Hydrocarbon Biofuel Production by Hydrocracking Process with Nickel-Iron Supported on HZSM-5 Catalyst

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Abstract. The production of hydrocarbon biofuel from coconut oil can substitute for fossil fuels to reduce the environmental issues. Hydrocracking is an effective method that can convert vegetable oil into biofuel using catalyst. In this experiment, nickel-iron was combined with HZSM-5 catalyst to produce biofuel. Hydrocracking of coconut oil was carried out in a batch reactor over Ni-Fe/HZSM-5 catalyst at a temperature of 350 and 400 °C for 2 h. Liquid hydrocarbon biofuel product was analyzed by gas chromatography-mass spectrometry (GC-MS). Based on GC-MS analysis, processing at the temperature of 350 °C produced sample containing 72.56% carboxylic acids. When the temperature increased to 400 °C, the carboxylic acids decreased rapidly from 72.56% to 24.83%. Analysis results suggested that increase of temperature promoted to the increase of desirable content, hydrocarbon compounds. At the same time, it also suppressed formation of undesirable compounds: acids, ketones, phenols, alcohols, and esters. Overall, synthesized catalyst in this study improved production of n-paraffin compounds such as (tridecane (n-C13), tetradecane (n-C14) and pentadecane (n-C15)) as high 71.85%.

Keywords: Coconut oil, Hydrocracking, Ni-Fe/HZSM-5 catalyst, n-paraffin

1. INTRODUCTION
The hydrocracking of vegetable oils (such as palm oil, jatropha oil, sunflower oil, soybean oil, coconut oil and etc) is a good promising technology for producing of biofuels to substitute the fossil fuels. The process of hydrocracking is combined of catalytic cracking process with the addition of hydrogen gas. As reported by previous study, hydrocracking with bifunctional heterogenous catalyst needs a higher temperature (300-400 °C) to crack vegetable oils into hydrocarbon compounds [1-2].

Zeolite catalyst was suitable as a catalyst for cracking of vegetable oil to produce biofuel. Some beneficial properties of zeolite are high thermal stability, high surface area, shape selectivity, and appropriate pore diameter [3]. The HZSM-5 catalyst was found to be efficient in the cracking process of vegetable oils. Metals (Ni, Mo, Co, Fe, and Zn) can be supported on ZSM-5 and have been widely used for the cracking process [4-5]. Researchers have reported the conversion of vegetable oils into hydrocarbons over a variety of catalyst lately. Iliopoulou et al. [6] was investigated catalytic cracking of biomass pyrolysis with transition metal-modified ZSM-5 (e.g., Co and Ni) and found that the
transition metal-modified ZSM-5 improved the production of aromatics. When Ni/HZSM-5 catalyst was used in the catalytic hydrotreatment on FAMEs, the increasing temperature of 260-280 °C will increased n-paraffin (C_{17}-C_{18}) and isoparaffin (C_{5}-C_{18}) [1]. Kovács et al. [7] was investigated catalytic hydrotreating of sunflower oil with NiMo/W/Al_{2}O_{3} catalyst. They found that high paraffin (77-81%) content could be produced through decarboxylation/decarbonylation reactions took place.

Verma et al. [8] reported that hydrotreating of jatropha oil with sulphided NiMo and NiW catalyst supported on hierarchical mesoporous SAPO-11 produced kerosene range hydrocarbons containing 8 vol% of desired aromatic. Al-Muttaqii et al. [9] was reported that when Co-Ni/HZSM-5 catalyst was used in hydrotreating of Sunan candle nut oil, a slightly n-paraffins and aromatic hydrocarbon were produced at temperature of 350 °C. Leng et al. [10] reported that NiFe/Al_{2}O_{3} improved the heating value of biofuel and the main involved reaction pathway was C-O cleavage rather than C-C cleavage during the hydrodeoxygenation process. Marlinda et al. [11] also reported that hydrotreating of Cerbera Manghas oil with Co-Ni/HZSM-5 catalyst produced pentadecane and heptadecane were the main abundant hydrocarbon compounds in gasoil-range hydrocarbon at temperature of 350 °C, 15 bar for 2 h. The author also reported that aromatic compounds (C_{15}-C_{17}) were found in this condition.

The purpose of this work is to transform of coconut oil into hydrocarbon biofuel with nickel-iron supported on HZSM-5 catalyst in a batch reactor. The influence of temperature on the hydrotreating process was also studied. The chemical composition of biofuel was analyzed by using Gas Chromatography-Mass Spectrometry (GC-MS). The ultimate goal is to produce hydrocarbon biofuel from coconut oil via hydrotreating process.

2. EXPERIMENTAL

2.1 Materials
The coconut oil was purchased from a local market in East Java Province, Indonesia. Ammonium ZSM-5 (NH_{4}-ZSM-5) was supplied from Zeolyst International, USA (SiO_{2}/Al_{2}O_{3}, Mole Ratio: 40). Nickel (II) nitrate hexahydrate (Ni(NO_{3})_{2}.6H_{2}O) and iron (III) nitrate nonahydrate (Fe(NO_{3})_{3}.9H_{2}O) was purchased from Merck with ≥98 % purity.

2.2 Preparation of catalyst
The Ni-Fe/HZSM-5 catalyst was prepared with procedure as reported by Al-Muttaqii et al. [9] and Marlinda et al. [12]. The first step, NH_{4}ZSM-5 zeolite was calcined at 550 °C in air for 5 h to convert into HZSM-5. Then, the aqueous solution contain of Ni(NO_{3})_{2}.6H_{2}O and Fe(NO_{3})_{3}.9H_{2}O were loaded into HZSM-5 catalyst. The catalyst was dried at 120 °C for 12 h. After being dried, the catalyst was calcined in 550 °C in air for 3 h and reduced in flowing H_{2} at 550 °C for 2 h to obtain metallic phase, as reported in previous study [12]. The Ni-Fe/HZSM-5 catalyst was characterized by X-Ray Diffraction (XRD) to determine crystallinity of catalyst using a PANalytical X′Pert PRO X-ray diffractometer with a Cu Ka radiation source operating at 40 kV and 30 mA and recorded on 20 of 5 to 70°. The amount of metal impregnated on HZSM-5 of catalyst was analyzed using Scanning Electron Microscope with Energy-Dispersive X-ray (SEM-EDX) series model: EVO MA10. Surface area and pore volume of the catalyst were characterized by Brunauer-Emmett-Teller (BET) series Quantachrome NovaWin Version 11.03.

2.3 Hydrocracking test
Hydrocracking of coconut oil was carried out in a batch reactor type Parr Instrument Company 4563 with a maximum volume of 600 ml. This reactor equipped with a magnetic stirrer. For these experiments, 200 ml of coconut oil and 2 g of Ni-Fe/HZSM-5 catalyst were added into the reactor. Then it was purged with nitrogen gases for 10 min to remove the remaining air in the reactor. Then, the reactor flow with hydrogen gas for 1 h and reactor pressure of 30 bar. The reaction temperature was carried out at a temperature of 350 °C for 2 h. After processing for 2 h, the liquid biofuel products were collected and analyzed.

2.4 Product analysis
The major components in liquid biofuel product were analyzed using a Gas Chromatography-Mass Spectrometry (GC-MS, Agilent HP 6890 models 19091S-433, HP–5MS capillary column 30 m x 250 µm x 0.25 µm). The major components of hydrocarbon biofuel were identified through a National Institute of Standards and Technology (NIST) mass spectra library and literature.

3. RESULTS AND DISCUSSION

3.1 Characterization of catalyst

The XRD spectra of HZSM-5 and Ni-Fe/HZSM-5 catalyst are shown in Figure 1. As can be seen in Figure 1, the HZSM-5 catalyst shows the characteristic peaks of an MFI structure type zeolite (2θ = 7-9° and 23-25°). After the impregnation metals of Ni and Fe into HZSM-5, structure of Ni-Fe/HZSM-5 catalyst was still similar to HZSM-5 catalyst. It indicates that the addition of nickel and iron on/into the HZSM-5 catalyst did not change their structures but reduce the intensity of each diffraction peaks, as reported by previous study [9, 12-13]. The result of EDAX measurement also proved the existence of nickel and iron in HZSM-5. From Table 1, the actual metal content on support HZSM-5 was 3.75 wt% of Ni and 5.43 wt% of Fe.

![Figure 1. XRD patterns of the HZSM-5 and Ni-Fe/HZSM-5 catalyst](image)

The surface area, average pore size, and pore volume of the Ni-Fe/HZSM-5 catalyst are listed in Table 1. The surface area of HZSM-5 catalyst was 407.386 m²/g [14]. After the impregnation of Ni and Fe into the HZSM-5, the surface area decreased. Some of the support HZSM-5 were filled up with metal after the impregnation of Ni and Fe. These changes implied that Ni and Fe particles deposited on the surface of HZSM-5. This assumption is in accordance with the result that the total pore volume of Ni-Fe/HZSM-5 catalyst decreased compared to HZSM-5. [9, 12, 15-16].

| Catalyst     | Surface area (m²/g) | Pore Size (nm) | Total Pore Volume (cm³/g) | Element (wt%) |
|--------------|---------------------|----------------|---------------------------|---------------|
| HZSM-5*      | 407.386             | 3.12           | 0.32                      | -             |
| Ni-Fe/HZSM-5 | 336.617             | 3.32           | 0.28                      | 3.75          |

|               | Fe                   |
|---------------|----------------------|
| Ni-Fe/HZSM-5  | 5.43                 |

3.2 Hydrocracking of coconut oil

3.2.1 GC-MS analysis

In this study, we used a Gas Chromatography-Mass Spectrometry (GC-MS) analysis to determine the composition of the liquid products. Figure 2 shown GC-MS chromatogram of hydrocarbon liquid
biofuel product produced at temperature of 350 and 400 °C using Ni-Fe/HZSM-5 catalyst. Figure 2 (a) shows n-paraffins produced from hydrocracking of coconut oil. The liquid product mainly contains tridecane, pentadecane, and heptadecane. The main component of carboxylic acids found in liquid product were octanoic acid and dodecanoic acid. According to Zhang et al. [17], triglycerides with long chain fatty acids were converted into short chain molecules by cracking, isomerization, cyclization, and aromatization reaction. It suggested that the temperatures above 350 °C were also needed to crack C=O bond through decarboxylation and/or decarbonylation reaction. Figure 2 (b) shows at temperature of 400 °C contained the highest hydrocarbon content (75.14 area%) and it contained n-paraffin, aromatic and olefin compounds. It suggested that the increasing temperature in hydrocracking reaction improve the catalytic activity and contributed to cleavage triglycerides of coconut oil into a short chain hydrocarbon molecules in liquid products as reported in previous study [9,12].

![Figure 2. GC-MS spectra of hydrocarbon biofuel liquid at (a) 350 °C and (b) 400 °C using Ni-Fe/HZSM-5 catalyst](image)

Table 2 shows the major components of hydrocarbon biofuel produced at different temperature. Hydrocarbon biofuel from coconut oil mainly contained hydrocarbons (such as n-paraffin, olefin, aromatic, and cycloparaffin), oxygenated compounds and carboxylic acids. A similar observation was found from the study of Al-Muttaqi et al. [9], Marlinda et al. [11], Xu et al. [18], that the hydrocarbon biofuel produced from hydrocracking of vegetable oil contained hydrocarbon and oxygenated compounds. The total amounts of carboxylic acid and oxygenated compounds at 350 °C was 72.56 area% and 2.55 area%, respectively. These compounds are responsible for the low quality of the hydrocarbon biofuels including low heating value, comparison with conventional fuel, chemical instability, high viscosity, and acidity of hydrocarbon biofuel. Hydrocarbon biofuel produced at temperature of 400 °C contained the lowest oxygen content, suggesting that the carboxylic acid including octanoic acid and dodecanoic acid were cracked to other products such as hydrocarbons, aromatic, and etc through dehydrogenation, decarboxylation and decarbonylation reaction over the Ni-Fe/HZSM-5 catalyst [12].

As shown in Table 2, n-C13, n-C15, and n-C17 were the main products at different temperatures. The amount of smaller molecule of aromatic (i.e. hexylbenzene) that was formed when the reaction temperature reached 400 °C. The monocyclic aromatic hydrocarbons (MAH), e.g hexyl benzene was found in small amount about 0.75 area%. These compounds can be used as a lead substitute for the octane number boosting of transportation fuel. As reported by previous study [19], when Co-Ni/HZSM-5 catalyst was used in the same condition in this work, the hydrocracking of sunan candlenut oil produced a liquid product containing aromatic compounds in the form of abundant monocyclic aromatic hydrocarbons, i.e. n-hexylbenzene, n-heptylbenzene, octylbenzene, and etc. The incorporation of transition metals (Ni and Fe) on/into HZSM-5 showed a bifunctional character catalyst which included acid- and metal sites to promote oligomerization and aromatization. The addition of transition metals
promoted the conversion of oxygenated compound to aliphatic (n-paraffin, olefin) and aromatics [9]. The incorporation of transition metal on/into HZSM-5 was expected to affect the deoxygenation and the hydrogen transfer during the hydrocracking process of coconut oils. Ni combined with acid site provided the ideal environment for alkenes followed by cyclization and dehydrogenation leading to small amount of aromatic formation [6].

Table 2. The Chemical composition of hydrocarbon biofuel (area% of liquid product) at temperature of 350 and 400 °C

| Compounds                 | Molecular formula | Area% (I) 350 °C | Area% (II) 400 °C |
|---------------------------|-------------------|------------------|------------------|
| n-paraffin                |                   |                  |                  |
| Dodecane                  | C_{12}H_{26}      |                  | 2.97             |
| 2,7-dimethyl undecane     | C_{13}H_{28}      | 1.25             | -                |
| Tridecane                 | C_{13}H_{28}      | 8.99             | 25.25            |
| Tetradecane               | C_{14}H_{30}      | 0.37             | 21.57            |
| Pentadecane               | C_{15}H_{32}      | 3.91             | 14.95            |
| Hexadecane                | C_{16}H_{34}      | -                | 1.72             |
| Heptadecane               | C_{17}H_{36}      | 1.26             | 5.39             |
| 2-methylhexadecane        | C_{17}H_{36}      | 1.14             | -                |
| Olefin                    |                   |                  |                  |
| 7-hexadecene              | C_{16}H_{32}      | 1.04             | -                |
| 2-tridecene               | C_{13}H_{26}      | 0.68             | -                |
| 5-tridecene               | C_{13}H_{26}      | -                | 1.52             |
| 2-tetradecene             | C_{14}H_{28}      | 0.54             | -                |
| 1-docoseno                | C_{12}H_{24}      | 2.32             | -                |
| 1-octadecene              | C_{18}H_{36}      | 0.09             | -                |
| 3-octadecene              | C_{18}H_{36}      | 0.16             | -                |
| 4-dodecene                | C_{12}H_{24}      | -                | 1.02             |
| Aromatic                  |                   |                  |                  |
| Hexylbenzene              | C_{12}H_{18}      | -                | 0.75             |
| Cycloparaffin             |                   |                  |                  |
| Cyclotetradecane          | C_{14}H_{28}      | 0.98             | -                |
| Oxygenated compound       |                   |                  |                  |
| 1,2-Epoxyhexadecane       | C_{6}H_{12}O      | 2.55             | -                |
| Carboxylic acid           |                   |                  |                  |
| Octanoic acid             | C_{10}H_{18}O_{2} | 18.53            | 9.76             |
| n-decanoic acid           | C_{10}H_{20}O_{2} | 7.98             | 2.42             |
| Dodecanoic acid           | C_{12}H_{26}O_{2} | 42.17            | 9.6              |
| Tetradecanoic acid        | C_{14}H_{28}O_{2} | 1.56             | -                |
| Hexadecanoic acid         | C_{16}H_{30}O_{2} | 1.28             | -                |
| Nonadecanoic acid         | C_{19}H_{32}O_{2} | 1.04             | -                |
| 9-octadecanoic acid       | C_{18}H_{30}O_{2} | -                | 1.13             |
| 8-heptadecanoic acid      | C_{17}H_{34}O_{2} | -                | 1.92             |

The results indicate that the reaction temperature also affected the hydrocarbon product distribution. On the other hand, reaction temperature had a relatively strong influence on the ratio of n-alkanes with an even and odd carbon atom number. In this research, when the temperature rised from 350 to 400 °C, the content of n-C_{13} and n-C_{15} increased from 8.99 to 25.25% and 3.91 to 14.95%, respectively. The final product in hydrocarbon biofuel contains aliphatic compounds in the range C_{12}-C_{22}. A high n-paraffins were produced at temperature of 400 °C. Based on the results, tridecane (n-C_{13}), tetradecane (n-C_{14}), pentadecane (n-C_{15}) and heptadecane (n-C_{17}) were the most abundant hydrocarbon compounds in biofuel liquid product, as reported in previous study [12, 20]. However, the initial hydrogen pressure and reaction temperature play a crucial role in this experiment. At temperatures lower than 310 °C, the final organic liquid product contained fatty acid and triglycerides, but at higher reaction temperatures only hydrocarbons were detected, mainly C_{15}, C_{17} and C_{18} n-alkanes [21]. Based on the composition of
liquid products, it can be concluded that the triglyceride is hydrogenated and broken down into various intermediate. Then the intermediates are converted into alkanes by two pathways: hydrocarbons with the same carbon number, i.e., C_{16}H_{36}, is the products of hydrodeoxygengation (HDO). Hydrocarbons with one carbon atoms, i.e., C_{17}H_{38} and C_{15}H_{32}, are the products of oxygen removal from triglyceride by hydrodeoxygenation (HDC), including decarboxylation and decarbonylation. It showed that with increasing reaction temperature, hydrocracking process proceeded via HDC was the dominant reaction pathways, lead to the formation of n-alkanes with an odd number of carbon atoms chain length [14, 16].

4. Conclusion
This study present the effect of reaction temperatures on the hydrocracking process with nickel-iron supported on HZSM-5 catalyst for the transformation of coconut oil into aliphatic (n-paraffin, olefin) and aromatics compounds. The highest amounts of n-paraffin compounds produced is 71.85 area% at temperature of 400 °C. When the reaction temperature rised from 350 to 400 °C, the content of n-C_{13} and n-C_{15} increased from 8.99 to 25.25% and 3.91 to 14.95%, respectively. The increasing reaction temperature was favoub to conduct further cracking of carboxylic acids into n-paraffin compounds. Hydrocracking process proceeded via HDC was the dominant reaction pathways, lead to the formation of n-alkanes with an odd number of carbon atoms chain length. The addition of transition metals (nickel and iron) promoted the conversion of oxygenated compounds to aliphatic (n-paraffin, olefin) and aromatics compounds. Ni-Fe/HZSM-5 catalyst is an effective catalyst to produce hydrocarbon biofuel by hydrocracking process of coconut oil.

References

[1] Chen L, Li H, Fu J, Miao C, Pengmei Lv, Yuan Z 2016 Catalytic hydroprocessing of fatty acid methyl esters to renewable alkane fuels over Ni/HZSM-5 catalyst. Catal. Today 259 266-276.
[2] Romero M, Pizzi A, Toscano G, Casazza A A, Busca G, Bosio B, Arato E 2015 Preliminary Experimental Study on Biofuel Production by Deoxygenation of Jatropha Oil. Fuel. Proc. Technol. 137 31-37.
[3] Vichaphund S, Aht-ong D, Sricharoenchaikul V, Atong D, 2014 Catalytic upgrading pyrolysis vapors of Jatropha waste using metal promoted ZSM-5 catalysts: An analytical PY-GC/MS. Renew. Energ. 65 70-77.
[4] Abdelsayed V, Shekhawat D, Smith M W 2015 Effect of Fe and Zn promoters on Mo/HZSSM-5 catalyst for methane dehydroaromatization. Fuel 139 401-410.
[5] Wang H, Yan S, Salley O S, Simon Ng K Y 2012 Hydrocarbon Fuels Production from Hydrocracking of Soybean Oil Using Transition Metal Carbides and Nitrides Supported on ZSM-5. Indust. Eng. Chem. Res. 51 (30) 10066-10073.
[6] Iliopoulou E F, Stefanidis S D, Kalogiannis K G, Delimitis A, Lappas A A, Triantafyllidis K S 2012 Catalytic upgrading of biomass pyrolysis vapors using transition metal-modified ZSM-5 zeolite. Appl. Catal. B: Envi. 127 281-290.
[7] Kovács S, Boda L, Leveles L, Thernesza A, Hancsók J 2010 Catalytic hydrotreating of triglycerides for the production of bioparaffin mixture. Chem. Eng. Trans. 21 1321 – 1326.
[8] Verma D, Rana B S, Kumar R, Sibi M G, Sinha A K 2015 Diesel and Aviation Kerosene with Desired Aromatics from Hydroprocessing of Jatropha Oil over Hydrogenation Catalysts Supported on Hierarchical Mesoporous SAPO-11. Appl. Catal. A: General 490 108-116.
[9] Al-Muttaqi M, Marlimda L, Roesyadi A, Danawati H P 2017 Co-Ni/HZSM-5 Catalyst for Hydrocracking of Sunan Candlenut Oil (Reutealis trisperma (Blanco) Airy Shaw) for Production of Biofuel. J. Pure Appl. Chem. Res. 6 (2) 84-92.
[10] Leng S, Wang X, He X, Liu L, Liu Y, Zhong X, Zhuang G, Wang J G 2013 NiFe/Y-Al_2O_3: a universal catalyst for the hydrodeoxygenation of bio-oil and its model compounds. Catal. Comm. 41 34-37.
[11] Marlimda L, Al-Muttaqi M, Roesyadi A, Danawati H P 2016 Production of Biofuel by Hydrocracking of Cerbera Manghas Oil Using Co-Ni/HZSM-5 Catalyst: Effect of Reaction Temperature. J. Pure. Appl. Chem. Res. 5 (3) 189-195.
[12] Marlinda L, Al-Muttaqii M, Gunardi I, Roesyadi A, Danawati H P 2017 Hydrocracking of Cerbera manghas Oil with Co-Ni/HZSM-5 as Double Promoted Catalyst. Bull. Chem. React. Eng. Catal. 12 (2) 167-184

[13] Vichaphund S, Aht-ong D, Sricharoenchaikul V, Atong D 2015 Production of aromatic compounds from catalytic fast pyrolysis of Jatropha residues using metal/HZSM-5 prepared by ion-exchange and impregnation methods. Renew. Energ. 79 28-37

[14] Al-Muttaqii M, Kurniawansyah F, Danawati H P, Roesyadi A 2019 Bio-kerosene and Bio-gasoil from Coconut Oils via Hydrocracking Process over Ni-Fe/HZSM-5 Catalyst. Bull. Chem. React. Eng. Catal. 14 (2) 309

[15] Zhao X, Wei L, Cheng S, Kadis E, Cao Y, Gu Z, Julson J 2016 Hydroprocessing of carinata oil for hydrocarbon biofuel over Mo-Zn/Al$_2$O$_3$. Appl. Catal. B: Envi. 196 41-49

[16] Al-Muttaqii M, Kurniawansyah F, Danawati H P, Roesyadi A 2019 Hydrocracking of Coconut Oil over Ni-Fe/HZSM-5 Catalyst to Produce Hydrocarbon Biofuel. Indo. J. Chemistry: Article in Press

[17] Zhang H, Lin H, Zheng Y 2014 The Role of Cobalt and Nickel in Deoxygenation of Vegetable Oils. Appl. Catal. B: Envi. 160-161 (1) 415-422

[18] Xu J, Jiang J, Sun Y, Chen J 2010 Production of hydrocarbon fuels from pyrolysis of soybean oils using a basic catalyst. Biore. Technol. 101 (24) 9803-9806

[19] Danawati H P, Roesyadi A, Al-Muttaqii M, Marlinda L 2017 Hydrocracking of Non-edible Vegetable Oils with Co-Ni/HZSM-5 Catalyst to Gasoil Containing Aromatics. Bull. Chem. React. Eng. Catal. 12 (3) 318-328

[20] Sotelo-Boyas R, Liu Y, Minowa T 2011 Renewable diesel production from the hydrotreating of rapeseed oil with Pt/Zeolite and NiMo/Al$_2$O$_3$ catalysts. Indust. Eng. Chem. Res. 50 2791-2799

[21] Simacek P, Kubicka D, Sebor G, Pospisil M 2010 Fuel properties of hydroprocessed rapeseed oil. Fuel 89 611-5.