production.

Results

A. Preliminary Treatment of Chicken Eggshells

Chicken eggshells were processed through drying, carbonization, and chemical activation to produce activated carbon for adsorption experiments. From an initial mass of 500 g of eggshells, 300 g of charcoal was obtained after carbonization. Subsequently, 50 g of charcoal was chemically activated using 3 M HCl, resulting in 16.15 g of activated carbon after washing and drying. The moisture content analysis showed a value of 6.50%, indicating that the activated carbon had a sufficiently low water content for adsorption applications.

Table 1 presents the mass of eggshell material measured before and after treatment, illustrating changes in sample mass resulting from the treatment process and providing a basis for comparison.

Table 1. Mass of eggshell material before and after treatment

Treatment	Before Treatment (g)	After Treatment (g)	Mass Reduction (%)
Charcoal production	500.00	300.00	40.00
Charcoal activation	50.00	16.15	67.70
Moisture content test	16.15	15.10	6.50

A substantial reduction in mass was observed during both carbonization and activation processes.

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B. Organoleptic Properties of Used Cooking Oil

Changes in the physical characteristics of used cooking oil were evaluated through organoleptic observations of color and odor before and after adsorption treatment. The results showed that increasing the contact time and adsorbent dosage improved the physical quality of the oil. The treated oil appeared clearer and exhibited a noticeable reduction in rancid odor intensity. Fig. 1 shows the effect of contact time on the organoleptic properties of used cooking oil, indicating improved clarity and reduced rancid odor, with optimal results at 90 minutes.

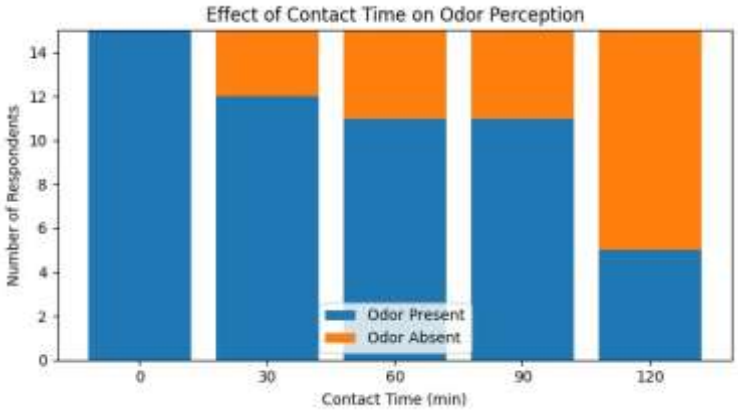


Fig. 1. Effect of contact time on the organoleptic properties of used cooking oil as evaluated by 15 respondents. Increasing contact time improved oil clarity and reduced rancid odor, with the best performance observed at 90 min.

Fig. 2 shows the effect of adsorbent dosage on used cooking oil quality, with increasing dosage improving appearance and reducing odor, and the best results obtained at 1.5 g.

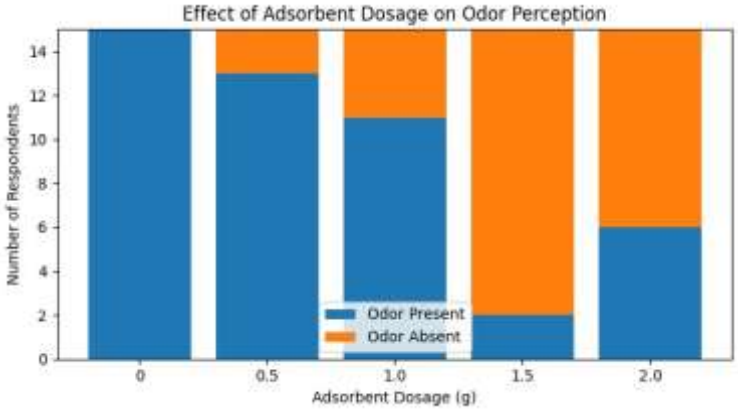


Fig. 2. Effect of adsorbent dosage on the organoleptic properties of used cooking oil as evaluated by 15 respondents. The greatest improvement in oil appearance and odor reduction was obtained using 1.5 g of adsorbent.

The greatest improvement in organoleptic quality was observed at a contact time of 90 min and an adsorbent dosage of 1.5 g.

C. Effect of Contact Time on Free Fatty Acid Content

Fig. 3 shows the effect of contact time on free fatty acid (FFA) content of used cooking oil. FFA content decreased continuously from 5.12% to 1.02% as contact time increased to 90 min. A slight

increase was observed at 120 min, indicating that adsorption equilibrium had been reached. The optimum contact time was 90 min.

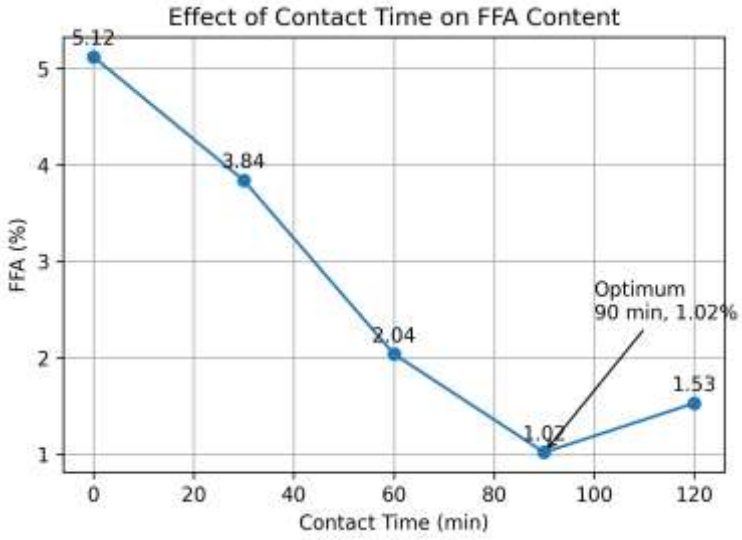


Fig. 3. Effect of Contact Time on Free Fatty Acid (FFA) Content

The FFA content decreased progressively with increasing contact time from 0 to 90 min, reaching a minimum value of 1.02%. At 120 min, the FFA content increased slightly to 1.53%.

D. Effect of Adsorbent Dosage on Free Fatty Acid Content

Fig. 4 shows the effect of adsorbent dosage on free fatty acid (FFA) content of used cooking oil. Increasing adsorbent dosage significantly reduced FFA content up to 1.5 g. Beyond this dosage, a slight increase in FFA content was observed, suggesting saturation of available adsorption sites. The optimum adsorbent dosage was 1.5 g.

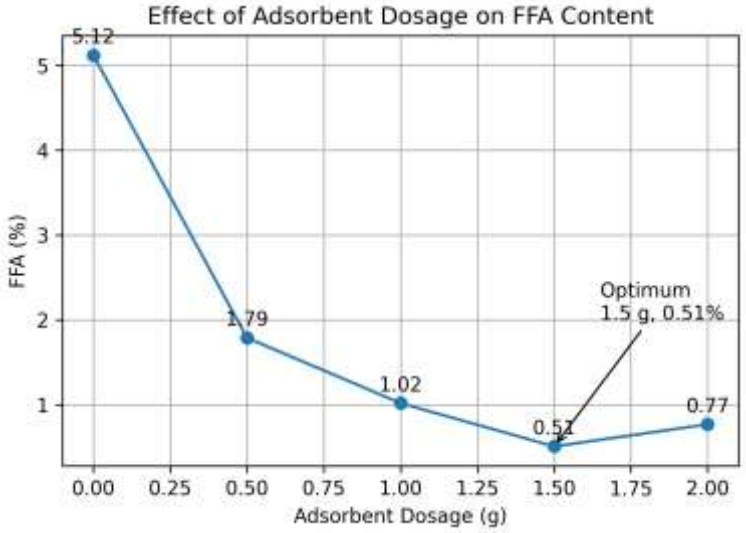


Fig. 4. Effect of Adsorbent Dosage on Free Fatty Acid (FFA) Content

The lowest FFA content (0.51%) was obtained using 1.5 g of adsorbent. A slight increase in FFA content was observed when the dosage was increased to 2.0 g.

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Discussion

A. Characteristics of Eggshell-Derived Activated Carbon

The substantial mass loss observed during carbonization and activation indicates the removal of moisture, volatile compounds, and organic constituents from the eggshell structure. Chemical activation using HCl likely dissolved mineral impurities and opened additional pores within the adsorbent matrix, thereby increasing the available surface area for adsorption. The moisture content of 6.50% suggests that the activated carbon possessed adequate dryness and pore accessibility, which are important factors influencing adsorption efficiency [9].

Chicken eggshells contain high concentrations of calcium carbonate ($CaCO_3$), which contributes to their adsorption potential. Gautron et al. [6] reported that eggshells consist predominantly of calcium carbonate and possess a unique biomineralized structure that can support adsorption processes. Furthermore, chemical activation using hydrochloric acid has been shown to enhance the physicochemical properties of adsorbent materials by increasing pore development and exposing active adsorption sites [10].

B. Improvement of Organoleptic Properties

The observed reduction in odor intensity and improvement in oil clarity indicate that the activated carbon successfully removed volatile degradation products and colored compounds generated during repeated frying cycles. Used cooking oil contains oxidation products, polymerized compounds, and residual food particles that contribute to undesirable color and odor characteristics [11].

The progressive improvement in organoleptic quality with increasing contact time and adsorbent dosage suggests that a larger number of active sites became available for contaminant adsorption. The optimum condition identified in this study (90 min and 1.5 g adsorbent) produced the most favorable sensory characteristics, indicating effective contaminant removal.

These findings are consistent with previous studies reporting that eggshell-based adsorbents can improve the physical quality of used cooking oil. Rahman et al. [1], Azizanie et al. [2], and Pardede and Mularen [4] similarly reported reductions in undesirable color and odor following treatment with eggshell-derived adsorbents. Comparable improvements have also been observed using activated carbon derived from coconut shell charcoal [12].

C. Effect of Contact Time on FFA Reduction

The reduction in FFA content with increasing contact time demonstrates the effectiveness of the adsorption process. During the initial adsorption stage, numerous active sites are available on the adsorbent surface, allowing rapid adsorption of free fatty acids and other polar compounds. As contact time increases, contaminants diffuse into the pore structure and become attached to active adsorption sites, thereby reducing the FFA concentration in the oil.

The optimum contact time was observed at 90 min, where FFA content decreased from 5.12% to 1.02%, corresponding to approximately 80.1% removal efficiency. This result confirms that eggshell-derived activated carbon can effectively adsorb free fatty acids from degraded cooking oil. Similar reductions in acid value and FFA content have been reported by Rahman et al. [1], Azizanie et al. [2], and

Niko et al. [7], who found that eggshell-based adsorbents significantly improved the chemical quality of used cooking oil.

However, extending the contact time to 120 min resulted in a slight increase in FFA concentration. This phenomenon may be associated with adsorption equilibrium, whereby the rate of adsorption becomes equal to the rate of desorption. Under prolonged contact conditions, previously adsorbed molecules may detach from the adsorbent surface, reducing overall removal efficiency. Similar adsorption behavior has been reported in studies investigating adsorption isotherms and equilibrium phenomena during FFA removal from used cooking oil [13].

D. Effect of Adsorbent Dosage on FFA Reduction

Increasing adsorbent dosage from 0.5 g to 1.5 g substantially improved FFA removal due to the greater availability of adsorption sites and larger effective surface area. The highest adsorption efficiency was achieved at 1.5 g, resulting in a reduction of FFA content to 0.51%, corresponding to approximately 90.0% removal efficiency.

The slight increase in FFA content observed at a dosage of 2.0 g suggests that adsorption efficiency does not increase indefinitely with adsorbent mass. Excessive adsorbent loading may promote particle agglomeration, reducing the effective surface area available for adsorption and limiting mass transfer between the oil and adsorbent particles. Consequently, additional adsorbent does not necessarily translate into improved purification performance.

Similar trends have been reported in previous studies utilizing eggshell-derived adsorbents [1],[2],[4]. In adsorption systems, an optimum dosage is commonly observed because the available contaminants become insufficient to occupy all active adsorption sites when excessive adsorbent is added [5].

E. Implications for Sustainable Waste Management

The results demonstrate that HCl-activated chicken eggshells can serve as an effective low-cost adsorbent for the purification of used cooking oil. This finding is consistent with previous studies demonstrating the potential of natural and eggshell-based adsorbents for improving the physicochemical quality of used cooking oils [14], [15]. The optimum operating conditions identified in this study were a contact time of 90 min and an adsorbent dosage of 1.5 g. The importance of these operating parameters is supported by previous adsorption studies showing that contact time and adsorbent dosage significantly influence the removal of free fatty acids and other impurities from used cooking oil [16], [17]. Under these conditions, substantial reductions in FFA content were achieved together with significant improvements in color and odor characteristics.

From an environmental perspective, the utilization of eggshell waste as an adsorbent contributes to waste valorization and supports circular economy principles. The conversion of discarded eggshells into functional materials for fatty acid removal has also been demonstrated as a sustainable approach to waste management and resource recovery [18]. This approach simultaneously addresses two waste streams—discarded eggshells and used cooking oil—while producing a value-added material for environmental remediation applications. Similar waste-to-resource strategies have been highlighted as economically and environmentally beneficial in studies on waste oil recycling and sustainable waste

management [8], [14]. Furthermore, the utilization of used cooking oil through purification and recycling pathways can reduce environmental pollution associated with improper disposal practices [3].

Overall, the findings of this study reinforce previous evidence that eggshell waste is a promising adsorbent material for used cooking oil treatment while contributing to sustainable resource utilization and environmental protection [7], [15], [18].

Conclusion

This study successfully demonstrated the potential of chicken eggshell waste as a raw material for producing activated carbon adsorbents for the purification of used cooking oil. The preparation process, involving carbonization followed by chemical activation with 3 M HCl, produced an adsorbent with a moisture content of 6.50%, indicating its suitability for adsorption applications.

The adsorption experiments revealed that both contact time and adsorbent dosage significantly influenced the quality of the purified oil. The optimum contact time was 90 min, reducing the free fatty acid (FFA) content from 5.12% to 1.02%, while the optimum adsorbent dosage was 1.5 g, resulting in the lowest FFA content of 0.51%. In addition to improving the chemical quality of the oil, the adsorbent effectively enhanced its organoleptic properties by reducing rancid odor and improving color clarity.

These findings indicate that HCl-activated eggshell-derived activated carbon is an effective, low-cost, and environmentally friendly adsorbent for the treatment of used cooking oil. Furthermore, the utilization of eggshell waste contributes to waste valorization, supports circular economy principles, and offers a sustainable approach to addressing both organic waste accumulation and used cooking oil pollution. Future studies are recommended to investigate the adsorption kinetics, surface characteristics, and reusability of the adsorbent to further optimize its practical application.

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