

## Effect of HCl/ $\gamma$ -Al<sub>2</sub>O<sub>3</sub> and HCl/Ni/ $\gamma$ -Al<sub>2</sub>O<sub>3</sub> Catalyst on The Cracking of Palm Oil

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### Abstract

Fuel oil has a deficit every year. Therefore, a substitute fuel is needed, which can be obtained more efficiently. One of the alternative fuels that have been widely researched is biofuel. Catalytic cracking is a method of producing biofuels such as biogasoline (C<sub>5</sub>-C<sub>9</sub>), bioavtur (C<sub>10</sub>-C<sub>15</sub>) and green diesel (C<sub>16</sub>-C<sub>22</sub>). This research aims to produce biofuels by catalytic cracking of palm oil using HCl/ $\gamma$ -Al<sub>2</sub>O<sub>3</sub> and HCl/Ni/ $\gamma$ -Al<sub>2</sub>O<sub>3</sub> catalysts (1, 3, 5 and 7%). The catalyst was prepared by wet impregnation and characterized by x-ray diffraction, Brunauer Emmett teller and ASTM-D664. The reaction cracking process was operated at a constant temperature of 370 °C, 50 ml volume, and 1 atm pressure. The best catalyst for cracking palm oil is HCl/Ni/ $\gamma$ -Al<sub>2</sub>O<sub>3</sub> (5%) with a yield of 81%, selectivity to biogasoline at 6.41%, bioavtur at 33.81%, and green diesel at 20.33%.

**Keywords:** Bioavtur, biogasoline, catalytic cracking, green diesel.

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### 1. INTRODUCTION

Biofuels are produced from the carbon chain cracking of complex triglyceride molecules. The addition of a catalyst can accelerate the reaction. The catalysts often used to manufacture biofuels are homogeneous catalysts made of strong alkalis such as NaOH and KOH or strong acids such as HCl and H<sub>2</sub>SO<sub>4</sub>. Using an acid or alkaline homogeneous catalyst has advantages and disadvantages. The performance of homogeneous alkaline catalysts in accelerating the transesterification reaction is better than acid catalysts. However, alkaline solid catalysts are prone to saponification, especially when the materials have free fatty acids and high water content. As a result, the reaction could run better. Acid catalysts are more resistant to water and free fatty acids, increasing the likelihood of the reaction succeeding.

Homogeneous catalysts also have other disadvantages. They are difficult to separate from the product, so the catalyst residue is frequently left behind, lowering the quality of the biofuel. Due to these drawbacks, using heterogeneous catalysts in biofuel production

is becoming more popular. The advantages of heterogeneous catalyst are that it is more environmentally friendly, not corrosive, easily separated from the product, and can be recycled without damaging the product quality, making production costs more economical (Khodijah & Irsan, 2020).

Heterogeneous catalysts require support, such as gamma alumina ( $\gamma$ -Al<sub>2</sub>O<sub>3</sub>). Gamma alumina ( $\gamma$ -Al<sub>2</sub>O<sub>3</sub>) can be used as catalyst support because it has a large surface area (150-300 m<sup>2</sup>/g) to extend the contact between the active core and the reactants without reducing the active phase activity of the active phase substances. Moreover, it has an acidic and alkaline active site with intense atmospheres, depending on how it is made (Rasyid *et al.*, 2018).

Several processes have been carried out to produce biofuels, including the esterification-transesterification process and the non-catalyzed cracking process (thermal cracking). Transesterification converts triglycerides (vegetable oils) into alkyl esters through a reaction with alcohol, producing a by-product, glycerol (Dewanti *et al.*, 2021). An

ingredient's free fatty acid (FFA) value must be low (<2%) before processing; otherwise, a saponification reaction will occur. Separation of products with catalysts and by-products from this process is quite tricky and takes a relatively long time (Budianto *et al.*, 2019). In contrast, the non-catalyzed cracking process makes biofuel that requires high temperatures and pressures, so it requires energy and enormous production costs (Rasyid *et al.*, 2018).

The production of biofuels with a catalyzed cracking process is currently being developed. This process cracks complex hydrocarbons into simpler molecules and can take place at low temperatures and pressures in the presence of a catalyst (Tambun *et al.*, 2016). The catalytic cracking process of vegetable oils carried out by previous researchers produced various types of biofuels whose composition was influenced by several factors, including reaction time, reaction temperature, and the selectivity of the catalyst used. Several types of catalysts have been used in the biofuel manufacturing process by catalytic cracking methods, including Ni/TiO<sub>2</sub> dan Co/TiO<sub>2</sub> (Latipah *et al.*, 2017), MoCo-HZ (Muryati *et al.*, 2018), CaO (Hajj *et al.*, 2019), Zn-HZSM-5/ $\gamma$ -Alumina, Pt/Al<sub>2</sub>O<sub>3</sub> (Monde *et al.*, 2019), Fe-Zeolit (Adhani *et al.*, 2020). The selection of heterogeneous acid catalysts with  $\gamma$ -Al<sub>2</sub>O<sub>3</sub> support in this research was based on the results of previous studies, which showed the results of acid catalysts had advantages

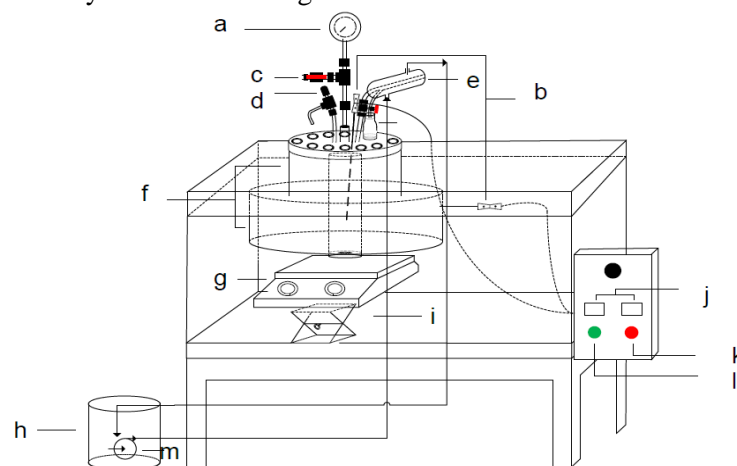
with a better reaction success rate than alkaline catalysts. It is because they were not sensitive to free fatty acids and water content in the material and were not easily poisoned by ambient air. Heterogeneous acid catalysts were divided into acid catalysts with and without a Ni promoter. Gamma-alumina ( $\gamma$ -Al<sub>2</sub>O<sub>3</sub>) supported acid catalyst has good performance and high-temperature resistant structures, so it will not interfere with the performance of each structure (Savitri *et al.*, 2016).

This research aims to make biofuels through a catalytic cracking process with a supported catalyst ( $\gamma$ -Al<sub>2</sub>O<sub>3</sub>) at a state of 1 atm with a heterogeneous acid catalyst without a promoter and a heterogeneous catalyst with Ni metal as the promoter. The selection of Ni metal as a promoter is based on the nature of Ni, which has high activity as a catalyst and forms a relatively weak bond to the reactants so that the reaction products will be easily separated from the surface of the catalyst and the reaction process will be faster. This research will produce several biofuel products, namely green diesel, bioavtur, and biogasoline, depending on the selectivity of the catalyst for the biofuel product.

## 2. MATERIALS AND METHODE

### Material and Instruments

Palm oil (commercial), HCl (pa), Ni(NO<sub>3</sub>)<sub>2</sub>.6H<sub>2</sub>O (p.a) Merck,  $\gamma$ -Al<sub>2</sub>O<sub>3</sub> (p.a) Merck.



**Figure 1.** Catalytic cracking reactor Information:

a. Pressure gauge  
b. Thermocouple  
c. Inletgas  
d. Closing valve  
e. Condenser

f. Reactor  
g. Magnetic hotplate  
h. Cooling water container  
i. Buffer  
j. Temperature indicator

k. heater button  
l. Power Button  
m. Pump

### Preparation of HCl/ $\gamma$ -Al<sub>2</sub>O<sub>3</sub> Catalyst

HCl 0.4 N impregnated up to 14 ml of 10 gram catalyst support ( $\gamma$ -Al<sub>2</sub>O<sub>3</sub>). Then the mixture was stirred using a hotplate magnetic stirrer while evaporating the water in the mixture to form a paste. When the mixture has formed a paste, stop stirring. Then, dry the mixture at 110 °C for 8 hours. The final step is to calcine the catalyst for 3 hours at a temperature of 650 °C (Delmon *et al.*, 1995). The catalyst was then characterized using XRD and other techniques to determine the distribution of HCl as the active site on the catalyst support.

### Preparation of HCl/Ni/ $\gamma$ -Al<sub>2</sub>O<sub>3</sub> Catalyst

HCl 0.4 N impregnated to 10 gram catalyst support ( $\gamma$ -Al<sub>2</sub>O<sub>3</sub>) and 1 gram Ni(NO<sub>3</sub>)<sub>2</sub>.6H<sub>2</sub>O mixture. Then HCl was dropwise as much as 14 mL and stirred using a hotplate magnetic stirrer while evaporating the water in the mixture to form a paste. When the mixture has formed a paste, stop stirring. Then, dry the mixture at 110 °C for 8 hours. The final step was calcining the catalyst for 3 hours at 650 °C (Delmon *et al.*, 1995). The catalyst was then characterized using XRD and other techniques to determine the distribution of HCl as the active site and Ni as the catalyst promoter on the catalyst support.

### Catalytic Cracking Process

The reaction was carried out in a batch reactor at a pressure of 1 atm, as shown in Figure 1. 50 ml of palm oil and 0.5 grams of HCl/ $\gamma$ -Al<sub>2</sub>O<sub>3</sub> catalyst (1% (w/w) of raw materials) are fed into the reactor with a magnetic stirrer. Then the reactor heater is run until it reaches a temperature of 370 °C, the stirrer is turned on at 200 rpm, and the reaction is run for 2 hours (Aziz *et al.*, 2020). During the reaction, the biofuel product will evaporate from the reactor to the liquid product container through the condenser. The residue remains in the reactor. The gaseous product that has not been condensed is calculated using the mass balance equation by subtracting the initial amount of raw material from the total product and residue obtained. Furthermore, the catalytic cracking process is carried out with an HCl/ $\gamma$ -Al<sub>2</sub>O<sub>3</sub> catalyst (3, 5, 7%) and HCl/Ni/ $\gamma$ -Al<sub>2</sub>O<sub>3</sub> catalyst (1, 3, 5, 7%).

Yield product calculations and GC-MS analysis were carried out to determine the

selectivity of the catalyst for biofuel products. The product yield and selectivity results are obtained from equations (1) and (2).

$$\text{Yield} = \frac{\text{Product Volume (ml)}}{\text{Palm Oil Volume (ml)}} \times 100 \% \dots\dots\dots(1)$$

$$\% \text{ Selectivity} = \frac{\text{Selected product area}}{\text{Total area of all products}} \times 100\% \dots\dots(2)$$

### Product Analysis

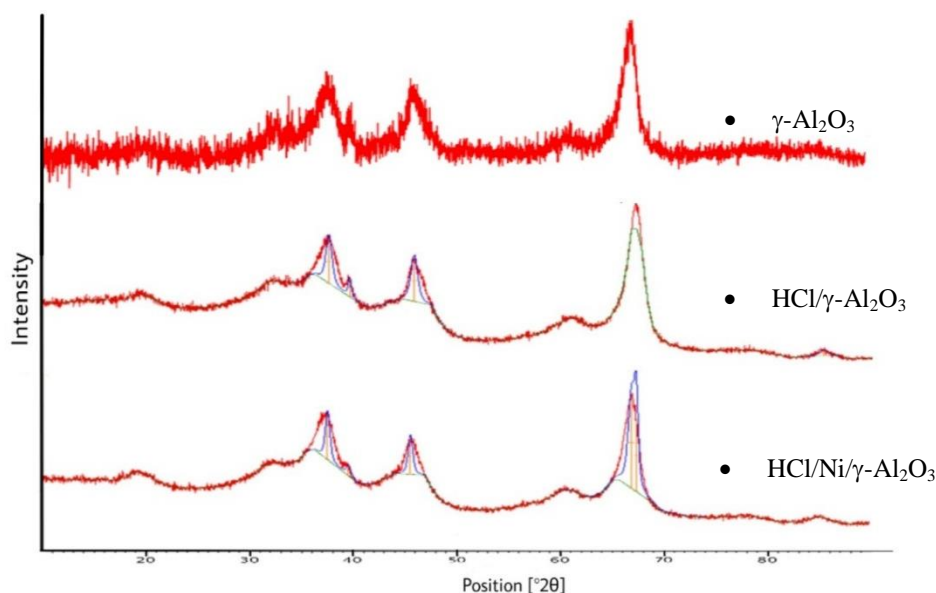
- 1) Catalyst characterization was carried out using X-Ray Diffraction (XRD) at conditions: 40 KV, 15 mA, CuK $\alpha$ /1.54060 Time/step of 23.9700 s, Step size of 0.0220 deg, and Scan axis Gonio, Brunauer Emmett Teller (BET) and ASTM D664.
- 2) Product Compound Component Analysis was carried out using Gas Chromatography-Mass Spectrometry (GC-MS) shimadzu type QP-2010 ultra with Agilent capillary number of 19,091 S-493, HP-5MS of 5% Phenyl Methyl siloxane, nominal length of 30.0 m, nominal diameter of 250  $\mu$ m, nominal film thickness of 0.25  $\mu$ m, and nominal initial pressure of 10.5 psi.

## 3. RESULTS AND DISCUSSION

### Characterization of HCl/ $\gamma$ -Al<sub>2</sub>O<sub>3</sub> and HCl/Ni/ $\gamma$ -Al<sub>2</sub>O<sub>3</sub> Catalyst

The XRD patterns of  $\gamma$ -Al<sub>2</sub>O<sub>3</sub>, HCl/ $\gamma$ -Al<sub>2</sub>O<sub>3</sub> and HCl/Ni/ $\gamma$ -Al<sub>2</sub>O<sub>3</sub> (**Figure 2**) show no change in the crystalline composition structure of  $\gamma$ -Al<sub>2</sub>O<sub>3</sub> significant even though it has undergone several treatments. In the XRD pattern,  $\gamma$ -Al<sub>2</sub>O<sub>3</sub> has three peaks 2 $\theta$  at 39.5359°, 45.7104°, and 67.2432°.

The catalyst impregnated with HCl showed increased crystallization, with peak 2 $\theta$  found at 39.5256°, 45.7472°, 67.5247° and new peak 2 $\theta$  at 85.1167° with a 12.77% intensity. Meanwhile, by impregnating HCl and loading Ni as a catalyst promoter, the diffraction peak 2 $\theta$  found at 37.4908°, 39.5111°, 45.4978°, 66.8480° and 67.2927°. Catalyst with  $\gamma$ -Al<sub>2</sub>O<sub>3</sub> support deposited on the catalyst's surface, namely NiO, with a peak position of 2 $\theta$  = 37.249° (based on ICDD 00-044-1159). This peak has shown that nickel is distributed in  $\gamma$ -Al<sub>2</sub>O<sub>3</sub>, where Ni cannot stand alone due to its high reactivity, so it binds oxygen (**Table 1**).



**Figure 2.** XRD diffractogram of  $\gamma$ -Al<sub>2</sub>O<sub>3</sub>, HCl/ $\gamma$ -Al<sub>2</sub>O<sub>3</sub> and HCl/Ni/ $\gamma$ -Al<sub>2</sub>O

**Table 1.** Peak List of  $\gamma$ -Al<sub>2</sub>O<sub>3</sub>, HCl/ $\gamma$ -Al<sub>2</sub>O<sub>3</sub> and HCl/Ni/ $\gamma$ -Al<sub>2</sub>O<sub>3</sub>

$\gamma$ -Al <sub>2</sub> O <sub>3</sub>		HCl/ $\gamma$ -Al <sub>2</sub> O <sub>3</sub>		HCl/Ni/ $\gamma$ -Al <sub>2</sub> O <sub>3</sub>	
Pos. [°2θ]	Rel. Int. [%]	Pos. [°2θ]	Rel. Int. [%]	Pos. [°2θ]	Rel. Int. [%]
39.5359	17.26	39.5256	40.05	37.4908	48.94
45.7104	44.83	45.7472	94.32	39.5111	10.57
67.2432	100.00	67.5247	100.00	45.4978	39.96
		85.1167	12.77	66.8480	100.00
				67.2927	78.93

Peak 2θ  $\gamma$ -Al<sub>2</sub>O<sub>3</sub> was found at 39.5359° with an intensity of 17.26%. Peak 2θ HCl/ $\gamma$ -Al<sub>2</sub>O<sub>3</sub>, which showed an increase in intensity after HCl impregnation, was 40.05%, while in HCl/Ni/ $\gamma$ -Al<sub>2</sub>O<sub>3</sub>, the initial peak 2θ was found at 37.4908° with increasing intensity of 48.94%. Peak 2θ was slightly shifted because NiO metal occupied peak 2θ at 37° and 39° occupied by HCl, which made the intensity decrease. The second peak of 2θ  $\gamma$ -Al<sub>2</sub>O<sub>3</sub> was at 45.7104° with an intensity of 44.83%. At the 45° peak, HCl/ $\gamma$ -Al<sub>2</sub>O<sub>3</sub> showed an increase in the intensity of 94.32%, and a decrease in intensity at HCl/Ni/ $\gamma$ -Al<sub>2</sub>O<sub>3</sub> was 39.96%. The last peak, 2θ of  $\gamma$ -Al<sub>2</sub>O<sub>3</sub>, was found at 67.2432° with 100% intensity. It was also found at HCl/ $\gamma$ -Al<sub>2</sub>O<sub>3</sub> at 67.5247° with 100% intensity, and two peaks appeared due to HCl impregnation at 85.1167°. In HCl/Ni/ $\gamma$ -Al<sub>2</sub>O<sub>3</sub>, there are two peaks at 66.8480° and 67.2927° with intensities of 100% and 78.93%, respectively.

The active surface area and the total pores volume on the catalyst used were analyzed by the Brunauer Emmett Teller

method (**Table 2**). The results of the BET analysis show that the surface area is still relatively small (<10 m<sup>2</sup>/g).

**Table 2.** BET analysis result

Catalyst	Surface Area (m <sup>2</sup> /g)	Total Pore Volume (cc/g)
HCl/ $\gamma$ -Al <sub>2</sub> O <sub>3</sub>	8.271	0.03882
HCl/Ni/ $\gamma$ -Al <sub>2</sub> O <sub>3</sub>	5.756	0.03961

The surface area of the catalyst will impact its activity; the more active phases dispersed across the surface of the catalyst, the higher the activity of the catalyst and the product as a whole. Although it is not necessarily inversely related to the catalyst activity, the surface area of heterogeneous catalysts plays a significant role in the process (Savitri *et al.*, 2016).

The catalyst's acidity also affects the catalyst's activity in its use as a cracking catalyst. The acidity value of the catalyst was

analyzed using the ASTM D664 method. The acidity analysis results show that the acidity of the HCl/Ni/ $\gamma$ -Al<sub>2</sub>O<sub>3</sub> catalyst is higher than that of the HCl/ $\gamma$ -Al<sub>2</sub>O<sub>3</sub> catalyst. The HCl/Ni/ $\gamma$ -Al<sub>2</sub>O<sub>3</sub> catalyst required 6.28 mg KOH/g to reach neutral conditions, while the HCl/ $\gamma$ -Al<sub>2</sub>O<sub>3</sub> catalyst required 4.71 mg KOH/g. It indicates the formation of Bronsted acid and Lewis acid sites on Ni metal, which has an empty d orbital (Lestari *et al.*, 2019).

### Palm Oil Analysis Results

Prior to the catalytic cracking process, palm oil was analyzed by GC-MS to determine the fatty acid content of the palm oil used. The analysis showed that the palm oil content used was dominated by palmitic acid and oleic acid (Table 3).

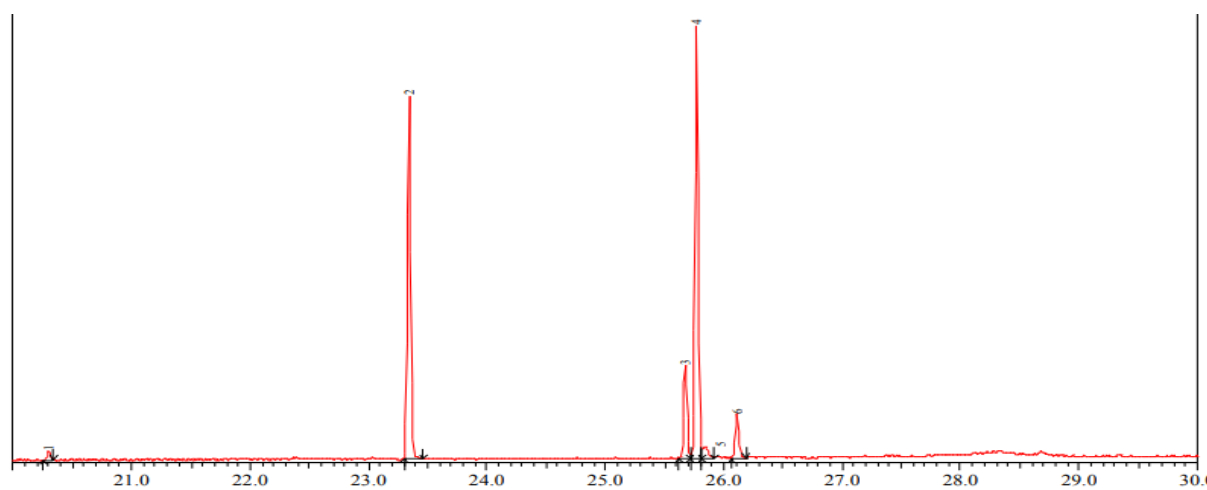
Palm oil compounds contain a high concentration of oleic acid (C<sub>18</sub>H<sub>34</sub>O<sub>2</sub>) and palmitic acid (C<sub>16</sub>H<sub>32</sub>O<sub>2</sub>), both of which have long hydrocarbon chains that can be cracked to produce biofuel products with various chains like biogasoline (C<sub>5</sub>-C<sub>9</sub>), bioavtur (C<sub>10</sub>-C<sub>15</sub>) and green diesel (C<sub>16</sub>-C<sub>22</sub>) (Alimin & Susanto, 2018). Palm oil, as the raw material of this research, is not treated prior to the reaction because the method used does not require free fatty acid levels and aims to produce biofuel products with the efficiency of processing raw materials without treatment.

### Yield Product Analysis Results

The catalytic cracking process produces biofuel in the form of liquid, gas, and residues, raw materials that have not been cracked. The product results are obtained in the form of liquid, and the gases are added up and then

calculated using equation (1) to determine the yield of each reaction.

The yield of the product obtained in the biofuel manufacturing process through the catalytic cracking of palm oil with the HCl/ $\gamma$ -Al<sub>2</sub>O<sub>3</sub> catalyst showed an increase that was directly proportional to the addition of the catalyst concentration, where the highest catalyst concentration used (7%) resulted in the highest product yield of 74%. According to Tambun *et al.* (2021), the higher the concentration of the catalyst used, the higher the conversion of the resulting reaction. While the yield of the product obtained in the biofuel manufacturing process through the catalytic cracking of palm oil with the HCl/Ni/ $\gamma$ -Al<sub>2</sub>O<sub>3</sub> catalyst showed an increase that was directly proportional to the addition of the catalyst concentration up to 5%, the addition of 7% catalyst concentration showed a decrease in the yield of the product. It proves the excellent performance of HCl as the active site of the catalyst keeps increasing the product yield. When a promoter is added, the catalyst performance improves and reaches the optimum point. If reviewed based on the literature by Zurohaina *et al.* (2020), adding a catalyst in a catalytic cracking reaction will increase the reaction rate so that the reaction runs faster and more yields are obtained. However, suppose the catalyst's performance in the reaction has reached the optimum limit. In that case, adding the above catalyst at the optimum concentration is not running effectively anymore. The biofuel production with this catalyst has reached its optimum point by using a catalyst HCl/Ni/ $\gamma$ -Al<sub>2</sub>O<sub>3</sub> (5%), which produces a product yield of 81%.

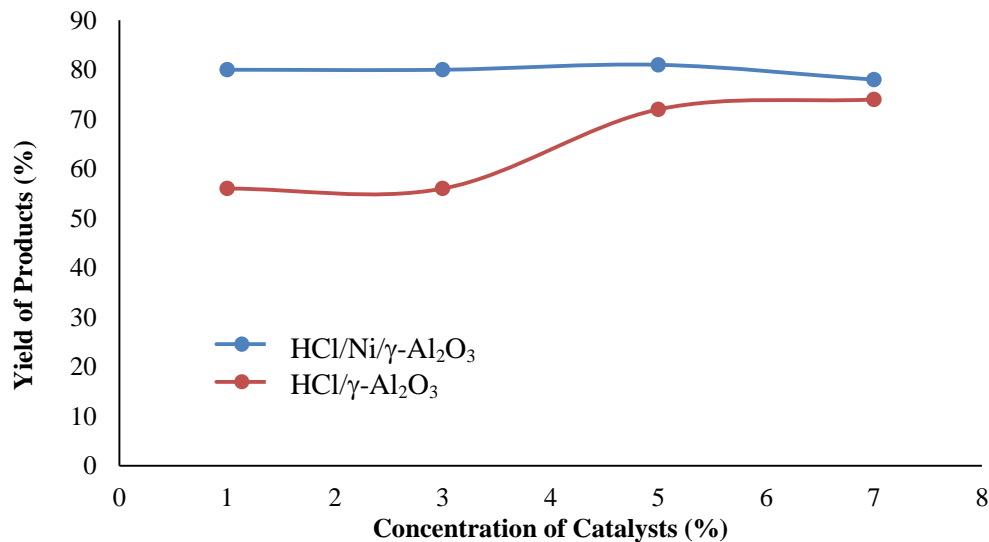


**Figure 3.** Results of analysis of palm oil raw materials using gas chromatography-mass spectrometry (GC-MS)



**Table 3.** Compound composition of palm oil

Peak	Compound	Chemical Formula	Composition (%)
1	Palmitoleic Acid	$C_{16}H_{30}O_2$	0.87
2	Palmitic Acid	$C_{16}H_{32}O_2$	36.76
3	Linoleic Acid	$C_{18}H_{32}O_2$	9.57
4	Oleic Acid	$C_{18}H_{34}O_2$	45.89
5	Oleic Acid	$C_{18}H_{34}O_2$	2.03
6	Stearic Acid	$C_{18}H_{36}O_2$	4.87

**Figure 4.** Graph of the relationship between catalyst concentration and yield in the palm oil catalytic cracking process

The yield of the product obtained in the biofuel manufacturing process through the catalytic cracking of palm oil with the HCl/γ-Al<sub>2</sub>O<sub>3</sub> catalyst showed an increase that was directly proportional to the addition of the catalyst concentration, where the highest catalyst concentration used (7%) resulted in the highest product yield of 74%. According to Tambun *et al.* (2021), the higher the concentration of the catalyst used, the higher the conversion of the resulting reaction. While the yield of the product obtained in the biofuel manufacturing process through the catalytic cracking of palm oil with the HCl/Ni/γ-Al<sub>2</sub>O<sub>3</sub> catalyst showed an increase that was directly proportional to the addition of the catalyst concentration up to 5%, the addition of 7% catalyst concentration showed a decrease in the yield of the product. It proves the excellent performance of HCl as the active site of the catalyst keeps increasing the product yield. When a promoter is added, the catalyst performance improves and reaches the optimum point. If reviewed based on the

literature by Zurohaina *et al.* (2020), adding a catalyst in a catalytic cracking reaction will increase the reaction rate so that the reaction runs faster and more yields are obtained. However, suppose the catalyst's performance in the reaction has reached the optimum limit. In that case, adding the above catalyst at the optimum concentration is not running effectively anymore. The biofuel production with this catalyst has reached its optimum point by using a catalyst HCl/Ni/γ-Al<sub>2</sub>O<sub>3</sub> (5%), which produces a product yield of 81%.

When compared to the yields of catalysts without a promoter, HCl/Ni/γ-Al<sub>2</sub>O<sub>3</sub> catalysts produced higher yields using fewer catalysts. It shows that the performance of the Ni promoter plays a good role in the catalytic cracking of palm oil into biofuel. The excellent attachment of Ni metal to the catalyst support detected by the XRD and a higher increase in acidity value due to the presence of Ni metal compared to HCl/γ-Al<sub>2</sub>O<sub>3</sub>. The reaction is greatly helped by the presence of vacant orbitals on the Ni metal, which can bind and

unbind with the reactants easily. Aini et al. (2020) explained that nickel has high activity and forms relatively weak bonds with reactants, so if it is intended as a catalyst, the reaction products are easily separated from the catalyst's surface. The reaction process can take place more quickly.

### Results of Analysis of Compound Components of Biofuel Products Made from Palm Oil through the Catalytic Cracking Process

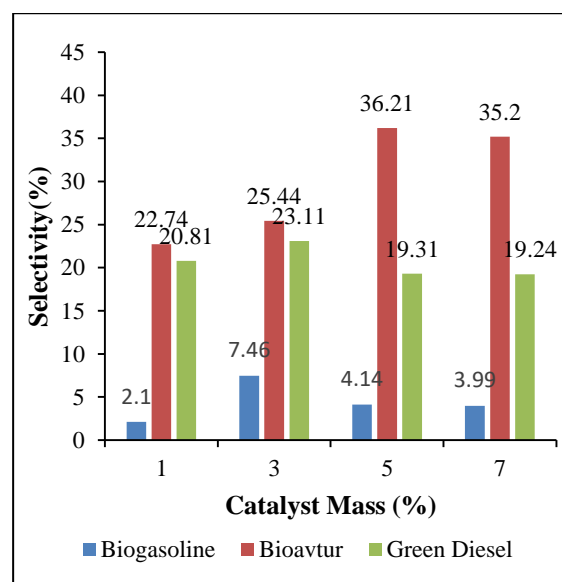
GC-MS analysis is carried out on the biofuel product produced through the cracking process of palm oil using HCl/ $\gamma$ -Al<sub>2</sub>O<sub>3</sub> and HCl/Ni/ $\gamma$ -Al<sub>2</sub>O<sub>3</sub> catalysts. They contain various kinds of hydrocarbon compounds, so to identify and classify them, GC-MS analysis is carried out. Types of biofuels are classified according to their constituent hydrocarbon chains, namely biogasoline (C<sub>5</sub>-C<sub>9</sub>), bioavtur (C<sub>10</sub>-C<sub>15</sub>) and green diesel (C<sub>16</sub>-C<sub>22</sub>) (Alimin & Susanto, 2018). Then calculate the selectivity of the catalyst for the type of biofuel produced by using equation (2).

The highest conversion of biogasoline products by catalytic cracking of palm oil was obtained by the HCl/ $\gamma$ -Al<sub>2</sub>O<sub>3</sub> (3%) catalyst, which was 7.46% (Figure 5a). When compared to the conversion of bioavtur and green diesel in each variable, the conversion of biogasoline is the lowest. It indicates that the catalyst used is less selective for biogasoline products. According to Badriyah & Falah (2017), to produce fuel with short carbon chains such as biogasoline, a catalyst that has high selectivity towards the desired product is needed so that the reactants are not first converted into fuel with a longer carbon chain.

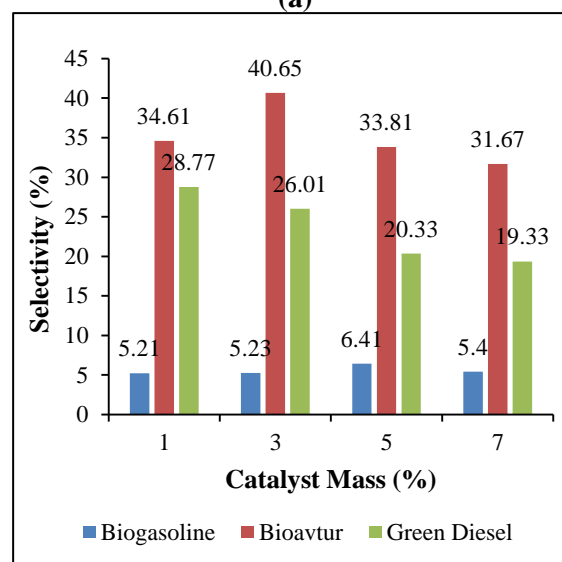
It can also be seen that the highest bioavtur product with catalytic cracking of palm oil was obtained using HCl/Ni/ $\gamma$ -Al<sub>2</sub>O<sub>3</sub> (3%) catalyst, which was 40.65% (Figure 5b). When compared to biogasoline and green diesel products, bioavtur is the product with the highest product conversion. It means that the catalyst used has a high selectivity to bioavtur, especially those with nickel metal as a promoter. Based on research conducted by Carli et al. (2018), the presence of nickel metal in the catalyst structure used in the catalytic cracking process has good selectivity for bioavtur products.

Meanwhile, the highest conversion of green diesel products was obtained using

HCl/Ni/ $\gamma$ -Al<sub>2</sub>O<sub>3</sub> (1%) catalyst, which was 28.77% (Figure 5b). The total conversion of green diesel in each catalyst variable also shows a relatively high value, which means that the catalyst used is quite selective in making green diesel. It follows the theory of Budianto et al. (2019), which states that using a supported Al<sub>2</sub>O<sub>3</sub> catalyst results in a relatively high conversion of green diesel products.



(a)



(b)

**Figure 5.** Graph of relationship between catalyst mass and selectivity of biofuel products using a catalyst (a) HCl/ $\gamma$ -Al<sub>2</sub>O<sub>3</sub> ; (b) HCl/Ni/ $\gamma$ -Al<sub>2</sub>O<sub>3</sub>

## 4. CONCLUSIONS

Palm oil can be converted into biofuel types of biogasoline (C<sub>5</sub>-C<sub>9</sub>), bioavtur (C<sub>10</sub>-C<sub>15</sub>)

and green diesel (C<sub>16</sub>-C<sub>22</sub>) through a catalytic cracking process at a pressure of 1 atm with HCl/γ-Al<sub>2</sub>O<sub>3</sub> and HCl/Ni/γ-Al<sub>2</sub>O<sub>3</sub> catalysts. The best catalyst for cracking palm oil is HCl/Ni/γ-Al<sub>2</sub>O<sub>3</sub> (5%) with a conversion rate of 81%; selectivity to biogasoline (C<sub>5</sub>-C<sub>9</sub>) 6.41%; bioavtur (C<sub>10</sub>-C<sub>15</sub>) 33.81% and green diesel (C<sub>16</sub>-C<sub>22</sub>) 20.33%.

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