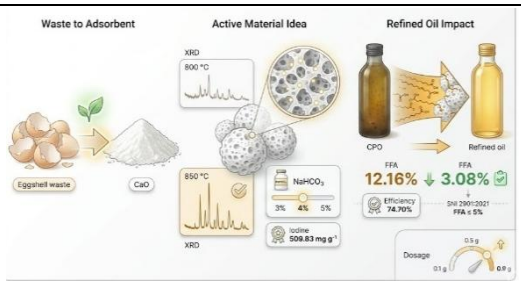
*JKPK (Jurnal Kimia dan Pendidikan Kimia),* Vol. 10, No. 3, 2025 pp. 628-641
Chemistry Study Program, Universitas Sebelas Maret ISSN 2503-4146
http://jurnal.uns.ac.id/jkpk ISSN 2503-4154 (online)

# Adsorption of Free Fatty Acids in Crude Palm Oil (CPO) Using Chicken Egg Shells

**Marsela, Adhitiyawarman*, Anthoni Batahan Aritonang**

*Department of Chemistry, Faculty of Mathematics and Natural Sciences, Universitas Tanjungpura, Pontianak, Indonesia*

## ABSTRACT




Chicken eggshell waste represents an abundant biomineral resource that can be converted into calcium oxide (CaO) to provide a low cost and environmentally friendly adsorbent for crude palm oil (CPO) refining. This study examined the effects of calcination temperature (800 and 850 °C), sodium bicarbonate ($NaHCO_3$) activator concentration (3, 4, and 5%), and adsorbent mass (0.1, 0.5, and 0.9 g) on the adsorption of free fatty acids (FFA) from CPO. Eggshell derived CaO was produced by calcination and chemical activation, and phase formation was verified using X ray diffraction (XRD). Adsorbent quality was screened using iodine adsorption capacity, which peaked at 509.83 mg/g for CaO activated with 4% $NaHCO_3$. XRD patterns showed that calcination at 850 °C yielded more crystalline CaO than calcination at 800 °C, supporting selection of 850 °C for subsequent activation and adsorption tests. Batch adsorption demonstrated that higher adsorbent dosage increased FFA removal, with 0.9 g providing the best performance. Under the optimum condition, FFA decreased from 12.16% to 3.08%, corresponding to 74.70% adsorption efficiency and meeting the Indonesian standard SNI 2901 2021 (maximum FFA 5%). These findings highlight chicken eggshell derived CaO as a promising, waste based substitute for commercial adsorbents in sustainable CPO purification.

**Keywords:** *Free Fatty Acids; Crude Palm Oil; Chicken Egg Shells; Calcination; Adsorption; Waste Utilization.*

**Corresponding Author:* adhitiyawarman@chemistry.untan.ac.id

**How to cite:** Marsela, Adhitiyawarman and A. B. Aritonang, "Adsorption of Free Fatty Acids in Crude Palm Oil (CPO) Using Chicken Egg Shells," *JKPK (Jurnal Kimia dan Pendidikan Kimia)*, vol. 10, no. 3, pp. 628-641, 2025. [Online]. Available: https://doi.org/10.20961/jkpk.v10i3.109240

***Received:*** *2025-09-22* ***Accepted:*** *2025-12-12* ***Published:*** *2025-12-31*

## INTRODUCTION

Palm oil is a major source of high-value vegetable oil and is widely used by industry and society. Palm oil consists of Crude Palm Kernel Oil (CPKO) from the kernel of the fruit and Crude Palm Oil (CPO) from the flesh of the fruit [1]. CPO is the main raw material for cooking oil because it contains α- and β-carotene compounds, as well as antioxidants such as tocopherol and tocotrienol [2]. CPO contains 93% triglycerides, 4.5% diglycerides and 0.9% monoglycerides. CPO also contains impurities such as free fatty acids, gums, phospholipids and glycolipids [3]. The content of free fatty acids in the oil indicates the level of damage to the oil due to the breakdown of triglycerides and oxidation of fatty acids [4]. The main problem with CPO is the high FFA content which often exceeds the SNI, while the use of eggshells as an adsorbent is not optimal [5], and increase cholesterol and heart disease [6]. The

Indonesian National Standard (SNI) 2901-2021 sets a maximum FFA limit of 5%.

The reduction of free fatty acid levels in CPO uses an adsorption method utilizing calcined chicken eggshells as an adsorbent to bind FFA molecules, thereby reducing their levels. Chicken eggshells are abundant as organic waste, but their potential for sustainable waste management remains underdeveloped. The use of eggshells as an adsorbent is highly economical due to their high calcium carbonate ($CaCO_3$) content, reaching 98.41%, magnesium carbonate ($MgCO_3$) (0.84%), and calcium phosphate ($Ca(PO_4)_2$) (0.75%) [7]. Calcium carbonate has a porous structure that is effective in attracting pollutants, such as those in CPO oil, making it an efficient adsorbent [8].

Chicken eggshells calcined at high temperatures have been shown to produce high levels of CaO with a stable crystalline structure [9–10]. The calcination process also forms abundant pores, thereby increasing the surface area of the adsorbent [11]. Further activation through heating can improve pore characteristics and increase material reactivity [12]. CaO has a hexagonal crystal structure that allows interaction with ions such as $H^+$ and $Na^+$ [13][14], making it effective for reducing free fatty acid (FFA) levels in CPO and other oils [13-15].

Chemical activation contributes to pore cleaning and surface modification, which can increase adsorption capacity. Sodium bicarbonate ($NaHCO_3$) is a promising activator because it releases $CO_2$ during heating and is considered more environmentally benign than many conventional activating agents. A previous study using $NaHCO_3$ activation on coconut shell based activated carbon reported optimal performance at 4% activator concentration, producing iodine adsorption capacity of 437.07 mg/g and methylene blue adsorption capacity of 734.5 mg/g, along with Pb(II) removal efficiency of 99.01% [16]. Limited studies have systematically evaluated the combined influence of calcination temperature, $NaHCO_3$ activation, and adsorbent mass on FFA adsorption from CPO, indicating the need for further investigation.

The study used chicken eggshells as an adsorbent with the aim of determining the effect of calcination temperature (800–850°C), $NaHCO_3$ activation (3–5%), and adsorbent mass (0.1–0.9 gram) on FFA adsorption. Chicken eggshells after calcination were tested with X-ray Diffraction (XRD) to determine the crystal structure, crystal phase and composition in chicken eggshells and Gas Sorption Analyzer (GSA) characterization to determine the pore volume, specific surface area, and pore size distribution after activation. This research contributes to the development of environmentally friendly adsorbents based on biomineral waste to improve the quality of CPO

## METHODS

The research methods section begins with an explanation of the general process flow, including material preparation, calcination, activation, characterization (XRD and GSA), CPO preparation, initial FFA measurement, adsorption process, and final FFA measurement. This study used a

laboratory experimental design with three treatment variables: calcination temperature (800°C and 850°C), $NaHCO_3$ activator concentration (3%, 4%, and 5%), and variations in adsorbent mass (0.1, 0.5, and 0.9 g). This design clarification provides a clear methodological context before the technical procedures are explained in detail.

**1. Materials and Equipment**

The materials used in this study include distilled water ($H_2O$), 85% phosphoric acid ($H_3PO_4$), chicken eggshells, crude palm oil (CPO), 96% ethanol ($C_2H_5OH$), 1% thymolphthalein indicator (TP), iodine ($I_2$), filter paper, potassium iodide (KI), sodium bicarbonate ($NaHCO_3$), sodium hydroxide (NaOH) 0.1 N, and sodium thiosulfate ($Na_2S_2O_3$).

The tools used in this study include pestles, sieves (100 mesh), stirring rods, bulbs, burettes, spray bottles, petri dishes, separating funnels, Erlenmeyer flasks, furnaces, beakers, hotplates, universal pH paper, filter paper, clamps, magnetic stirrers, mortars, analytical balances, ovens, measuring pipettes, stands, thermometers, X-Ray Diffraction (XRD) and Gas Sorption Analyzers (GSA).

**2. Chicken Eggshell Preparation**

Chicken egg shells are obtained from egg martabak traders. Preparation begins with washing the chicken eggshells with clean water and then soaking them in water for 24 hours. The membrane layer is separated and rinsed again with distilled water, then dried at room temperature [17]. The dried chicken eggshells are then ground using a mortar and pestle, then sieved to a particle size of 100 mesh [10][18]. Calcination is carried out in a furnace at 800°C and 850°C for 4 hours. Afterward, they are placed in a desiccator and characterized using X-Ray Diffraction (XRD).

**3. Adsorbent Activation**

Twenty grams of CaO adsorbent is soaked in sodium bicarbonate (NaHCO3) activator (3%, 4%, and 5%) for 24 hours, then filtered. The resulting residue was then washed with distilled water (pH=7), then oven-dried for 3 hours at 105°C [16]. The activated adsorbent was then characterized using a Gas Sorption Analyzer (GSA) (full isothermal 20 pts).

**4. Iodine Absorption Test (SNI 06-3730-1995)**

The test was carried out by weighing 1 gram of $NaHCO_3$ activated CaO adsorbent (3%, 4% and 5%) each. CaO was then mixed with 25 mL of 0.125 N iodine solution, then homogenized and stored in a closed and dark place, then left for 2 hours and filtered. 10 mL of the filtered filtrate was taken and titrated with 0.125 N sodium thiosulfate solution. Titration was carried out until a faint yellow solution was formed, then 1% starch indicator was added and titrated again until the blue color became clear [19]. The same thing was done for the $NaHCO_3$ activated adsorbent. The calculation formula for iodine absorption capacity can be seen in equation 1 [19].

$$DSI = \frac{\left(\frac{A-B}{n} \times N\ Na_2S_2O_3 \times 126{,}93 \times fp\right)}{a} \quad (1)$$

Description:

DSI = iodine adsorption capacity ($I_2$)

a = mass of adsorbent
n = reactant valence
A = volume of iodine solution (mL)
B = volume of $Na_2S_2O_3$ used (mL)
N (iodine) = iodine concentration (N)
N ($Na_2S_2O_3$) = concentration of $Na_2S_2O_3$ (N)
Fp = dilution factor
126.93 = Amount of iodine per mL of $Na_2S_2O_3$

**5. Crude Palm Oil (CPO) Preparation**

CPO is obtained from PT. Gunung Rinjuan Sejahtera in raw condition without any pre-treatment. CPO first undergoes a degumming process to remove gums or slime (phospholipids and other impurities). The degumming process begins by heating 1 kg of CPO on a hotplate to 100°C. 85% phosphoric acid ($H_3PO_4$) at 0.1% w/w is added to the CPO with stirring for 20 minutes. The CPO is then filtered to separate the gums. Next, 2M NaOH is added to the CPO for neutralization. The mixture is heated to 75°C for 20 minutes. The CPO is filtered again and washed with warm water (60°C). The oil is oven-dried for 2 hours at 105°C [20].

**6. Standardization of NaOH Solution with Oxalic Acid**

10 mL of oxalic acid is pipetted into an Erlenmeyer flask. 3 drops of 1% phenolphthalein indicator were added, then titrated with NaOH solution until the solution turned pink [21]. Triplo treatment.

**7. Free Fatty Acid Testing (before adsorption)**

CPO is weighed as much as ±2.5 grams and put into in Erlenmeyer flask, then 50 mL of 95% neutral ethanol was added. The mixture was heated above hotplate for ±15 minutes, then added 3 drops of indicator 1% thymolphathalein, then titrated with 0.1 N NaOH solution, until color solution changed become blue young. Treatment triplo (SNI 2901-2021).

**8. Adsorption of Free Fatty Acids on Variations in Adsorbent Mass**

Adsorption process started with add as much as 10 grams of CPO then poured to in beaker glass. Variations mass adsorbent used namely 0.1; 0.5 and 0.9 grams. CPO then mixed with adsorbent in each variation mass. CPO is stirred with speed of 300 rpm for 2 hours and filtered. Treatment triplicate.

**9. Determination of Free Fatty Acid Levels (after adsorption)**

CPO of ± 2.5 grams is put into in 250 mL Erlenmeyer flask, then added 50 mL of 95% neutral ethanol. Mixture the heated on hotplate for ± 15 minutes, then added 3 drops of indicator 1% thymolphathalein then titrated with 0.1 N NaOH, until color solution changed become blue young. Free fatty acid levels were calculated use equation 2 as following (SNI 2901-2021):

$$\%FFA = \frac{256 \times V \times N}{W \times 1000} \times 100\% \quad (2)$$

Description:

W = mass sample (g)
V = titration volume of NaOH (mL)
N = normality of NaOH (N)
256 = Specific gravity oil is counted as sour palmitate (g/mL)

Capacity adsorption counted use equation 3 and efficiency adsorption counted use equation 4.

$$Q = \frac{(Co - Ci) \times V}{W_{adsorben}} \quad (3)$$

$$\%\text{Adsorption efficiency} = \frac{(Co - Ci)}{Co} \times 100\% \quad (4)$$

Description:

Q = capacity adsorption (mg/g)
V = volume of NaOH solution (L)
$C_i$ = final FFA concentration (mg/L)
$C_o$ = initial FFA concentration (mg/L)
W = mass adsorbent (g)

%FFA is used to compare free fatty acid levels before and after adsorption. Adsorption capacity indicates the amount of FFA that can be bound per gram of adsorbent. Adsorption efficiency is calculated to determine the percentage of FFA reduction. All calculations use the average data from three replicates (triplicates).

## RESULTS AND DISCUSSION

### 1. Making Adsorbent Shell Chicken eggs

Calcination process functioning for decompose calcium carbonate ($CaCO_3$) becomes calcium oxide (CaO) which is marked with change color powder become white [12]. As shown in Figure 1, the powders calcined at 800°C and 850°C both became white, confirming $CaCO_3$ decomposition. The sample treated at 850°C appears more uniformly white, suggesting a more complete conversion and fewer residual components. Literature also reports that eggshell derived CaO requires temperatures above 800°C for proper calcination and effective formation of the CaO active phase. The calcination process is also accompanied by with release compound organic and $CO_2$ gas accordingly reaction [22].

$$CaCO_{3(s)} \rightleftharpoons CaO_{(s)} + CO_{2(g)}$$

(a) (b)

**Figure 1**. Adsorbent results calcination temperature 800ºC (a) adsorbent results calcination temperature 850ºC(b)

**Table 1**. Yield CaO adsorbent at temperatures of 800°C and 850°C

| Temperature (ºC) | Yield (%) |
|---|---|
| 800°C | 91.4 |
| 850°C | 95.1 |

Based on Table 1 it is obtained CaO yield calcination at 850° C ie as big as 95.1% more tall compared to a temperature of 800°C of 91.4%. Increase This caused by decomposition $CaCO_3$ which takes place more perfect at temperature high, so that content $CaCO_3$ remaining and compound hydrate like $Ca(OH)_2$ decreases in a way significant. Thermal energy at a temperature of 850°C also accelerates release compound

organic and $CO_2$, producing CaO with purity more high [23]. This result in line with literature that reports that improvement temperature calcination enlarge pores, increase wide surface, and optimize characteristic adsorptive CaO. With Thus, the condition calcination at 850°C has the potential produce more adsorbent effective for the adsorption process next [24].

**2. X-Ray Diffraction (XRD) Characterization**

Characterization *X-Ray Diffraction* (XRD) aims for identify phase crystals and levels crystallinity from a material with utilise X-rays [25]. In the study This XRD analysis was performed to shell egg chicken results calcination at temperatures of 800ºC and 850ºC, which aims to for know change phase compounds that occur consequence treatment thermal.

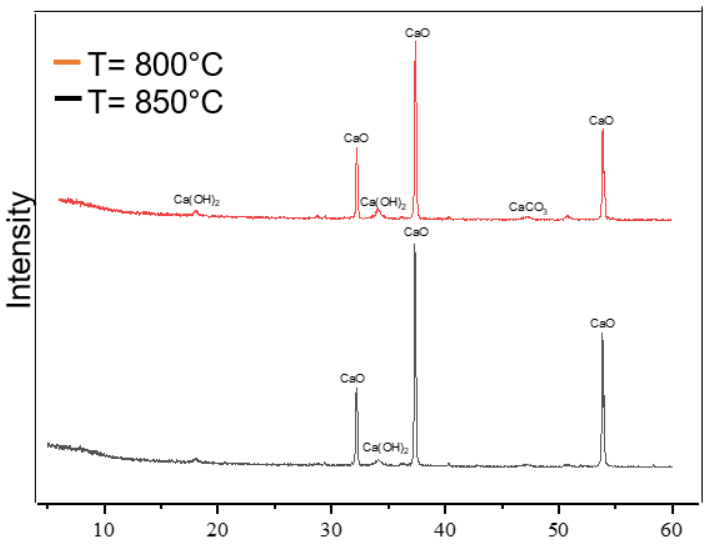



**Figure 2.** XRD pattern of the shell egg chicken at temperature calcination 800°C and 850°C

Based on results XRD analysis in Figure 2, shell egg chicken results calcination show pattern diffraction with sharp peaks. At 850°C , identified three peak The main angles are at 2θ = 32.2°; 37.4°; and 53.9°, while at 800°C they are at 2θ = 32.2°; 37.3°; and 53.9°. The three peak This in accordance with ICDD data and indicates existence phase crystal calcium oxide (CaO) with orientation planes (111), (200), and (220) which have structure cubic centered face (FCC). However, at a temperature of 800°C, it is still detected minor peak around 2θ≈ 47° which indicates existence remainder phase $CaCO_3$, as well as peaks at 18° and 34° which indicate formation calcium hydroxide [$Ca(OH)_2$] due to characteristic hygroscopic CaO which absorbs water vapor during cooling or storage sample. At 850°C, the peak $CaCO_3$ no again detected, indicating almost complete decomposition perfect. Although this, the peak at 2θ ≈ 34° is still present. appear with intensity low, indicating existence [$Ca(OH)_2$] in amount small.

This result in line with literature that reports that peak CaO diffraction is located at

angles 2θ= 32.26°; 37.41°; 53.90°; 64.20°; 67.43°; 79.71°; and 88.57° [26], while peak $CaCO_3$ is at 29.4°; 39.5°; 43.2°; and 47.5° [27]. The peaks CaO diffraction at 37°; 53°; 64°; 67°; 79°; 88°; and 91°, as well as peak $Ca(OH)_2$ at 18° and 34° [10]. Peak CaO diffraction is also present in angle 2θ= 32°; 37.4°; 53.8°; 64.1°; and 67.3°, as well peak $CaCO_3$ at angles 2θ= 29.5°; 39°; 43.2°; 47°; and 48° [9]. Intensity higher peaks taller and taller sharp at 850°C shows crystallinity and purity the higher CaO phase good compared to a temperature of 800°C.

## 3. Activation Adsorbent

Based on results XRD analysis, optimum calcination temperature used for activation adsorbent is 850°C. Activation done use sodium bicarbonate solution ($NaHCO_3$) with variation concentrations of 3 %, 4%, and 5%. $NaHCO_3$ is compound inorganic shaped powder white with mass molecules of 84 g/mol, were obtained from sodium carbonate reaction with $CO_2$ gas and will decompose become $Na_2CO_3$ and $CO_2$ when heated [28]. Selection $NaHCO_3$ is based on its friendly nature environment as well as his abilities releases $CO_2$ when react with distilled water, which can help formation pores on the surface adsorbent [16].

Activation process done with soak adsorbent in solution $NaHCO_3$ for 24 hours, then filtered for separate solids. Activation This aim for increase porosity and area CaO surface through release of $CO_2$ which can remove dirt and open pores, at the same time give source carbon addition. The resulting residue then wash it with distilled water (pH=7) for remove remaining $NaHCO_3$ that has not been react and neutralize the surface. The adsorbent is dried to in the oven for 3 hours at 105°C for remove level the water [16].

## 4. Iodine Absorption Test

The iodine test is used for determine ability beginning adsorbent in absorb substance, where the value tall signify wide surface and effectiveness greater adsorption big [29].

**Table 2**. The forces iodine absorption

| The concentration of $NaHCO_3$ (%) | The mean DSI (mg/g) |
|---|---|
| 3 | 406.23 |
| **4** | **509.83** |
| 5 | 503.32 |

Based on Table 2, the power test results highest iodine absorption found in the activator $NaHCO_3$ concentration of 4% is 509.83 mg/g. Capacity adsorbent in adsorption of iodine increases along with big wide the surface. High iodine absorption capacity show ability greater adsorption big [29]. Highest value namely in this 4% $NaHCO_3$ show that activator the own wide optimum surface and porosity so that effective used For stage adsorption to free fatty acids. High mark power Iodine absorption in $NaHCO_3$ 4% shows condition effective activation in form structure pore open and active, whereas decrease in concentration of 5% possible caused by the closure part pore consequence residue excessive activator [29] [30]. These results in line with theory that success of the activation process No only influenced by the type activator, but also the optimum concentration that can produce wide surface maximum without cause damage or blockage pores.

### 5. Gas Sorption Analyzer (GSA) Characterization

Analysis results use The *Gas Sorption Analyzer* presented in Table 3 shows characteristics wide surface area, total pore volume, and average pore diameter.

**Table 3.** Characterization Results Shell Chicken Eggs with *Gas Sorption Analyzer* (GSA)

| Surface area BET specific ($m^2/g$) | Total pore volume (cc/g) | Average pore diameter (nm) |
|---|---|---|
| 16.24 | 0.05 | 5.96 |

Based on results analysis Gas Sorption Analyzer (GSA) in Table 3, the CaO adsorbent derived from from shell egg chicken and calcined at 850°C for 4 hours as well activated with sodium bicarbonate ($NaHCO_3$) 4% has wide surface of 16.24 m²/g, total pore volume of 0.05 cc/g, and average pore diameter of 5.96 nm. Characteristics This show that the material classified as to in mesoporous (2–50 nm). These characteristics indicate that this material is mesoporous, which provides more active sites for CaO–FFA interactions. The larger the surface area, the more effective the adsorption process. Compared with a number of study previously, value wide the surface obtained classified as morehigh, namely 4.6 m²/g and pore volume of 0.03 cm³/g [31], as well as wide surface that only reached 3.26 m²/g in the sample without treatment beginning [32].

Difference results this is greatly influenced by the method preparation. Research Zabeti et al., (2010) succeeded get wide surface of 39.2 m²/g through combination washing acid, calcination gradual, and impregnation metal for modify morphology pores [33]. While that, Minakshi et al., (2019) reported that calcination at 600°C for 3 hours produced wide surface area of 21.95 m²/g, pore volume of 0.06 cm³/g, and pore diameter of 10.35 nm. However, the increase temperature calcination up to 900°C actually lower wide surface to 10.07 m²/g, pore volume 0.04 cm³/g, and pore diameter 8.68 nm. These results show that temperature calcination and treatment the beginning is very influential in determine characteristics texture surface CaO [34].

### 6. Preparation Of Crude Palm Oil (CPO)

The reduction of free fatty acid (FFA) levels in crude palm oil (CPO) was performed using an adsorption method, preceded by an initial purification step consisting of degumming and neutralization. The overall pretreatment workflow prior to adsorption is presented in Figure 3.

(a) (b)

**Figure 3.** CPO before degumming(a) CPO after degumming(b)

The degumming step was conducted to remove gums or latex containing phosphatides, water, carbohydrates, proteins, and fine particles that can reduce oil stability and negatively affect adsorbent performance [35]. In this study, degumming was carried out by heating 1 kg of CPO to 100°C, followed by the addition of 0.7 mL of 85% $H_3PO_4$ under continuous stirring for 20 minutes. Phosphoric acid promotes gum precipitation by converting phosphatides into a form that is more readily associated with the aqueous phase, thereby facilitating separation [36]. The oil was then filtered to remove the dark-colored gum that accumulated at the bottom.

After degumming, neutralization was performed using a 2 M NaOH solution to further reduce the FFA content. The reaction between NaOH and FFAs produces soap through saponification, resulting in phase separation into neutral oil in the upper layer and soapstock in the lower layer [37]. The mixture was heated at 75°C for 20 minutes to break the emulsion. The oil was subsequently filtered and washed with warm water (60°C). The process was completed by drying the oil in an oven for 2 hours at 105°C to evaporate residual moisture [20]. The purified CPO was then analyzed for its FFA content as the baseline value before the adsorption stage.

### 7. Free Fatty Acid Testing on CPO (before adsorption)

Alkalimetric titration of CPO prior to the adsorption stage showed an average NaOH titration volume of 12.03 mL. Based on the calculation of free fatty acid (FFA) content using palmitic acid as the reference, the CPO exhibited an average FFA value of 12.16%, as summarized in Table 4. This value substantially exceeds the maximum limit specified in SNI 2901:2021 (≤ 5%), indicating that the oil quality does not meet the required standard.

**Table 4.** Results of free fatty acid test before adsorption

| Repetition to - | CPO mass (g) | Normality of NaOH | Titration volume (mL) | Free fatty acids (%) | Average free fatty acids (%) |
|---|---|---|---|---|---|
| 1 | 2.5 | | 12.1 | 12.23 | |
| 2 | 2.5 | 0.0987 | 12 | 12.13 | 12.16 |
| 3 | 2.5 | | 12 | 12.13 | |

The high FFA content suggests significant oil degradation, which is commonly associated with triglyceride hydrolysis and fatty acid oxidation processes [4]. In the alkalimetric method, a larger NaOH volume is required when more fatty acids are present to be neutralized. Therefore, the relatively high titration volume observed in this study directly reflects the elevated FFA concentration in the CPO [38].

### 8. Results of Free Fatty Acid Adsorption on Variations in Adsorbent Mass

Free fatty acid (FFA) adsorption from CPO was evaluated by varying the adsorbent mass (0.1, 0.5, and 0.9 g). The optimum adsorption time was fixed at 120 min, following the conditions reported by Almahibi et al. [8].

**Table 5.** Adsorption results use variation mass adsorbent

| Mass of adsorbent (g) | Initial FFA (%) | Final FFA (%) | Capacity adsorption (mg/g) | Efficiency adsorption (%) |
|---|---|---|---|---|
| 0.1 | | 9,16 | 2991.1 | 24,66 |
| 0.5 | 12,16 | 6,16 | 1200.7 | 49,21 |
| 0.9 | | 3,08 | 1009.2 | 74,70 |

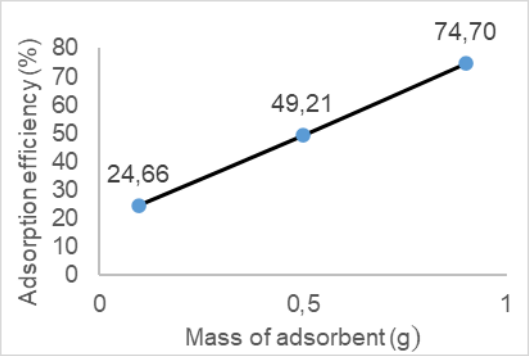



**Figure 4**. Efficiency adsorption on variations mass adsorbent

**Figure 5**. CPO after adsorption

Based on Table 5, Figure 4, and Figure 5, increasing the adsorbent mass led to greater FFA removal, indicating that more free fatty acids were captured as more adsorbent was added. This trend occurs because a higher adsorbent dosage provides a larger surface area and more available active sites to bind FFA molecules in CPO [23]. The initial FFA level of the CPO was 12.16%. After adsorption, the FFA decreased to 9.16% using 0.1 g adsorbent, 6.16% using 0.5 g, and 3.08% using 0.9 g. These results confirm that FFA content decreases as adsorbent mass increases, and the adsorption efficiency improves accordingly, showing that adsorption performance depends strongly on the amount of adsorbent available. At 0.9 g, the removal efficiency reached 74.70%, suggesting that the number of active sites was nearly sufficient to bind most of the FFA molecules.

Although the overall removal efficiency increased with higher adsorbent mass, the adsorption capacity per gram of adsorbent decreased. This decline occurs because, at higher dosages, the same amount of FFA is distributed across more adsorbent mass, reducing the uptake per unit mass even though total FFA removal increases.

FFA reduction occurs through combined adsorption and neutralization mechanisms. Adsorption occurs due to attractive interactions between FFA molecules and the adsorbent surface, which may involve van der Waals forces or stronger chemical interactions that enable selective attachment [39]. In addition, CaO promotes neutralization because oxide ions ($O^{2-}$) can abstract protons ($H^+$) from FFA carboxyl groups (–COOH), forming water, while the resulting carboxylate ions ($–COO^-$) bind with $Ca^{2+}$ to form insoluble calcium carboxylate (soap), which can be removed by filtration or precipitation [26]. The reaction can be written as:

$2R–COOH + CaO \rightarrow (R–COO)_2Ca + H_2O$

Figure 5 further visually confirms the post-adsorption condition of the CPO, consistent with the improved purification observed at higher adsorbent dosages.

This study has several limitations, namely the use of two calcination temperatures (800°C and 850°C) which do not represent the full optimization range, and the GSA characterization was only carried out at one condition, thus not allowing comparison of pore properties between treatments. In addition, variables such as calcination time, adsorbent particle size, and activation pH have not been thoroughly analyzed. These limitations indicate the need for further research to obtain more comprehensive and accurate adsorbent optimization conditions.

## CONCLUSION

This study showed that the calcination process at 850°C produced CaO with better crystallinity and more developed pore structure compared to 800°C under experimental conditions. Activation using 4% $NaHCO_3$ solution provided better adsorbent performance than 3% and 5% concentrations, indicated by higher iodine adsorption values. An adsorbent mass of 0.9 g produced greater adsorption yield in this study, with a decrease in FFA content from 12.16% to 3.08%, an adsorption efficiency of 74.70%, and an adsorption capacity of 1009.2 mg/g.

This study shows that the structure of CaO and the surface area of the adsorbent play a role in increasing the FFA adsorption capacity, and has the potential to be used as an environmentally friendly adsorbent in the CPO refining process. However, this study is still limited to the temperature variation, activation type, and characterization parameters tested. Further research is recommended to evaluate a wider temperature range, smaller particle size, activation pH variation, and testing in a continuous process system to support industrial-scale applications.

## ACKNOWLEDGEMENT

The authors would like to express their sincere gratitude to all parties who contributed to this study, especially the supervising lecturer for the guidance, suggestions, and valuable input provided from the planning stage through to the completion of the research. Appreciation is also extended to the Department of Chemistry, Faculty of Mathematics and Natural Sciences, Universitas Tanjungpura,

Pontianak, for the support and facilities provided during the course of this study.

## REFERENCES

[1] S. Sujadi, H. A. Hasibuan, and M. Rivani, "CHARACTERIZATION OF OIL DURING FRUIT RIPENING OF OIL PALM (Elaeis guineensis Jacq) VARIETY D X P SIMALUNGUN", *J. Penelitian Kelapa Sawit*, vol. 25, no. 2, pp. 59-70, Aug. 2017. doi: https:10.22302/iopri.jur.jpks.v25i2.25

[2] A. Rifin, "Efisiensi Perusahaan Crude Palm Oil (CPO) di Indonesia", *jma*, vol. 14, no. 2, p. 103, Jul. 2017, doi: 10.17358/jma.14.2.103.

[3] M. R. Harahap, A. A. Agustania, dan S. Agustiar, "Analisis kadar air dan minyak dalam sampel *press fibre* dan kadar asam lemak pada CPO (*crude palm oil*) di PMKS PT. X," *AMINA*, vol. 2, no. 3, 2022, doi: 10.22373/amina.v2i3.1183.

[4] I. Ilmi, "Kualitas minyak goreng dan produk gorengan selama penggorengan di rumah tangga Indonesia," *Jurnal Aplikasi Teknologi Pangan*, vol. 4, 2015, doi: 10.17728/jatp.2015.12.

[5] R. Silalahi, D. Sari, dan I. Dewi, "Pengujian *free fatty acid* (FFA) dan *colour* untuk mengendalikan mutu minyak goreng produksi PT. XYZ," *Industria: Jurnal Teknologi dan Manajemen Agroindustri*, vol. 6, no. 1, pp. 41–50, 2017, doi: 10.21776/ub.industria.2017.006.01.6.

[6] N. Fanani dan E. Ningsih, "Analisis kualitas minyak goreng habis pakai yang digunakan oleh pedagang penyetan di daerah Rungkut Surabaya ditinjau dari kadar air dan kadar asam lemak bebas (ALB)," *Jurnal IPTEK*, vol. 22, pp. 59–66, 2019, doi: 10.31284/j.iptek.2018.v22i2.436.

[7] K. Darkun, L. Febrina, dan A. Lutfansa, "Utilization of a mixture of eggshells and husk ash to reduce environmental impact," *Environmental Research, Engineering and Management*, vol. 78, pp. 110–118, 2022, doi: 10.5755/j01.erem.78.3.31084.

[8] S. Almahibi, R. Nurlaila, S. Suryati, M. Muhammad, S. Bahri, dan T. M. Hafli, "Adsorpsi asam lemak bebas CPO dengan adsorben dari limbah cangkang kulit telur ayam," *Chemical Engineering Journal Storage (CEJS)*, vol. 4, pp. 109–121, 2024, doi: 10.29103/cejs.v4i1.14784.

[9] T. Pornchai, A. Imkum Putkham, dan A. Putkham, "Effect of calcination time on physical and chemical properties of CaO-catalyst derived from industrial-eggshell wastes," *J. Sci. Technol. MSU*, vol. 35, pp. 693–697, 2016. Tersedia: https://www.thaiscience.info/Journals/Article/JSMU/10985185.pdf.

[10] E. Siswoyo dan G. Gunawan, "Synthesis and characterization of hydroxyapatite from calcium oxide (CaO) chicken eggshell with precipitation method," *Malaysian International Journal of Science and Technology (MIJST)*, vol. 4, no. 2, pp. 40–45, Jul. 2018, doi: 10.20319/mijst.2018.42.4045.

[11] H. Hoo, M. Mohamad, R. Wannahari, M. Masri, T. Ter, dan N. A. Mohidem, "Optimization study of malachite green dye adsorption by eggshell using response surface methodology," *Key Engineering Materials*, vol. 908, pp. 367–372, 2022, doi: 10.4028/p-66g2qs.

[12] F. Ferdoush, M. Khan, dan A. Mustafa, "Preparation and characterization of adsorbent using eggshell and determination of removal efficiency of hexavalent chromium and total organic carbon," *Daffodil International University Journal of Science and Technology*, vol. 7, pp. 1–14, 2020, doi: 10.36481/diuhls.v07i1-2.e2jb9p55.

[13] S. Oko dan M. Feri, "Pengembangan katalis CaO dari cangkang telur ayam dengan impregnasi KOH dan aplikasinya terhadap pembuatan biodiesel dari minyak jarak," *JurTek: Jurnal Teknologi*, vol. 11, no. 2, pp. 103–110, Jul. 2019, doi: 10.24853/jurtek.11.2.103-110.

[14] Fitriyana and E. Safitri, "Utilization Shell Chicken Eggs as Adsorbent for Increase Quality Used Cooking Oil," *Conversion*. vol. 4, no. 1, pp. 2-16, 2015. Doi: 10.20527/k.v4i1.260

[15] E. S. Yusmartini, M. Mardwita, A. Atikah, dan S. C. Kaswari, "Egg shells as an adsorbent for the adsorption of lead (Pb) and iron (Fe) metals," *AJARCDE (Asian Journal of Applied Research for*

*Community Development and Empowerment)*, 2024, doi: 10.29165/ajarcde.v8i1.349.

[16] E. Maruni, N. Nurlina, dan N. Wahyuni, "Isoterm adsorpsi Pb(II) pada karbon aktif tempurung kelapa dengan variasi konsentrasi aktivator natrium bikarbonat (*isothermal adsorption of Pb(II) by activated carbon with variations in concentration of sodium bicarbonate*)," *Indonesian Journal of Pure and Applied Chemistry*, vol. 5, p. 73, 2022, doi: 10.26418/indonesian.v5i2.52987.

[17] E. Hajar, R. Sitorus, N. Mulianingtias, dan F. Welan, "Efektivitas adsorpsi logam $Pb^{2+}$ dan $Cd^{2+}$ menggunakan media adsorben cangkang telur ayam," *Jurnal Konversi*, vol. 5, pp. 1–7, 2016, doi: 10.20527/k.v5i1.4771.

[18] M. T. Haryono, C. Natanael, R. Rukiah, dan Y. Yulianti, "Kalsium oksida mikropartikel dari cangkang telur sebagai katalis pada sintesis biodiesel dari minyak goreng bekas," *Jurnal Material dan Energi Indonesia*, vol. 8, p. 8, 2018, doi: 10.24198/jmei.v8i01.17865.

[19] L. Laos, "Pemanfaatan kulit singkong sebagai bahan baku karbon aktif," *JIPF (Jurnal Ilmu Pendidikan Fisika)*, vol. 1, p. 32, 2016, doi: 10.26737/jipf.v1i1.58.

[20] D. Onwumelu, "A comparative analysis of activated carbons from African teak (iroko) wood and coconut shell in palm oil bleaching," *International Journal of Progressive Sciences and Technologies*, vol. 32, no. 1, pp. 383–396, 2022, doi: 10.52155/ijpsat.v32.1.4249.

[21] I. Iswandi, E. W. Sipa, dan E. Rejeki, "Penetapan kadar asam lemak bebas pada berbagai minyak goreng sebelum dan setelah penggorengan dengan metode titrasi alkalimetri," *Medfarm: Jurnal Farmasi dan Ilmu Kesehatan*, vol. 12, no. 1, pp. 1–8, Jun. 2023, doi: 10.48191/medfarm.v12i1.145..

[22] A. Nurlaela, S. Dewi, K. Dahlan, dan D. Soejoko, "Pemanfaatan limbah cangkang telur ayam dan bebek sebagai sumber kalsium untuk sintesis mineral tulang," *Jurnal Pendidikan Fisika Indonesia*, vol. 10, no. 1, 2014, doi: 10.15294/jpfi.v10i1.3054.

[23] S. Oko, A. Kurniawan, dan D. Angreni, "Pengaruh massa adsorben blending CaO dari cangkang telur dan karbon teraktivasi untuk adsorpsi zat warna methylene blue," *METANA*, vol. 18, no. 2, pp. 99–104, Nov. 2022, doi: 10.14710/metana.v18i2.49376.

[24] C. Zhang, J. Fang, Z. Han, P. Chen, X. Xu, K. Wang, Y. Shi, dan J. Liao, "Optimizing CaO-based $CO_2$ adsorption: Impact of operating parameters," *iScience*, vol. 28, no. 8, Art. no. 113127, Jul. 2025, doi: 10.1016/j.isci.2025.113127.

[25] L. Hakim, M. Dirgantara, dan M. Nawir, "Karakterisasi struktur material pasir bongkahan galian golongan C dengan menggunakan X-ray diffraction (XRD) di Kota Palangkaraya," *Jurnal Jejaring Matematika dan Sains*, vol. 1, pp. 44–51, 2019, doi: 10.36873/jjms.v1i1.136.

[26] N. Widiarti, Y. L. Nimah, H. Bahruji, dan D. Prasetyoko, "Development of CaO from natural calcite as a heterogeneous base catalyst in the formation of biodiesel: A review," *Journal of Renewable Materials*, vol. 7, pp. 915–939, 2019, doi: 10.32604/jrm.2019.07183.

[27] A. Lesbani, P. Tamba, R. Mohadi, dan Fahmariyanti, "Preparation of calcium oxide from *Achatina fulica* as catalyst for production of biodiesel from waste cooking oil," *Indonesian Journal of Chemistry*, vol. 13, pp. 176–180, 2013, doi: 10.22146/ijc.21302.

[28] M. Sibhat, G. Yao, N. Zhu, G. Tsegay, K. Fang, Q. Zhu, Y. Zhou, dan J. Zhao, "Advancement in sodium carbonation pathways for sustainable carbon capture and utilization: A review," *Results in Engineering*, vol. 23, Art. no. 102536, 2024, doi: 10.1016/j.rineng.2024.102536.

[29] Y. Siregar, R. Heryanto, N. Lela, dan T. Lestari, "Karakterisasi karbon aktif asal tumbuhan dan tulang hewan menggunakan FTIR dan analisis kemometrika," *Jurnal Kimia VALENSI*, pp. 103–116, 2015, doi: 10.15408/jkv.v0i0.3146.

[30] C. Feng, J. E, W. Han, Y. Deng, B. Zhang, X. Zhao, dan D. Han, "Key technology and application analysis of

zeolite adsorption for energy storage and heat-mass transfer process: A review," *Renewable and Sustainable Energy Reviews*, vol. 144, Art. no. 110954, 2021, doi: 10.1016/j.rser.2021.110954.

[31] A. A. Ayodeji, O. E. Modupe, B. Rasheed, dan J. M. Ayodele, "Data on CaO and eggshell catalysts used for biodiesel production," *Data in Brief*, vol. 19, pp. 1466–1473, Jun. 2018, doi: 10.1016/j.dib.2018.06.028.

[32] R. Djayasinga, A. Setiawan, A. Purnomo, A. Z. Amien, dan H. Hartanti, "Utilization of breed chicken eggshells for biodiesel preparation from waste cooking oil," *Journal of Multidisciplinary Applied Natural Science*, vol. 2, no. 1, pp. 41–46, Jan. 2022, doi: 10.47352/jmans.v1i1.9.

[33] M. Zabeti, W. M. Daud, dan M. K. Aroua, "Activity of solid catalysts for biodiesel production: A review," *Fuel Processing Technology*, vol. 90, pp. 770–777, 2009, doi: 10.1016/j.fuproc.2009.03.010.

[34] M. Minakshi, S. Higley, C. Baur, D. R. G. Mitchell, R. T. Jones, dan M. Fichtner, "Calcined chicken eggshell electrode for battery and supercapacitor applications," *RSC Advances*, vol. 9, pp. 26 981–26 995, Aug. 2019, doi: 10.1039/C9RA04289J.

[35] R. Kurniawan, S. F. Azzahra, dan N. T. Yohaningsih, "Pengaruh jenis adsorben pada proses bleaching di pemurnian *crude palm oil* (CPO) sebagai bahan baku pada proses green fuel," *Rekayasa Hijau: Jurnal Teknologi Ramah Lingkungan*, vol. 7, no. 2, pp. 101–111, Jul. 2023, doi: 10.26760/jrh.v7i2.101-111.

[36] A. J. Dijkstra, "About water degumming and the hydration of non-hydratable phosphatides," *European Journal of Lipid Science and Technology*, vol. 119, no. 9, 2017, doi: 10.1002/ejlt.201600496.

[37] F. Wibowo, M. I. Rozi, dan J. S. Sembiring, "Pengaruh variasi jenis adsorben terhadap kualitas *crude palm oil* (CPO) yang dihasilkan," *Jurnal Ilmu dan Teknologi (JIST)*, vol. 6, no. 1, pp. 45–52, 2022. Doi: 10.59141/jist.v3i07.450

[38] L. Legasari, R. Riandi, W. Febriani, dan R. Pratama, "Analisis kadar air dan asam lemak bebas pada produk minyak goreng dengan metode gravimetri dan volumetri," *Jurnal REDOKS: Jurnal Pendidikan Kimia dan Ilmu Kimia*, vol. 6, pp. 51–58, 2023, doi: 10.33627/re.v6i2.1228.

[39] P. Raja dan G. Giyanto, "Aplikasi karbon aktif dari cangkang kelapa sawit sebagai adsorben pada minyak jelantah bahan sabun," *Jurnal Agro Fabrica*, vol. 2, pp. 49–57, 2021, doi: 10.47199/jaf.v2i2.171.