

SYNTHESIS OF METHYL ESTER FROM OFF GRADE CRUDE PALM OIL USING CaO/ α -Fe₂O₃ AND ITS POTENTIAL AS BIODIESEL

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Abstract— Crude Palm Oil (CPO) with low quality was known as Off Grade CPO. It is potential as biodiesel feedstock. The study was to synthesize methyl esters from Off Grade CPO using a CaO/ α -Fe₂O₃ catalyst. The experimental laboratory carried out: activation of natural zeolite, characterization of Off Grade CPO, refinement, synthesis of CaO/ α -Fe₂O₃, esterification, trans-esterification using CaO/ α -Fe₂O₃ with mass variation (8:2, 7:3, 6:4), characterization, and identification by GC-MS test. The results showed that Off Grade CPO had the characteristics, i.e: 0.923 g.cm⁻³ density, 52.27 cSt viscosity, and 15.20% free fatty acid (FFA). CaO/ α -Fe₂O₃ catalyst was successfully synthesized by wet impregnation. The best conditions for trans-esterification occurred at a mole ratio of oil:methanol (1:12), catalyst 3% wt of oil, 60 °C, 3 hours, and mass ratio of CaO: α -Fe₂O₃ (8:2). The synthesized methyl ester had the characteristics of: 0.851 g.cm⁻³ density, 4.790 cSt viscosity, 1.447 refractive index, and 0.50 acid number which was suitable with SNI Biodiesel 7182:2015.

Keywords — heterogeneous catalyst, off grade crude palm oil, methyl ester, transesterification.

I. INTRODUCTION

Crude Palm Oil (CPO) was important oil with 54% of the world's total production (Rahman *et al.*, 2016). CPO is the main raw material in the process of edible oil production. The edible oil industry has quality standards, and the palm fruit that was still young, overripe, and rotten (off grade) was not used and ended up as waste, because it reduced the quality of edible oil products. Off grade CPO contained high levels of fatty acids. It had the potential to be used as raw material for biodiesel production. More than 75% of the cost of biodiesel production came from the cost of raw materials for vegetable oils and animal fats with good quality. It could reduce the efficiency value of biodiesel production (Huang and Chang, 2010; Lee *et al.*, 2015). In addition, the use of good vegetable oils and good animal fats as raw materials for biodiesel was feared to affect the stability of edible oil production, so that the use of Off Grade CPO as an alternative raw material for biodiesel could increase the efficiency value of biodiesel production. The large CPO production was directly proportional to the produced off grade CPO, so

the availability of raw materials will remain sufficient and biodiesel production will continue (Sumari *et al.*, 2021).

Biodiesel is an alternative energy source that can replace petro-diesel. Biodiesel has biodegradable, renewable, and environmentally friendly properties. Biodiesel has advantages such as reducing air pollution levels, increasing efficiency in vehicle engines, non-toxic and renewable. The growing industry and transportation caused to also increase the use of fuel. The use of petroleum as an energy source was necessary to be replaced by using biodiesel to reduce the risk of air pollution and global warming, due to the increased concentrations of SO_x and CO gases in the air (Kim *et al.*, 2004).

Biodiesel is produced through a trans-esterification reaction between fatty acids (triglycerides) and alcohol assisted by catalyst to produce alkyl esters and glycerol. Homogeneous catalysts were difficult to separate biodiesel products and the resulting waste was not environmentally friendly. Alternatively, a homogeneous catalyst was replaced by heterogeneous catalyst. Heterogeneous catalysts that have been used in trans-esterification included alkali metal oxides and various alkali metal oxides supported by alumina or zeolite. The advantages of using heterogeneous catalysts were non-corrosive, non-toxic, environmentally friendly, easily separated from biodiesel products, and have higher activity (Liu *et al.*, 2008).

Calcium oxide (CaO) was a solid base catalyst that has been widely studied in the trans-esterification process. CaO had strong alkaline properties and was recognized as a strong base catalyst by many researchers (Liu *et al.*, 2008; Sumari *et al.*, 2022). The use of CaO as a solid base catalyst had many advantages, including high catalytic activity, stable catalyst conditions, strong catalyst resistance, abundance of catalyst and reusable. CaO had also a weakness, i.e.: the specific surface area of the small particles, so that it was less efficient and caused low conversion rates of alkyl esters by CaO (Lin *et al.*, 2012). As a problem solving, catalyst was necessary to be impregnated with a support catalyst to optimize the catalytic activity of CaO.

Iron nanoparticle (magnetite, maghemite, and hematite) has potential as catalysts because of their large surface area. Research on CaO/Fe₃O₄ catalysts in trans-esterification showed the highest conversion rate of methyl

ester at 7:1 catalyst composition and the decreased conversion at 10:1 catalyst composition (Liu *et al.*, 2010). Hematite ($\alpha\text{-Fe}_2\text{O}_3$) was an iron nanoparticle that has a higher thermal stability than other iron oxides (including Fe_3O_4). It was an excellent material as catalyst (Khan *et al.*, 2011). Hematite is expected to find the optimization of reaction process, so that hematite nano-particles have the potential as a support catalyst for CaO.

Research on the synthesis of methyl esters from off grade CPO using a CaO/ $\alpha\text{-Fe}_2\text{O}_3$ catalyst needs to be carried out. The study also tested its potential as biodiesel based on SNI 7182:2015. The purposes of the study were: to determine the characteristics of off grade CPO, to determine the best conditions for the synthesis of methyl esters from off grade CPO using a CaO/ $\alpha\text{-Fe}_2\text{O}_3$ catalyst, and to determine the characteristics of the synthesized methyl esters.

II. METHODS

The research was experimental laboratory research at Chemistry Laboratory, Universitas Negeri Malang for 6 months. The used tools were glassware, staves, clamps, filler, digital balance with an accuracy of 0.0001 g (Durasclae DAB 200), porcelain dish, crucible, 100 mL separating funnel (iwaki brand), a set of 300 mL reflux apparatus (iwaki brand), thermometer 100°C, mortal and pastel, universal indicator (Merck), filter paper, aluminium foil, desiccator, buncher set, centrifuge (H-103n kokusan), magnetic stirrer, hot plate (HMS-79), furnace (Thermolyne), oven (Memmert), 50 mesh sieve, Ostwald viscometer, X-Ray Diffraction (Panalytical Xpert-Pro), X-Ray Fluorescence (Pananalyticalminipal 4). GC-MS (Shimadzu QP2010 Plus). Meanwhile, the used materials in the study were natural zeolite obtained from Blitar, East Java, Indonesia, CaO p.a, Off Grade Crude Palm Oil obtained from Industry, solid FeCl_3 p.a. (Merck), solid FeSO_4 p.a. (Merck), solid NaOH p.a. (Merck), anhydrous MgSO_4 , Methanol p.a. (Merck), 95% ethanol, HCl 37% p.a. (Merck), H_2SO_4 p.a. (Merck), Sodium oxalate p.a. (Merck), phenolphthalein indicator, KOH p.a. (Merck), and distilled water.

A. Activation of Natural Zeolite Using HCl

Natural zeolite was activated physically and chemically before application as an adsorbent in the refining process. Physical activation of zeolite was carried out by grinding and sieving zeolite with a size of 100 mesh to uniform particle size and widen the surface of the zeolite. Chemical activation was carried out by reacting the zeolite with 3 M HCl to remove impurities in the zeolite. Natural zeolite was sieved with a particle size of 100 mesh and it was washed with distilled water. Then, the natural zeolite was filtered using a Buchner funnel. Next, it was dried at 105°C for 2 hours. Furthermore, the dry zeolite was characterized using X-Ray Fluorescence (XRF). Then, 100 g dry zeolite and 100 mL HCl 3 M were stirred for 3 hours at room temperature. The zeolite was neutralized to pH 6-7. Furthermore, the zeolite was heated at 105 °C for 2 hours, then it calcined at a temperature of 300 °C (Santoso *et al.*, 2019). The activated Zeolite was characterized using X-Ray Fluorescence (XRF)

B. Refining of Off Grade CPO Using Activated Natural Zeolite

Off grade CPO was characterized before being used as biodiesel feedstock to determine its free fatty acid content. The characterization of off grade CPO in the study included density, viscosity, free fatty acid content of off grade CPO (Santoso *et al.*, 2021).

Refining of Off grade CPO was carried out by adding 3% (w/w) HCl-activated natural zeolite into off grade CPO oil in a 500 mL beaker. Then, the mixture was heated at a temperature of 170 °C and it was stirred using a magnetic stirrer for 1 hour. The refined CPO off grade was centrifuged at 3,000 rpm for 10 minutes. Then, it was characterized by its density, viscosity, and free fatty acid content (Santoso *et al.*, 2018, 2019, 2021).

C. Synthesis of CaO/ $\alpha\text{-Fe}_2\text{O}_3$ Catalyst

$\alpha\text{-Fe}_2\text{O}_3$ (Hematite) nanoparticles were synthesized by modified method (Puspasari, 2013; Septiana *et al.*, 2013). The synthesis was carried out by reacting 20 mL of 0.25 M FeSO_4 solution with 20 mL of 0.5 M FeCl_3 . The resulting mixture was added 50 mL of 1.5 M NaOH solution slowly and it was stirred using a magnetic stirrer until homogeneous. Then, the mixture was filtered using fine filter paper and it was washed using distilled water until the pH of the filtrate at 7. The obtained residue was heated in an oven at a temperature of 60-65 °C for 3 hours. The solid was calcined at temperatures of 300 °C and 800 °C to produce maghemite ($\gamma\text{-Fe}_2\text{O}_3$) and hematite ($\alpha\text{-Fe}_2\text{O}_3$). The obtained Hematite ($\alpha\text{-Fe}_2\text{O}_3$) was characterized by X-Ray Diffraction (XRD).

CaO/ $\alpha\text{-Fe}_2\text{O}_3$ catalyst was synthesized by wet impregnation method. The synthesis applied various mass ratios of CaO and $\alpha\text{-Fe}_2\text{O}_3$ (8:2, 7:3, 6:4). For mass ratio of 8:2, the procedures were: dissolving of 8 g CaO with a little distilled water in a three-neck flask and adding of 2 g $\alpha\text{-Fe}_2\text{O}_3$ (hematite) powder. The formed mixture was refluxed at 70 °C for 3 hours with stirring. The reflux mixture was dried at 100 °C and it was calcined at 700 °C for 4 hours. The obtained CaO/ $\alpha\text{-Fe}_2\text{O}_3$ catalyst was characterized by X-Ray Diffraction (XRD).

D. Esterification of Off Grade CPO Using H_2SO_4

The esterification process was carried out by putting 50 g of refined off grade CPO in a three-neck flask which had been assembled with reflux and a magnetic stirrer. Then, the mixture was added methanol with a mole ratio of oil: methanol about 1:12 to the oil. The mixture was refluxed at 40 °C, then 1% H_2SO_4 was added with stirring for 3 hours at a constant temperature of 60 °C. Moreover, the mixture was separated in a separatory funnel for 24 hours until 2 layers were formed. The formed two layers were separated between oil phase (top layer) and water phase (bottom layer). The obtained oil was washed using warm water in a separating funnel. Then, the oil was heated to a temperature of 90-100 °C and anhydrous MgSO_4 was added. The esterified off-grade CPO oil was measured for its density, viscosity, and free fatty acid content.

E. Transesterification of Off Grade CPO Using CaO/ $\alpha\text{-Fe}_2\text{O}_3$

The esterified off grade CPO oil was weighed about 20 g. Then, it put into a reflux set with 60 °C heating. After the temperature reached 60 °C, methanol was added to the oil with a mole ratio of oil: methanol about 1:12, and CaO/ α -Fe₂O₃ catalyst was added too (variations of the catalyst composition were 8:2, 7:3, and 6:4). Next, the mixture was stirred and refluxed at 60 °C for 4 hours. The obtained results were centrifuged at 3000 rpm for 10 minutes. The resulting oil and glycerol were put into a separating funnel for 24 hours until two layers were formed. The top layer suspected to be methyl ester was washed with warm water. The obtained methyl ester was heated at a temperature of 90-100 °C and anhydrous MgSO₄ was added. Then, yield was calculated by:

$$\text{Yield} = \frac{\text{mass of synthesized methyl ester}}{\text{mass of theoretical methyl ester}} \times 100\% \quad (1)$$

F. Characterization and Identification of The Synthesized Methyl Ester

Characterization of methyl esters included shape, color, density, viscosity, refractive index, and acid number. The shape and color of the methyl ester was observed by comparison between before and after treatment.

Density was determined with picnometer 25 mL. Methyl ester was put into picnometer full and nothing bubble. Then, it weighed. Density value was calculated by:

$$\text{density} (\rho) = \frac{m_2 - m_1}{V} \quad (2)$$

where m_1 is mass of vacuum picnometer 25 mL, m_2 is mass of piknometer 25 mL + oil and V is oil volume.

Viscosity was determined by viscosimeter *Ostwald*. Oil was sucked until two boundary marks. Then, time was noted from up boundary mark to down boundary mark. Then, viscosity was calculated by:

$$\frac{\eta_{\text{water}}}{\eta_{\text{sample}}} = \frac{\rho_{\text{water}} \times t_{\text{water}}}{\rho_{\text{sample}} \times t_{\text{sample}}} \quad (3)$$

where η is viscosity (cSt), ρ is density (g.cm⁻³) and t is time (s).

Refractive index was determined by refractometer Abbe. CPO was dripped at glass with ethanol. Refractive index value was calculated by:

$$n = n' + k(T' - T) \quad (4)$$

where n is refractive index value at 25°C, n' is refractive index value at observation temperature, k is correction factor (0.00045), T' is observation temperature and T is 25°C.

Acid number was carried out with: 1 g CPO 5 mL ethanol were put into Erlenmayer 100 mL. Then, it was heated into water bath for 10 minutes. Then, it was added Phenolphthalein indicator and titration with KOH 0,1N.

Acid number was calculated by:

$$\text{Acid number} = \frac{56.1 \times N \times V}{m} \quad (5)$$

where N is the Normality KOH (N), V is the volume of KOH (mL), m is the sample mass (g), and 56.11 is the equivalent mass of KOH.

Identification of the synthesized methyl ester components used GC-MS test, in order to obtain chromatogram data and mass spectra (Santoso *et al.*, 2021). These data were analyzed further.

III. RESULTS

A. Active Natural Zeolite

Zeolite before and after activation can be seen the difference in Fig. 1.

The color of the zeolite before activation changed to be dark in color, while the zeolite after activation had a lighter color. The color fading was caused by the zeolite had lost impurities in the zeolite structure. Zeolite that has been reacted in HCl will undergo a dealumination process. The release of Al from the zeolite structure caused the Si/Al ratio to increase in the Si/Al ratio as shown in Table 1. That is, the pore surface area of natural zeolite increased due to the loss of impurity components in the zeolite (Pamungkas *et al.*, 2015; Imandiani *et al.*, 2018; Santoso *et al.*, 2022).

B. Refined Off Grade CPO

Crude palm oil (CPO) was characterized prior to the refining process to determine the quality of CPO through its physico-chemical properties. The results of CPO characterization are shown in Table 2.

The Off Grade CPO was still not suitable as biodiesel raw material because the free fatty acid content in CPO was still high which was known as off grade (Sumari *et al.*, 2021). Therefore, Off Grade CPO oil needed to be refined. The refining process aimed to produce oil that was clean, has a good color, and can be used as raw material. Off grade CPO oil before and after refinement was shown in Fig. 2.

The refining process using activated zeolite could also reduce the density, and free fatty acid content of the oil as shown in Table 2. Table 2 showed that the fatty acid content of CPO oil which will be used as biodiesel raw material was still above 2%. The synthesis of methyl esters through the trans-esterification reaction can be

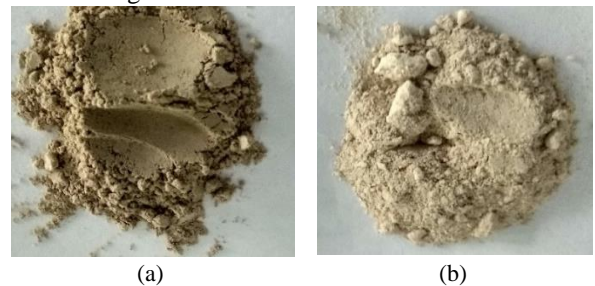


Figure 1: Natural Zeolite: (a) Before Activation, and (b) After Activation.

Table1. Ratio of Si/Al of Natural Zeolite on Before Activation and After Activation

Zeolite	% Si	% Al	Ratio of Si/Al
Before Activation	58.7	7.6	7.459
After Activation	73.8	5.6	12.734

Table2. Characterization Result of Off Grade CPO

Parameter	Before refining	After refining
Density (g.cm ⁻³)	0.923	0.907
Free Fatty Acid (FFA) (%)	15.20	10.01



Figure 2: Off Grade CPO from: (a) Before Refinement and After Refinement.

carried out if the free fatty acid content in the raw materials used is less than 2% so that to reduce the acid content of the refined oil, it is necessary to carry out an esterification reaction first.

C. Synthesized $\text{CaO}/\alpha\text{-Fe}_2\text{O}_3$

The catalyst synthesis in the study was carried out in two stages, i.e. the synthesis of hematite ($\alpha\text{-Fe}_2\text{O}_3$) and impregnation of CaO into hematite. The synthesized hematite ($\alpha\text{-Fe}_2\text{O}_3$) was then characterized using X-Ray Diffraction (XRD) (Fig. 3). The hematite XRD diffractogram is indicated by the appearance of peaks at an angle of $2\theta = 24.32^\circ; 33.35^\circ; 35.80^\circ; 41.05^\circ; 49.67^\circ; 54.28^\circ; 62.64^\circ; 64.20^\circ; \text{ and } 72.19^\circ$ according to JCPDS No. 89-0598 and showed that hematite ($\alpha\text{-Fe}_2\text{O}_3$) has been successfully synthesized.

Synthesis of $\text{CaO}/\alpha\text{-Fe}_2\text{O}_3$ through impregnation method (Ho *et al.*, 2014). The formed $\text{CaO}/\alpha\text{-Fe}_2\text{O}_3$ catalyst was brown. Then, the synthesized catalyst was tested for basicity using the Hemmet indicator and a purple color was produced after the addition of phenolphthalein indicator which indicated that the catalyst was alkaline properties. Furthermore, the diffractogram of $\text{CaO}/\alpha\text{-Fe}_2\text{O}_3$ characterization using XRD was shown in Fig. 3, and it showed the appearance of peaks at an angle of $2\theta = 28.68^\circ; 33.33^\circ; 47.24^\circ; 54.30^\circ; \text{ and } 57.96^\circ$. In accordance with JCPDS No. 32-0168, it proved that the $\text{CaO}/\alpha\text{-Fe}_2\text{O}_3$ catalyst has been successfully synthesized. The morphology of the $\text{CaO}/\alpha\text{-Fe}_2\text{O}_3$ catalyst was characterized using Scanning Electron Microscopy (SEM) with a scale of 10 μm and a magnification of 2500 times which was presented in Fig. 3. The SEM image showed the shape of the catalyst in the form of an amorphous powder.

D. Synthesis of Methyl Ester with $\text{CaO}/\alpha\text{-Fe}_2\text{O}_3$

Methyl ester synthesis was carried out in two stages, i.e. esterification using an H_2SO_4 catalyst and trans-esterification using a $\text{CaO}/\alpha\text{-Fe}_2\text{O}_3$ catalyst. Esterification was carried out by reacting excess oil and methanol assisted by H_2SO_4 . Esterification using strong acids was very effective for oils that still have high levels of free fatty acids (Fukuda *et al.*, 2001). After esterification, the oil was characterized by density, viscosity and free fatty acid content. The characteristic of the esterified oil was $0.910 \text{ g}\cdot\text{cm}^{-3}$ of density, 18.13 cSt of viscosity, and 0.816% of free fatty acid. The results showed that the free fatty acid content of the esterified oil was less than 2%, so the oil was ready to be used in the next synthesis process

through the trans-esterification reaction to produce biodiesel methyl esters. The transesterification process was carried out after esterification. The results of the transesterification of off grade CPO using a $\text{CaO}/\alpha\text{-Fe}_2\text{O}_3$ catalyst showed the formation of two layers, the bottom layer was glycerol and the top layer was estimated to be

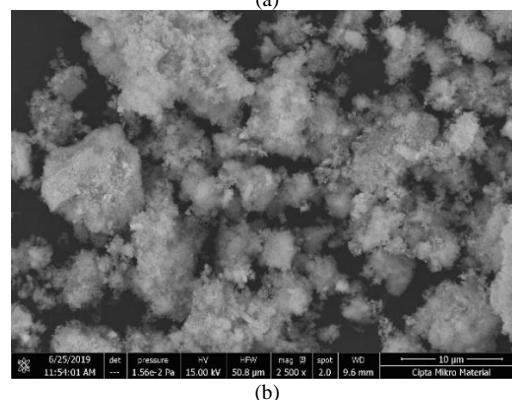
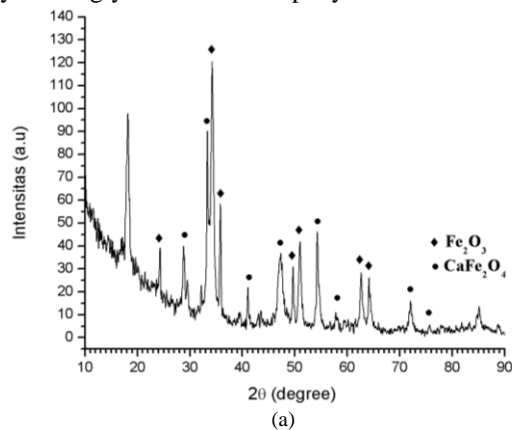


Figure 3: $\text{CaO}/\alpha\text{-Fe}_2\text{O}_3$ Results: (a) Diffractogram and (b) SEM.

synthesized methyl ester.

E. Characterization of Methyl Ester of Off Grade CPO Katalis $\text{CaO}/\alpha\text{-Fe}_2\text{O}_3$

The characterization of the synthesized methyl ester included density, viscosity, refractive index, and acid number. The results of the characterization were compared with SNI Biodiesel 7182:2015 as shown in Table 3.

The density of the synthesized methyl ester of off grade CPO decreased from $0.923 \text{ g}\cdot\text{cm}^{-3}$ to 0.851 , 0.867 , and $0.871 \text{ g}\cdot\text{cm}^{-3}$. The synthesized methyl ester using a catalyst composition ratio of 8:2, 7:3, and 6:4 had potential as biodiesel because the density values of the three met the SNI Biodiesel quality standard 7182:2015. The density of methyl ester that exceeded the quality standard of SNI Biodiesel 7182:2015 was not good for use as biodiesel fuel because it can interfere with the combustion process in the engine.

The viscosity of the synthesized methyl ester from off grade CPO decreased from the viscosity of refined CPO 30.64 cSt to 4.79 cSt, 5.04 cSt, and 6.02 cSt. The synthesized methyl ester using a catalyst composition ratio of 8:2 and 7:3 had potential as biodiesel because the viscosity values of both met the SNI Biodiesel No. 7182:2015.

The refractive index of the synthesized methyl ester

Table 3. Characterization of Methyl Ester Compared with SNI Biodiesel

Characterization	Mass Ratio of CaO and Fe ₂ O ₃			SNI Biodiesel 7185:2015
	8:2	7:3	6:4	
Density (g.cm ⁻³)	0.851	0.867	0.871	0.850 – 0.950
Viscosity (cSt)	4.790	5.042	6.022	2.3 – 6.0
Refractive Index	1.447	1.445	1.446	1.3 – 1.45
Acid Number	0.50	1.23	0.48	Max, 0.5
Yield (%)	57.73	53.53	51.58	
Potential as Biodiesel	Potential	-	Potential	

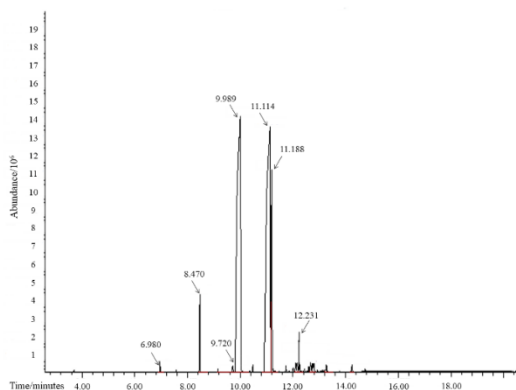
Figure 4: GC-MS Chromatogram of Methyl Ester of Off Grade CPO Using CaO/ α -Fe₂O₃.

Table 4. Characterization Data of Methyl Ester Component

Peak	Retention Time	Component	Percentage(%)
1	6.964	Methyl laurate	0.28
2	8.468	Methyl myristate	2.17
3	9.990	Methyl palmitate	42.56
4	11.110	Methyl oleate	43.61
5	11.187	Methyl stearate	7.52
6	12.230	Methyl arachidate	1.12

using a CaO/ α -Fe₂O₃ catalyst with mass ratios (8:2), (7:3), and (6:4) met the SNI Biodiesel 7182:2015. So, it had the potential to be used as biodiesel fuel.

The acid number of methyl esters synthesized using a CaO/ α -Fe₂O₃ catalyst with a catalyst composition ratio of 8:2 and 6:4 met the quality standard of SNI Biodiesel 7182:2015, so that it had the potential to be used as biodiesel fuel. Catalysts with a mass ratio of 6:4 did not meet the quality standards because the synthesis and washing processes of the synthesis products were not optimal, so that the acid number of the methyl esters was still high.

Furthermore, the increasing amount of CaO in the catalyst, the greater the yield produced because the more active sites are on the catalyst, so that the reaction can run more optimally (Liu *et al.*, 2010). The larger the mass ratio of Ca to Fe can affect the active site of the catalyst so that the yield of methyl ester produced will increase.

Thus, the synthesized methyl ester using a CaO/ α -Fe₂O₃ catalyst with a catalyst composition ratio of 8:2 and 6:4 had characteristics that were in accordance with the SNI Biodiesel 7182:2015, so that it can potentially be used as biodiesel fuel. Catalysts with a mass ratio of 7:3 did not meet the standards because the acid number was still high so it was not potentially used as biodiesel.

F. Identification of Methyl Ester of Off Grade CPO Using GC-MS

Chromatogram of GC-MS methyl ester from off grade CPO synthesis using CaO/ α -Fe₂O₃ catalyst was shown in Fig. 4

Figure 4 showed that in the GC-MS chromatogram there were six compounds that make up methyl esters. The retention time and area of the compound composing methyl esters were shown in Table 4. The mass spectrum of the synthesized methyl ester was shown in Fig. 5. The mass spectra at each retention time were compared for similarity with the library data on W10N14.L, and the fragmentation pattern was analyzed (data not shown here).

Table 4 showed the composition of the synthesized methyl esters with the highest concentrations of methyl palmitate 42.56% and methyl oleate 43.61%. These results were in accordance with the research of Gee (2007) which showed that the main constituent compounds of CPO were palmitic acid and oleic acid. It will produce methyl palmitate and methyl oleate in large percentages (Fig. 5).

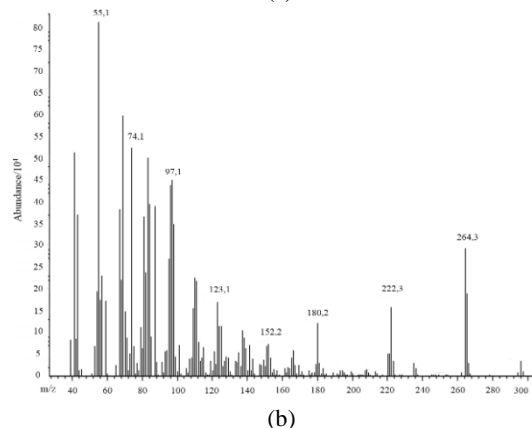
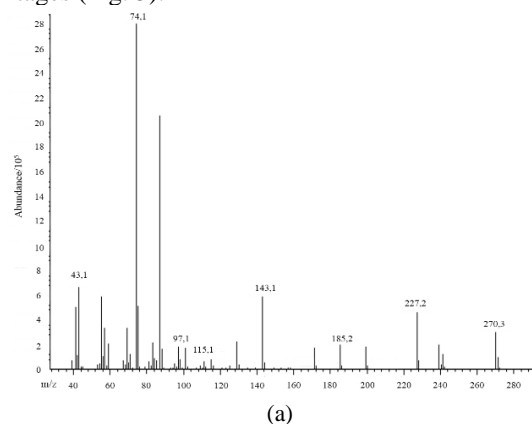


Figure 5: Mass Spectra of Methyl Ester with Retention Time (minutes): (a) 9.990, (b) 11.110.

V. CONCLUSIONS

Based on the results of the research that has been carried out, conclusions were (1) the characteristics of off grade CPO used as raw material for methyl ester synthesis had 0.923 g,cm^{-3} density, 52.27 cSt viscosity, and 15.20% free fatty acid content, (2) CaO/ α -Fe₂O₃ catalyst was successfully synthesized by impregnating CaO into α -Fe₂O₃ indicated by the results of XRD diffractogram according to JCPDS No. 32-0168, (3) the best conditions for the synthesis of methyl esters from off grade CPO using a CaO/ α -Fe₂O₃ catalyst were achieved at a catalyst composition of 8:2, a temperature of 60 °C, and a synthesis time of 3 hours, (4) the characteristics of the synthesized methyl esters from Off grade CPO using CaO/ α -Fe₂O₃ had 0.851 g,cm^{-3} density, 4.79 cSt viscosity, 1.447 refractive index, and 0.45 acid number which was in accordance with the quality standard of SNI Biodiesel 7182:2015. The components of the methyl ester synthesis from off grade CPO using a CaO/ α -Fe₂O₃ catalyst included: 0.28% methyl laurate, 2.17% methyl myristate, 42.56% methyl palmitate, 43.61% methyl oleate, 7.52% methyl stearate, and 1.12% methyl arachidate.

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