Heliyon 8 (2022) e09146

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

Techno-economics of coconut coir bioadsorbent utilization on free fatty acid level reduction in crude palm oil

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ARTICLE INFO

Keywords:
Crude palm oil
Coconut coir
Free fatty acid
Adsorption
Bioadsorbent

ABSTRACT

The quality of crude palm oil (CPO) is generally determined by the levels of free fatty acids (FFA). This helps in balancing the level of acidity during transportation and storage processes. However, high FFA in CPO is not good for consumer health. One of the methods for adsorbing FFA is adsorption, which is the adhesion of atoms, ions, or molecules from a gas, liquid, or dissolved solid to a surface. Therefore, this study aims to analyze the effect of contact time (40, 80 and 120 min) and Coconut Coir (CC) bioadsorbent concentrations of 1, 2 and 3 (%, w/v) on the reduction of CPO FFA levels. This began with the activation of CC biochar synthesis by using NaOH and HCl, which produced CC-NaOH and CC-HCl bioadsorbents based on the product of NaOH. Furthermore, the adsorption process was carried out by mixing CPO with CC-NaOH and CC-HCl bioadsorbents in a three-necked flask. After this, the filtrate product was obtained and analyzed for its FFA levels. The results showed that the largest percentage reduction for the effect of bioadsorbent concentration was 3% (w/v) at a contact time of 120 min. It also indicated that this study enabled lower levels of FFA in CPO. Based on the detailed cost estimate, the production cost of the CC-NaOH bioadsorbent was USD 481,874, sold at USD 95/ton with annual sales and net profit (after tax) at USD 684,000 and USD 141,188, respectively. This profit after tax and rate of return on investment was found to be 20.68 and 39.49% of the entire estimation, respectively. It also had a payback period of 2.95 years and a break-even point at a capacity of 43.16%. In addition, the prepared adsorbent showed significant ability as an inexpensive, reproducible and environmentally friendly compound used in reducing the FFA levels of CPO.

1. Introduction

Crude palm oil (CPO) is a raw cooking material and is one of the most widely consumed vegetable commodities in the world (Ndé et al., 2019). The quality of this oil is often evaluated based on the content of Free Fatty Acid (FFA), which needs to be removed through a purification process, in order to meet domestic and international needs (Azeman et al., 2015; De Almeida et al., 2013). However, high levels of this FFA (>3%) cause rancidity, as well as changes in the taste and color of the oil (Cowan et al., 2012). Besides food purposes, it is also used for the production of biodiesel and oleo-chemical derivatives (Garcia-Nunez et al., 2016). The CPO is a reddish-orange vegetable oil containing triglyceride compounds, formed from glycerin and fatty acids, non-glyceride materials (phosphatides, raffinose, pentosan, carotene, gossypol) and hydrocarbons (sterols, ketones, butyric acid, tocopherols) (Constant et al., 2017; Leticia et al., 2012; Priatni et al., 2017).

A common method used by vegetable oil industries to remove free fatty acids is known as the adsorption process (Cren and Meirelles, 2012). This is the adhesion of atoms, ions, or molecules from a gas, liquid, or dissolved solid to a surface. Several studies have examined the adsorbent on the reduction of FFA levels, such as Silva et al. (2014), which focused on the effect of citric acid and water during bleaching. The results showed an increase in citric acid and FFA levels at 0.09–0.27% and 8.46%, respectively. Furthermore, Purwasasmita et al. (2015) studied the effect of NaOH reactant concentrations ranging from 0.1 to 0.5 N. The results showed a low CPO FFA removal efficiency at NaOH concentrations below 0.25 N. Based on the effect of Deodorized Palm Oil time, Riyadi et al. (2016), obtained a 0.33% FFA removal efficiency that was

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https://doi.org/10.1016/j.heliyon.2022.e09146
Received 15 September 2021; Received in revised form 23 December 2021; Accepted 15 March 2022

slightly larger than that of0.29% at 1 h Putranti, Wirawan and Bendiyasa (2018), also analyzed the effect of adsorbent on low-grade cooking oil, using NaOH and HCl-activated, as well as unactivated natural zeolites, respectively. The results showed that the NaOH-activated zeolite was able to reduce FFA levels to 62.5%. Abdi, Gharachorloo and Ghavami (2021), analyzed the effect of adsorbents through commercial BE, which showed an increase of 96.77%inthe FFA levels of soybean oil. Meanwhile, the use of eggshell powder activated with 2% H_2SO_4 completely removed (100%) FFA from this oil. Based on the use of zeolites, Anang et al. (2020), further studied the effect of time on decreasing the FFA levels in coconut and palm kernel oils. The results showed that a duration of 4 h produced the largest FFA reduction values of 89.36 and 93.25% for palm kernel and coconut oils, respectively. The study conducted by Oktavian et al. (2020), also showed a decrease in the FFA levels at 93% for 45 min Chakawa, Nkala, Hlabangana and Muzenda (2019), studied the effect of calcium sulfate dihydrate ($CaSO4._2H_2O$) on the percentage reduction of FFA in soybean oil. This showed a constant value of 0.56% for the adsorbent concentration of 0–30%. In addition, Ifa et al. (2021), analyzed the contact time effect of bentonite on the percentage reduction in FFA levels, which obtained a 2.99% decrease at 60 min.

One of the commonly used adsorbents is the biomass-based sorbent (Anastopoulos et al., 2019), which is often grouped as inorganic, synthetic, natural and organic (agricultural) products. Agricultural sorbents are inexpensive, efficient, environmentally friendly and easy to use. However, the utilization of its waste materials is increasingly becoming a concern, due to the creation of serious disposal problems. Several sources of waste biomass are available in different parts of the world, where many experimental adsorption properties have been reported. This includes sesame and banana peels (El-Araby et al. 2017; Castro et al., 2011), coconut coir, powder and stalk (Abel et al., 2020; Israel et al., 2011; Etim et al., 2016; Ofudje et al., 2015), cocoa husk charcoal (Aderonke et al., 2014), seed coat (Amuda et al. 2013), mango leaf powder (Sethu et al., 2010), eggshell (Abdi et al., 2021), pine needles (Malik et al., 2016) and palm leaf sheaths (Salman et al., 2011).

Coconut coir is often a discarded residue that is neither frequently utilized nor developed for industrial use (Chaudhuri and Saminal, 2011). It contains water, cellulose, lignin and ash content of 25.2, 35.99, 53.5 and 9%, respectively. High contents of lignin and cellulose with a low ash level of coir powder indicate a characteristic of agricultural by-products, generally known as lignocellulosic materials (Israel et al., 2011). In addition, hemicellulose and cellulose in the structure of lignocellulosic materials are bound or veiled by lignin (Isroi et al., 2011). Furthermore, coconut coir naturally provides a porous structure to a bioadsorbent, at surface areas of 826 and 691.8 m^2/g (Chaudhuri and Saminal 2011; Abel et al., 2020). The larger the contact surface area, the greater the adsorption process of coconut coir as a bio adsorbent (Etim et al., 2016; Oktavian et al., 2020; Sari et al., 2021). The conversion of this residue into activated carbon also has a dual purpose, namely (1) Unwanted agricultural waste is converted into useful and value-added adsorbents, (2) The use of agricultural by-products is the potential source of an adsorbent, as a solution to several CPO quality problems (Abel et al., 2020; Tan et al., 2008).

The primary process used to convert biomass into bioadsorbent is carbonation or pyrolysis. Besides being rich in carbon, biochar generally serves as a raw material for bioadsorbent production, with a pore structure developed through activation (Na et al., 2019). This aims to improve the nature of the pores and activated sites. Activation of biomass is performed through two approaches, namely physical and chemical methods. In the chemical method, biomass raw material is often mixed with several synthetic activation reagents, such asH_3PO_4, NaOH, $ZnCl_2$, HCl, H_2SO_4, etc. These reagents are known to often influence the chemical method (Ayinla et al., 2019), with their main functions based on degrading or dehydrating organic components during the activation process, in order to suppress hydrocarbon depolymerization on the carbon surface (Mohammad-Khah and Ansari, 2009). The biggest advantage of this method is the one-step process at lower temperatures (Ali et al., 2014). It is also an economical and environmentally friendly process, due to the recovery and recycling of chemical reagents (Tsai et al., 1997). Acid activation also significantly improves its surface properties, in order to serve as a bioadsorbent in vegetable oil refining processes. The most commonly used compounds in this process are hydrochloric and sulfuric acids (Ndé et al., 2019; Usman et al., 2012; Joy et al., 2007; Steudel et al., 2009; Taha et al., 2011). So far and as far as the author knows, the production of bioadsorbent based on coconut coir is still not available, both studies on a laboratory scale to the development on a commercial factory one.

For the development of the use of coconut coir bioadsorbents, an economic study is needed on the feasibility of using bioadsorbents on the commercial stage. This study aimed to examine the economic feasibility of making coconut fiber bioadsorbent by viewing the effect of concentration, contact time of coconut fiber bioadsorbent and the type of activator on the percentage reduction in CPO FFA levels. The economic feasibility of making coconut fiber bioadsorbent was seen from the percent Profit on Sales, Rate of Return on Investment, Pay Out Time and Break Event Point.

2. Materials and methods

2.1. Materials

Coconut coir and CPO (FFA level of 5.2%) were obtained from the traditional market of Makassar and PT. Astra Agro, Indonesia, respectively. The chemical substances used were 0.5 N sodium hydroxide (NaOH) and hydrochloric acid (HCl) of 37%.

2.2. Production of coconut coir bioadsorbent

Coconut coir samples were severally washed and rinsed with tap and distilled water, then dried in the sun for 8 h. After drying, the fiber was blended into small pieces, as well as grounded. The dried samples were ground and sieved using a 300 μm sieve. Furthermore, the coconut coir granules were dried to a constant weight in a drying oven at 105 °C to remove excess water content and some volatile components. The process of making bioadsorbent from coconut coir was done by charring the crushed coconut coir sample using a hot plate at a temperature of 150 °C. The formed bioadsorbent was cooled to room temperature and then stored in a desiccator.

2.3. Coconut coir activation process

2.3.1. Activation of bioadsorbent with 0.5 N NaOH and 0.5 N HCl

Activation process using 0.5 N NaOH activator: A total of 100 g of bioadsorbent formed was immersed in 500 mL of 0.5 N NaOH into 1000 mL beaker glass. The mixture was allowed to stand for 24 h, filtered and washed with distilled water until a neutral pH = 7. Furthermore, the bioadsorbent obtained was dried in an oven at 150 °C for 2 h. The bioadsorbent which has been activated with 0.5 N NaOH is called CC-NaOH bioadsorbent. CC-NaOH bioadsorbent was stored in a desiccator until needed for the adsorption process.

The activation process used 0.5 N HCl activator: A total of 100 g of bioadsorbent formed was immersed in 500 mL of 0.5 N HCl into 1000 mL beaker glass. The mixture was boiled while stirring at 110 °C for 15 min. After the mixture has cooled, it was then filtered and washed with distilled water until the pH = 3. Furthermore, the resulting bioadsorbent was dried in an oven at 150 °C for 2 h. The bioadsorbent been activated using 0.5N HCl is called CC-HCl bioadsorbent. CC-HCl bioadsorbent was stored in a desiccator until needed for the adsorption process.

2.4. CC bioadsorbent performance test

CPO as raw material was characterized before being used to test the adsorption performance of its FFA content. The CPO adsorption process was carried out by mixing CC-NaOH and CC-HCl at the concentrations of 1, 2 and 3% w/v in a three-neck flask using a magnetic stirrer with contact times of 40, 80 and 120 min. These FFA levels were determined by the method of titration, as written with some modifications in the American Oil Chemists Society (AOCS, 1990). A total of 2.5 g preheated CPO oil (about 50 °C) was weighed in a beaker and mixed with 50 mL of ethyl alcohol. Through the process of titration, this solution was neutralized with 0.1026 N of sodium hydroxide. After this, the percentage of FFA was calculated as palmitic acid, where its molecular weight was assumed to be 256 based on Eq. (1) (Henry, 2011).

$$\mathit{FFA\ as\ palmitic}\ (\%) = \frac{V \times m \times M}{10\, w} \times 100\% \tag{1}$$

where, V = volume (mL) of NaOH, m = molarity of NaOH solution, w = sample weight (g) and M = FFA molecular weight (g/mol).

Based on this condition, Eq. (1) is further written as Eq. (2) (Ali et al., 2014; Bahadi et al., 2016; Hashim et al., 2019).

$$\mathit{FFAas\ palmitic}\ (\%) = \frac{V \times N \times 25.6}{w} \times 100\% \tag{2}$$

where, V = volume of NaOH (mL), N = normality of NaOH (0.1026 N), w = weight of CPO (g).

2.5. Economic analysis

Economic analysis is used to analyze the feasibility of a factory (Ulrich, 1984), based on the comparison of social interventions with production costs. Based on the CC-NaOH bioadsorbent, this analysis was carried out using the following assumptions (Ifa et al., 2020).

a) The production capacity of CC-NaOH is 7,200 tons/year.
b) CC-NaOH products are sold to meet domestic needs and the factory is located in Pasang Kayu Regency, South Sulawesi, Indonesia.
c) Owned capital of 60 and 40%.
d) Annual bank interest by 5.75%.
e) The annual inflation rate is 3.18%.
f) The factory is estimated at 10 years, with an annual depreciation of 10%.
g) Labor costs are associated with wages collected for the biomass and operations of the CC-NaOH plant. These laborers are categorized as skilled and unskilled workers, which are readily available to CC-NaOH plant owners and rural communities.
h) The plant reportedly operates 330 days per year, with the remaining periods set aside for maintenance (Okolie et al., 2021).

All currency values used in this study are in US dollars (USD), with the conversion rate of USD 1 producing IDR 14,340. This study was further economically analyzed using general profitability criteria (Aries and Newton, 1955; Turton et al., 2009). The level of factory profitability was evaluated using certain basic indicators, including Rate of Return on Investment (ROI), Pay Out Time (POT), Percent Profit on Sales (POS) and Break-Even Point (BEP) (Ifa et al., 2020; Kpalo et al., 2020; Soetaredjo et al., 2021; Lee et al., 2020; Lim et al., 2021; Vlysidis et al., 2011). This research to study the economic feasibility of CC-NaOH bioadsorbent. Furthermore, Soetaredjo et al. (2021) analyzed the economic feasibility of BE processing production, for reducing the levels of CPO FFA in the Madiun area, East Java province, Indonesia. For a factory capacity of 450 tons/month, BE production was profitable when sold for USD 100/ton. Therefore, the annual sales (S) of BE products were USD 540,000, with a net profit on sales (POS) after tax of approximately USD 120,000.

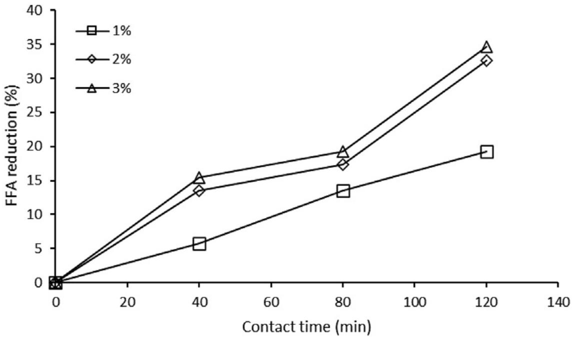

Figure 1. The effect of contact time on FFA reduction using CC-HCl bioadsorbent

3. Result and discussion

3.1. Free fatty acid level

The FFA is a natural monobasic aliphatic compound consisting of a hydrocarbon chain and carboxylate group (Chakawa et al., 2019). These acids are produced by hydrolysis and oxidation processes, often in combination with neutral fats. Using CC bioadsorbent, this study was conducted to improve the quality of CPO through the adsorption method. It also analyzed the effect of concentration and contact time of CC-NaOH and CC-HCl bioadsorbents with CPO. Moreover, the best synthetic concentration and duration to improve the CPO quality were expected. In this study, the adsorption performance of CC was evaluated based on the reduction of FFA. Figures 1, 2, 3, 4, and 5 further showed the CPO concentration and contact time relationship profiles of CC-NaOH and CC-HCl bioadsorbents to the percentage reduction of FFA. In addition, adsorbent dose and contact time were among the factors that affected the adsorption capacity of biomass (Abel et al., 2020; Bilal et al., 2013).

3.2. The effect of contact time on reducing FFA levels using CC-HCl and CC-NaOH bioadsorbents

The effect of contact time and concentration on FFA adsorption is presented in Figures 1, 2, 3, and 4. These showed that the adsorption rate improved with increasing CC-HCl bioadsorbent concentration and time. According to Salman et al. (2011), longer interaction between the solution and adsorbent caused more adsorbate absorption on the surface. This was in line with the results of several studies (Abel et al., 2020; Amuda et al., 2013; Ates and Tezcan Un, 2013; Chaudhuri & Saminal, 2011; Cowan et al., 2012; Purwasasmita et al., 2015; Putranti et al., 2018). Furthermore, the efficiency of FFA removal was linear with time according to Cowan et al. (2012), with the addition of 1 and 2% w/w lipase and glycerol at 14 h producing 65.26% (from 4.98 to 1.73%). Purwasasmita et al. (2015), also reported an increase in the efficiency of CPO FFA removal due to the long contact time, where the largest reduction of 98% was obtained at 4 h (Purwasasmita et al., 2015). This was similarly reported in Riyadi et al. (2016), where the FFA reduction of 0.33% was obtained at 2 h. This was slightly higher than the reduction of 0.29% in 1 h (Riyadi et al., 2016).

Figure 1 showed that the decrease in FFA levels increased with the length of contact time, between the CPO and bioadsorbent. This was reportedly in line with the results of several studies (Abel et al., 2020; Anang et al., 2020; Cowan et al., 2012; Ifa et al., 2021; Olufemi and Otolorin, 2017; Purwasasmita et al., 2015; Riyadi et al., 2016). It also indicated that longer contact time led to greater chances of the FFA being trapped in the pores of the bioadsorbent, therefore, increasing the levels of percentage reduction. According to Cowan et al. (2012), the percentage reduction of FFA level was linear with the contact time, where the addition of 1/2% w/w lipase and glycerol at 14 h produced 65.26%. However, the best conditions in this study were obtained at 120 min, with the concentration of CC-HCl bioadsorbent at 3% w/v. Also, a reduction of 34% was obtained (from the initial FFA level of 5.2%–3.4%). This study was limited to the maximum contact time of 120 min because the results obtained above 120 min tended to be constant, this refers to

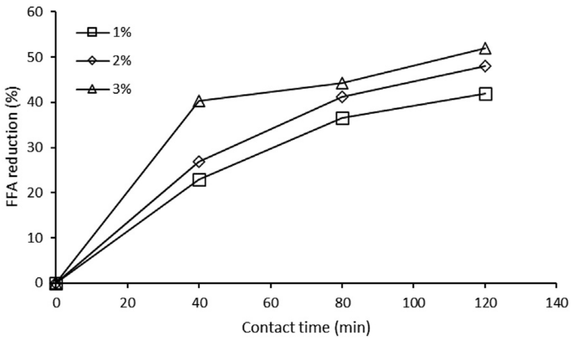

Figure 2. The effect of contact time on FFA reduction using CC-NaOH bioadsorbent

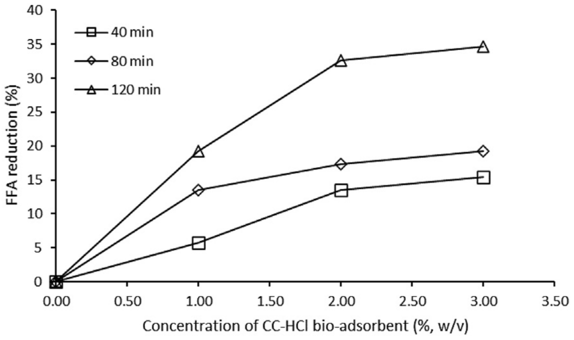

Figure 3. The effect of CC-HCl bioadsorbent concentration on FFA reduction.

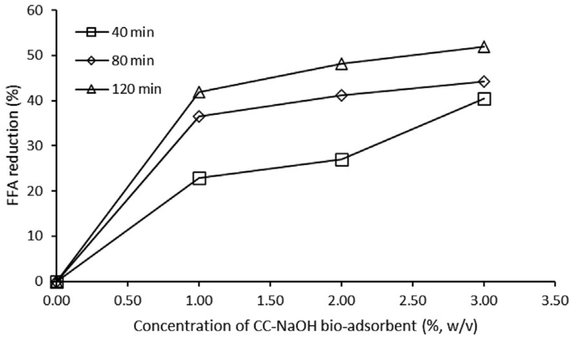

Figure 4. The effect of CC-NaOH bioadsorbent concentration on FFA reduction.

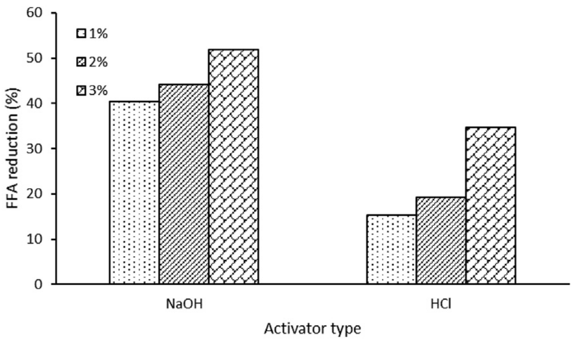

Figure 5. The effect of activator type on FFA reduction (contact time of 120 min).

the research conducted by Abe et al. (2020) which used the same bioadsorbent and adsorbate as used in this study.

Figure 2 showed the levels of FFA reduction and the increasing contact time of CC-NaOH bioadsorbent with CPO. This result was in line with Chaudhuri and Saminal (2011), which used coconut coir activated carbon (CCAC) bioadsorbent that was ignited with NaOH. The use of an alkaline NaOH activator resulted in a greater percentage reduction in FFA levels than an acidic HCl activator. This occurred because at alkaline pH the negative charge density on the activated carbon surface increased to carry out the deprotonation process at the adsorption site so that the adsorption increases. The results obtained were also in line with several previous studies, where the decrease in FFA levels was linear with contact time (Anang et al., 2020; Cowan et al., 2012; Oktavian et al., 2020). Cowan et al. (2012), reported that a 65.26% reduction of FFA in CPO was produced at 14 h, through enzymatic remediation. Furthermore, Riyadi et al. (2016), similarly reported that a reduction of 0.32% was obtained at 2 h, which was slightly larger than 0.29% at 1 h. Meanwhile, the percentage in this study was smaller than Anang et al. (2020), which used zeolite with core oil to obtain the reduction value of 89.36% at 4 h (Anang et al., 2020). Similar results were also reported by Oktavian et al. (2020), which focused on the synthesis and performance assessment of CC bioadsorbents, for the purification of used cooking oil. This showed a decrease of 93% in FFA levels for 45 min (Oktavian et al., 2020).

Figure 2 also showed that the adsorption process of FFA to the bioadsorbent increased at the initial stage of contact time, before gradually decreasing. The percentage of FFA removal indicated the presence of empty active sites on the surface of the adsorbent and also to the strong attractive forces between the adsorbate and bioadsorbent molecules, which decreased with increasing contact time (Olufemi and Otolorin, 2017). This decrease in efficiency was due to the limited mass transfer of the adsorbate molecules, from the solution to the outer surface of the bioadsorbent (Onundi et al., 2011). Furthermore, the adsorption process became slow due to the movement of FFA through the pores of the bioadsorbent material (Barakat et al., 2014). This was similarly reported by Budiana et al. (2021), which showed that the adsorbent adsorbed 88% Cr(III) for 45 min. After this, the adsorption of Cr(III) gradually decreased to 73.6% at 150 min (Budiana et al., 2021).

According to Belay and Hayelom (2014), the effect of contact time on the adsorbate percentage elimination occurred in two phases, namely the fast and slow stages. In the first stage, the increase in the adsorption percentage was associated with the presence of large active sites on the surface of the adsorbent, rapidly occupied by several greater adsorbates. In the second stage, the low absorption rate occurred due to two reasons: (1) The pores of the adsorbent became saturated at an early stage (Belay and Hayelom, 2014); (2) The binding sites immediately became limited and the remaining unfilled surface sites were difficult to be occupied by the adsorbent. This was based on the emergence of a repulsive force between the solid and liquid surface adsorbates (Hossain et al., 2012).

3.3. The effect of CC-HCl and CC-NaOH bioadsorbent concentrations on reducing FFA levels

The effect of concentration on CPO FFA adsorption is shown in Figure 3. This showed that the adsorption increased and achieved maximum results at 3.0% coconut coir concentration, which was in accordance with several previous studies (Abel et al., 2020; Chaudhuri and Saminal, 2011; Etim et al., 2016; Kumar et al., 2010; Olufemi and Otolorin, 2017). Moreover, the adsorption increment through the concentration of the bioadsorbent was associated with surface increase and more site availabilities (Kumar et al., 2010; Wambu, Muthakia, Wa-Thiong'o, & Shiundu, 2011). As shown in Figure 3, the increase in adsorbent concentration and active sites caused an increment and decrease in the percentage reduction of FFA levels, respectively. The more the available active sites on the surface of the CC-HCl, the higher the interactions between the FFA and bioadsorbents (Olufemi and Otolorin, 2017). Similar results were also reported by Itodo and Itodo

(2010). Meanwhile, these results were different from those reported by Silva et al. (2014), where the addition of citric acid to acid-activated BE produced an 8.46% increase in FFA levels (from 4.61% to 5%). Similar results were further reported in Abdi et al. (2021), where the FFA content of soybean oil bleached with commercial BE experienced an increase of 96.77% (from 0.31 to 0.61%). This was probably due to the hydrolysis of triacylglycerol to diacylglycerol and FFA, which in turn increased free fatty acid levels.

Figure 3 showed that the addition of CC-HCl bioadsorbent concentration from 1-3% (w/v) increased the percentage reduction of FFA level. However, the concentrations from 2-3% (w/v) obtained insignificant percentages from 30 to 32%. It also showed saturation of the bioadsorbent ability, indicated by a decrease in FFA level reduction. The addition of 3% CC-HCl bioadsorbent concentration at 120 min further indicated the largest percentage decrease in FFA levels at 32% (from 5.2% to 3.4%). These results contradicted that of Chakawa et al. (2019), where an increase in the adsorbent concentration of 0–30% did not affect constant FFA levels at 0.56% (Chakawa et al., 2019). In addition, the percentage of FFA level reduction in this study was smaller than those reported by Anang et al. (2020) at 89.22% (Anang et al., 2020).

Figure 4 showed the increase in the percentage reduction of FFA level and the high concentration of bioadsorbent. This was in line with the results of Chaudhuri and Saminal (2011), based on KOH-activated CCAC bioadsorbents. By improving the concentration of CC-NaOH bioadsorbent, the increase in the adsorption percentage was due to an increment in the active sites. This facilitated the penetration of FFA molecules into the bioadsorbent site. The increase in the active site also caused a higher percentage removal of the adsorbate. This was because more active sites occurred with higher adsorbent concentrations (Itodo and Itodo, 2010; Olufemi and Otolorin, 2017; Pérez Marín et al., 2009). It also caused higher interactions between the adsorbate and adsorbent particles (Abel et al., 2020). Furthermore, the number of adsorption increased with higher adsorbent concentration and the removal efficiency directly indicated several available sites (Duwiejuah et al., 2017; Souundarrajan et al., 2012). Therefore, the adsorption sites or surface areas increased with the adsorbent concentration, leading to a higher percentage (Amarasinghe and Williams, 2007). This result was in line with previous reports, based on the effect of adsorbent concentration on FFA removal (Purwasasmita et al., 2015; Putranti et al., 2018). In addition, Purwasasmita et al. (2015), reported that the effect of 0.1–0.5N NaOH concentration caused a large FFA removal efficiency, obtained above 0.25 N.

The biggest percentage of FFA level reduction in this study was the addition of 3% w/v CC-NaOH bioadsorbent concentration, which showed the greatest decrease of 51.92% (from 5.2% to 2.5%) at 120 min. This result was greater than those of Imaroh and Efendi (2019) and Ifa et al. (2021) by 45.17 and 2.99%, respectively. However, it was different from the study of Abdi et al. (2021), which stated that the use of an alkaline eggshell powder adsorbent removed all FFA (100%) from soybean oil. The difference in the decrease was due to the type of adsorbent used. In this case, the neutralization of FFA was based on the alkalinity of the eggshell adsorbent. Moreover, the percentage of decrease in this study was smaller than the results of Putranti et al. (2018), which obtained the reduction of 62.5% by using alkaline-activated zeolite with low FFA content (0.4%) (Putranti et al., 2018). The differences in the efficiency levels of several studies (Abdi et al., 2021; Putranti et al., 2018) were due to the types of utilized adsorbent, where the alkaline properties of the zeolite and eggshell caused the neutralization of FFA.

3.4. The effect of activator type on FFA reduction

Figure 5 showed the percentage reduction of FFA level influenced by the type of utilized activator. Based on this condition, the NaOH activator obtained a larger value of 51.92%, indicating higher effectiveness in FFA reduction. This was in accordance with the study of Putranti et al. (2018), which stated that the adsorption of FFA on low grade cooking oil was better with the use of NaOH-activated zeolite at 62.5%, compared to HCl and natural indicators (Putranti et al., 2018). It was also in line with Abdi et al. (2021), which reported that an alkaline eggshell powder removed all FFA (100%) from the oil. This was due to the type of adsorbent used, as the alkaline properties of the eggshell powder caused the complete neutralization of the FFA levels. Therefore, the CC bioadsorbent produced in this study reduced FFA CPO to 51.92%, at a concentration of 3% CC-NaOH in 120 min. This indicated that the CC-NaOH reduced the FFA content in CPO from 5.2 to 2.5%.

3.5. Economic analysis of CC-NaOH plant

Economic analysis was carried out using the discounted cash flow method, whose value was presently projected. This analysis was used to determine the economic feasibility of the project (Ulrich, 1984).

3.6. Estimated total capital investment (TCI)

Total capital investment is the cost incurred to set up and operate the factory. In producing a commodity from raw material, it is calculated from the amounts of fixed and working capital investment (FCI and WCI) (Aries and Newton, 1955; Ziyai et al., 2019). Fixed capital is the total cost of installing process equipment, buildings and tools, in establishing a new factory (Aries and Newton, 1955). Furthermore, FCI consists of two main components, namely direct and indirect costs (D and I) (Özdenkçi et al., 2019; Soetaredjo et al., 2021), with its calculation for fixed capital estimation mathematically formulated by Eq. (3). The FCI of a plant with a similar process and different capacities should also be identified (Aries and Newton, 1955; Kaoma and Gheewala, 2021; Maltsoglou et al., 2014).

$$I_{Fb} = I_{Fa}\left(\frac{r_{mb}}{r_{ma}}\right)^{0.7} \tag{3}$$

where

r_{ma} = factory a monthly production capacity (450 tons/month) or (540 tons/year) (Soetaredjo et al., 2021)
r_{mb} = factory b monthly production capacity (600 tons/month) or (7200 tons/year)
I_{Fa} = fixed capital of factory a (USD 358,250) (Soetaredjo et al., 2021)
I_{Fb} = fixed capital of factory b

Based on Eq. (3), the calculations of IFb and RMB should be conducted IFa and RMA are determined. The exponent of 0.7 for the equation above also changed, because of the process of the plant's condition. From Eq. (3), the total FCI obtained is USD 438,171.

3.7. Working capital investment (WCI)

Working capital includes raw material, in-process, product, extended credit and available cash inventories. The amount of this investment is generally 10–15% of the TCI or 25% of the annual production selling values (Aries and Newton, 1955). For this process, the WCI obtained was 15% of the TCI (Equation 4), which was in line with the study of Lee et al. (2020). Meanwhile, this value was different from that of Soetaredjo et al. (2021) at 30%. As shown in Eq. (5), TCI determination was obtained by the summation of FCI and WCI (Ifa et al., 2020; Özdenkçi et al., 2019; Saba et al., 2019; Ranganathan and Savithri, 2019).

$$WCI = 15\% \cdot TCI \tag{4}$$

$$TCI = FCI + WCI = FCI + 15\% \cdot TCI \tag{5}$$

$$TCI = \frac{FCI}{0.85} \tag{6}$$

Therefore, the total cost to establish and operate the factory is USD 515,495 (from Equation 6).

3.8. Production cost

This is the sum of all Direct, Indirect and Fixed Manufacturing Costs arising from the production process. Besides this, the General Expenses (GE) are known to be factory-based, including administrative, product sales, research and shopping costs, respectively. The TPC results are further shown in Table 1 (Aries and Newton, 1955).

3.9. Profitability and its analysis of project feasibility

Profit is the result obtained from the differences of sales and total production costs and is defined as the excess of income after the deduction of expenses. Furthermore, the estimates of gross and net profits are presented in Eqs. (7) and (8) (Aries and Newton, 1955; Towler and Sinnott, 2013), as well as Table 2.

$$Profit\ before\ taxes = Sales - \ TPC \tag{7}$$

$$Profit\ after\ taxes = \ Profit\ before\ taxes - Income\ taxes \tag{8}$$

Based on Table 2, the income tax according to Lee et al. (2020), was 30%. This result showed an annual net profit of USD 114,400, greater than that of Stolarski et al. (2013), at €30413 or USD 36,157.41 (Stolarski et al., 2013). However, it was lower than the results of Soetaredjo et al. (2021), which was USD 120,000 for a production capacity of 5,400 tons/year (Soetaredjo et al., 2021).

3.10. The Percent Profit on Sales

This is a profit unit expressed as a selling price percentage before and after taxes. It is also the ratio of annual profit divided by income, with the mathematical formula shown in Eq. (9) (Aries and Newton, 1955; Vlysidis et al., 2011).

Table 1. The TPC of the CC-NaOH plant.

No	Item		Unit cost, USD
1	Raw material		192,251
2	Labor	L	46,862
3	Supervision	10%L	68,400
4	Maintenance (M)	2%FCI	8,763
5	Plant supplies	15%M	1,315
6	Royalty and patens	1%S	6,840
7	Utilities	10%S	4,320
Direct Manufacturing Cost (DMC)			329,117
8	Payroll overhead	15%L	7,029
9	Laboratory	10%L	4,686
10	Plant overhead	50%L	23,431
Indirect Manufacturing Cost (IMC)			35,146
11	Depreciation	10%FCI	43,817
12	Property taxes	1%FCI	4,382
13	Asuransi	1%FCI	4,382
13	Packaging	4%S	27,360
	Fixed Manufacturing Cost (FMC)		79,940
Manufacturing Cost (MC)			409,058
14	Administration	3%MC	12,272
15	Distribution & marketing	5% MC	20,453
16	R&D cost	3.5% MC	14,317
17	Financing	5% TCI	25,775
General Expenses (GE)			72,816
Total Production Cost (TPC) = MC + GE			481,874

Table 2. Estimated profit of CC-NaOH plant.

Item	Unit cost, USD	Total, USD
Sales	432,000	
Total production cost	481,874	
Profit before taxes		163,428
Income taxes (30%)	49,028	
Profit after taxes		114,400

$$POS = \frac{Profit}{Product\ selling\ price} \text{x} \ \ 100\% \tag{9}$$

The POS after tax was calculated based on Eq. (9) and the result obtained is observed as 20.68%.

3.11. Rate of return on investment (ROI)

Companies should also have the ability to return capital based on being oriented to profit, especially when they are in form of loans. The annual payback period is expressed as an ROI percentage, which is formulated as a ratio of profit to fixed capital (Peters and Timmerhaus, 2003; Ulrich, 1984; Vlysidis et al., 2011). Moreover, ROI is a certain interest rate based on discounted cash flow, where all receipts exactly cover the capital expenditures. The price trial method was further carried out to comply with Eq. (10).

$$ROI = \frac{Profit}{FCI} \text{x} \ \ 100\% \tag{10}$$

Based on Eq. (10), the ROI price was 39.49% per year, after the collection of taxes. This result was greater than that of Soetaredjo et al. (2021), at 25.77% (Soetaredjo et al., 2021).

3.12. Rate of return (ROR)

The ROR is a certain interest rate based on discounted cash flow (Table 3), where all receipts exactly cover the capital expenditures. The price trial method was used in this process, therefore, producing Eq. (11) (Towler and Sinnott, 2013). The value is found by trial-and-error calculations or the appropriate function (e.g., Goal Seek) in the spreadsheet. Besides the utilized capital, plant life and actual applicable interest rate, the ROR provides a useful method to compare budget performances for different projects. When used as an investment criterion, companies often expected greater ROR than the cost of capital. It is also known as the IRR (Internal Rate of Return) based on being directly compared to interest rates (Towler and Sinnott, 2013).

$$\sum = \left(\frac{CF}{(1+i)^n}\right) = \text{TCI} \tag{11}$$

where

CF = cash flow on n-th year, n = year, $1/(1 + \text{i})^{\text{n}}$ = discount factor.

$$\text{Ratio} = \frac{TPV}{TCI} = 1 \tag{12}$$

(Peters and Timmerhaus, 2003; Towler and Sinnott, 2013).

The interest rate (i) was determined by plotting Eq. (12) and assuming the ratio to be 1.0. When i price is greater than the interest rate of the loan funds, the plant or project is stated to have potentials (Peters and Timmerhaus, 2003). From the above calculation, 28.88% ROR price was obtained per year, with the produced i price observed to be greater than that of the capital loans to banks (5.75%). This indicated a low investment risk (Vlysidis et al., 2011). Therefore, a project/investment is found to be obtained when the ROR is greater than the ROI in the bank. This showed that the feasibility of the factory should continue towards the next stage.

Table 3. Discounted cash flow for i value (Ifa et al., 2020).

n-th year	Net Cash Flow (CF)	Trial i = Present Value
1	109,433	84,906
2	152,327	91,697
3	184,769	86,296
4	185,853	67,347
5	186,938	52,557
6	188,022	41,014
7	189,106	32,005
8	190,190	24,974
9	191,274	19,487
10	192,358	15,205
Total PV		515,487

3.13. Pay out time (POT) or payback period (PBP)

The POT serves as a rapid assessment of risky investment capital period (Short et al., 1995). It is the number of years required to calculate and measure the time value of money and risk level, respectively (Kpalo et al., 2020). The POT is also the time required to receive FCI (Vlysidis et al., 2011). In calculating the POT, the accumulated investment is counted up as shown in Table 4.

Based on Table 4, the interpolation between years 2 and 3 obtained POT at 2.95 years for FCI of USD 438,171. This was shorter than the POT of Soetaredjo et al. (2021), at 2 years and 10 months (Soetaredjo et al., 2021). Okolie et al. (2021), also found longer POT ranging from 3.2-5.4 years (Okolie et al., 2021). For profitable investment, the POT should always be less than the estimated project life (Okolie et al., 2021). Furthermore, fewer years to recover the investment is found to be better for the project (Kpalo et al., 2020). In addition, the POT of this present study was less than the project life, indicating that the proposed plant for CC-NaOH production is profitable.

3.14. Break-even point (BEP)

This is a point when the company neither accumulates profit nor incurs a loss. However, the factory is found to suffer a loss when operated at a capacity below the BEP point. It is also a condition that arises when the plant is operating at full capacity. A good Break-Even Point value for chemical plants often ranged from 40-60% (Aries and Newton, 1955). The BEP analysis is further used to determine the amount of production capacity, where the result of the TPC is the same as the sales. The components of Sales, Fixed, Variable and Semi-Variable Costs (S, FC, VC and SVC), are calculated and presented in Table 5 (Ifa et al., 2020). In addition, the BEP is calculated using Eq. (10) (Aries and Newton, 1955; Soetaredjo et al., 2021).

$$BEP = \frac{FC + 0.3 \cdot SVC}{S - 0.7 \cdot SVC - VC} \, x\, 100\% \tag{13}$$

where;

FC = Fixed Cost
S = Sales
SVC = Semi Variable Cost
VC = Variable Cost

The results obtained a value of 41.68%, indicating that the CC-NaOH plant had no profit or loss (break-even) with a capacity of 3,107.52 tons/year. This was better than the BEP values of Hakizimana and Kim (2016) with Soetaredjo et al. (2021), at 38.02 and 21.5%, respectively. Also, a good BEP value for chemical plants often ranged from 40-60% (Aries and Newton, 1955).

Table 4. Cumulative cash flow (USD) (Ifa et al., 2020).

n-th year	Net Cash Flow	Cumulative Cash
1	109,433	109,433
2	152,327	261,761
3	184,769	446,530
4	185,853	632,383
5	186,938	819,321

Table 5. Fixed cost, variable cost, semi variable cost, sales.

No	Item	Unit cost, USD
1	Fixed Cost, FC	79,940
2	Variable Cost, VC	
	a. Raw materials	192,251
	b. Utilities	68,400
	c. Packaging & shipping	27,360
	Royalty and patent	6,840
	Total variable cost (VC)	294,851
3	Semi-variable Cost, SVC	
	a. Labor	46,862
	b. Supervision	8,763
	c. Maintenance & repairs	4,686
	d. Operating supplies	1,315
	d. Laboratory	4,686
	e. General Expenses	72,816
	f. plant overhead cost	7,029
	Total Semi-variable cost	146,158
4	Total Sales (S)	684,000

Based on this study, the FCI of the CC-NaOH plant was calculated using Eq. (3). Furthermore, WCI and TCI were calculated through Eqs. (4) and (6), with values at USD 65,725.65 and USD 503,896.65, respectively. The TPC of the CC-NaOH plant also contained the MC and GE. The calculated TPC was observed at 481,874 and the details of its components were shown in Table 1. Also, the CC-NaOH was sold for USD 95/ton, which was USD 5/ton lower than the reported selling price (Soetaredjo et al., 2021). Therefore, the annual sales (S) of CC-NaOH Products cost USD 684,000, with gross and net profits of USD 202,126 and USD 141,188 after taxes, respectively. The value of POS after tax was further calculated through Eq. (9), obtaining 20.68%. The ROI value was also calculated based on Eq. (10) and obtained a value of 39.49%. The factory selling price was found above the break-even point, indicating profitability (Okolie et al., 2021). In addition, the POTwas calculated based on the discounted cash flow method, leading to a payment period of 2.95 years. From Eq. (13), the calculated BEP obtained 43.16%.

4. Conclusion

The CC bioadsorbent of 3% w/v produced the largest percentage reduction in FFA levels (34.62%) at the best contact time (120 min). Using the NaOH activator, this time produced a reduction of 51.92%. Meanwhile, these FFA level reductions depended on the utilized concentration and contact time. In this study, the results were able to reduce FFA levels from the utilized CPO. Based on the detailed estimates, the production cost of CC-NaOH was 481,874, sold at USD 95/ton with annual sales and net profit (after tax) at USD 684,000and USD 141,188. The after-tax profit (POS) was also 20.68%, with an annual ROR, POT and BEP of 39.49%, 2.95 years and 43.16% (3,107.52 tons/year), respectively. This indicated that the CC- NaOH was in a state of neither profit nor loss (break-even).

Declarations

Author contribution statement

La Ifa: Conceived and designed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data.

Takdir Syarif, Sartia Sartia: Conceived and designed the experiments; Performed the experiments.

Juliani Juliani: Performed the experiments; Analyzed and interpreted the data.

Nurdjannah Nurdjannah, Heri Septya Kusuma: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper.

Funding statement

This work was supported by the Ministry of Education, Culture, Research and Technology, Republic of Indonesia through the PTUPT scheme (No. Kontrak 070/SP2H/LT/DRPM/2021).

Data availability statement

Data included in article/supplementary material/referenced in article.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

Acknowledgements

The authors are grateful to Universitas Muslim Indonesia (UMI) and the Department of Chemical Engineering, for providing necessary laboratory equipment and facilities important to this study.

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