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#### Research Article

# The Influence of Metal Loading Amount on Ni/Mesoporous Silica Extracted from Lapindo Mud Templated by CTAB for Conversion of Waste Cooking Oil into Biofuel

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#### Abstract

The synthesis and characterization of Ni/mesoporous silica (Ni/MS) catalysts from Lapindo mud with various metal loading for the hydrocracking of waste cooking oil into biofuel has been conducted. The MS was synthesized by the hydrothermal method using CTAB as a template. The nickel-metal of 4, 6, and 8 wt% was loaded into the MS using salt precursors of Ni(NO<sub>3</sub>)<sub>2</sub>.6H<sub>2</sub>O via wet impregnation, produced the Ni(4)/MS, Ni(6)/MS, and Ni(8)/MS catalysts, respectively. The materials produced were then characterized by X-ray Powder Diffraction (XRD), Fourier-Transform Infrared Spectroscopy (FT-IR), and Surface Area Analyzer (SAA), and Absorption Atomic Spectrophotometry (AAS). The catalytic activity test was carried out for hydrocracking of waste cooking oil and the resulted liquid product was analyzed by Gas Chromatography-Mass Spectrometry (GC-MS). The results showed that the specific surface area of Ni(4)/MS, Ni(6)/MS, and Ni(8)/MS catalysts are 63.08, 91.45, and 120.45 m²/g, respectively. The liquid products of the hydrocracking using Ni(4)/MS, Ni(6)/MS, and Ni(8)/MS catalysts were 80.57, 74.63, and 75.77 wt%, where the total biofuel produced was 55.46, 50.93, and 54.05 wt%, respectively. Based on these results, Ni(4)/MS material was successfully used as the most potent catalyst in the hydrocracking of waste cooking oil into the biofuel.

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Keywords: Nickel; mesoporous silica; Lapindo mud; CTAB; Waste cooking oil; Biofuel

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#### 1. Introduction

Energy supply in the future is a problem that attracts the attention of all nations because human welfare in modern life is closely related to the amount and quality of energy used. At current production rates, Indonesia's proven reserves for crude oil are estimated to last for 23 years and 52 years respectively [1,2]. Due to Indonesia's rapid depletion of oil and natural gas reserves, the country must discover an alternative energy source to sustain economic development in the future. The transportation and in-

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dustrial sectors are expected to become the highest energy consumers followed by the household sector [3]. The crucial challenge facing the power sector in Indonesia is the issues of sustainability. The country should be urged and should fully support the utilization of new and renewable energy to improve energy security and create energy autonomy, especially fuel.

There has been growing global interest in developing alternative sources of energy. Biofuels offer much promise on these frontiers. In addition to the above, they also offer benefits on environmental impact in comparison to fossil fuels [4]. Since the used cooking oil is a waste, which can be converted into biodiesel and this will be helpful for the reduction of pollution, since waste cooking oil is wasted into the environment. The conversion of waste cooking oil into biodiesel will be a valuable addition of energy in the existing energy grid [5].

During the deep fat food frying process, the frying media, oil, continuously degenerate when exposed to high temperature, oxygen, and moisture. This leads to physical and chemical changes including the formation of hydrolysis products, such as: free fatty acids (FFAs) [6]. The activity and selectivity of heterogeneous catalysts can also be improved using auxiliary groups [7,8]. In this regard, it is particularly attractive to use groups that can selectively adsorb reactants or byproducts to control the course of catalytic processes. Lercher and coworkers have applied the combination between adsorbents and catalysts to the hydrogenation of FFAs [9,10]. In recent work, they supported Ni on ZrO<sub>2</sub> and observed efficient conversion of FFAs to hydrocarbons. Since bio-oils are complex mixtures containing raw materials for diverse applications, a catalyst for hydrogenation could benefit from the incorporation of an auxiliary group capable of selectively sequestering their FFA substrates. This group would feed the catalyst with FFAs, leaving all other substances in the mixture unmodified and available for downstream processing.

The mesoporous materials have attracted the attention of numerous researchers in different application fields [11]. The choice of basic mesoporous material is critical because it acts as a building block. One of the main ingredients that are superior is silica since it has properties that are thermally stable, safe, and inexpensive [12]. Pure silica materials are MCM, SBA, HMS, while the Non-silica mesoporous materials include transition metal oxides [13]. Silica can be found in natural materials, including Lapindo mud because of the high silica

content [14]. Lapindo mud is the result of an erupting mud volcano in the subdistrict of Porong, Sidoarjo in East Java, Indonesia. Lapindo mud can be the main source of material in the synthesis of mesoporous because of its high silica content (>47%). Hence, Lapindo mud has enormous potential as one of the advancement sources of silica production [15].

One of the main factors of the mesoporous material synthesis is the selection of the template. The primary requirement for being the template is to have the amphiphilic character the forming characteristics mesostructure [16]. The type of surfactant that was used here is a cationic surfactant, which is cetyl trimethyl ammonium bromide (CTAB). CTAB has been researched as an additive for forming MD structures of conducting polymers including nanomaterials. Therefore, it is promising to use surfactant CTAB in a low acid environment [17]. Consequently, the addition of CTAB produces samples with more quantity of interconnected pores, and thus, the specific surface area increases [18].

Mesoporous silica (MS) is a silica material obtained by non-ionic surfactants to template the synthesis of MS [16]. MS material is uncharged, so that it can be used as a catalyst in the catalytic process (hydrocracking) then MS is carried out by transitional metals. Catalyst activity with transition metal modification on the carrier solids has been widely studied and shows good activity and selectivity [19]. Development of MS application as a catalyst, one of the catalysts is Ni/MS. Hybrid adsorbentcatalyst nanostructure material consisting of nickel nanoparticles can work selectively which can capture free fatty acids (FFA) and can convert them into saturated hydrocarbons [20]. This research investigated the variation of the concentration (4, 6, and 8 wt%) of the nickelmetal which will be impregnated into the MS catalyst, as well as the correlation between the character of the catalysts on catalytic activity in producing liquid fraction and selectivity to gasoline and diesel oil fraction.

#### 2. Materials and Methods

#### 2.1 Materials

Silica with purity over 96.86% by Trisunaryanti *et al.* [21] was extracted from Lapindo mud that was collected from Sidoarjo Regency, East Java, Indonesia. Also, HCl 37%, NaOH, Ni(NO<sub>3</sub>)<sub>2</sub>.6H<sub>2</sub>O, AgNO<sub>3</sub>, NH<sub>3</sub>, and cetyltrimethylammonium bromide (CTAB) were each bought from Merck & Co. N<sub>2</sub> and H<sub>2</sub> gasses were purchased from technical, PT. Sa-

mator Gas and also waste cooking oil was obtained from the traditional market.

#### 2.2 Instrumentations

Fourier-Transform Infrared Spectroscopy (FTIR) (Shimadzu Prestige-21) was used to investigate the characteristic functional groups of materials. X-Ray Diffraction (XRD) (Philips X'Pert MPD) using Cu target at 40 kV and 30 mA was utilized to determine the crystallinity of materials. The surface morphology of mesoporous silica was captured by using Scanning Electron Microscopy (SEM) (JSM-6510LA) operated at 15 kV accelerating voltage. The surface area and pore size of each mesoporous catalvsts prepared were analyzed by using Surface Area Analyzer (SAA) Nitrogen gas sorption (Quantachrome NOVAtouch 4LX). The surface areas were calculated using the Brunauer-Emmett-Teller (BET) method. Atomic Absorption Spectroscopy (AAS) (Perkin Elmer 5100 PC) was used to calculate the metal content of catalysts. Gas Chromatography-Mass Spectrometry (GC-MS) (QP2010S Shimadzu) was applied to analyze the composition of liquid products resulted from the hydrocracking process.

#### 2.3 Experimental Procedures

#### 2.3.1 Synthesis of Mesoporous Silica by CTAB

For the synthesis of mesoporous silica (MS) by CTAB, 3.18 g of CTAB was dissolved in 65 mL of distilled water, then stirred at 40 °C. The homogenized solution was put in the PET glass. After that, 6 g of silica and 200 mL of NaOH 1.5 M were mixed, so the Na<sub>2</sub>SiO<sub>3</sub> was formed. CTAB solution was dripped by Na<sub>2</sub>SiO<sub>3</sub> solution bit by bit while the solution was stirred for 1 h. The solution was added by HCl 3 M until it reaches pH 11 and awaited for 4 h. The solution was poured into the autoclave and put in the oven at 100 °C for 24 h. The formed white solid was washed by distilled water until it was neutral. The solid was dried at 80 °C for 24 h. The produced MS was calcined for 5 h at 540 °C with a temperature increment of 5 °C/minute. The calcined MS was characterized by XRD and SEM.

# 2.3.2 Impregnation of Nickel Metal on Mesoporous Silica

Each Ni metal of 4, 6, and 8 wt.% from a salt precursor of Ni(NO<sub>3</sub>)<sub>2</sub>.6H<sub>2</sub>O was loaded into 1 g of MS (with physical properties: specific surface area of 874.28 m<sup>2</sup>/g, a pore diameter of 3.59 nm, and total pore volume 0.81 cm<sup>3</sup>/g from

Trisunaryanti *et al.* [21]) by wet impregnation method and dissolved in 50 mL of distilled water. The solution was stirred at 300 rpm for 24 h. The mixture was evaporated at 70 °C. The solid was calcined using N<sub>2</sub> gas at 500 °C for 3 h. The sample was reduced by H<sub>2</sub> gas (15 cm<sup>3</sup>/minute) at 450 °C for 3 h. The catalysts produced were Ni(4)/MS, Ni(6)/MS, and Ni(8)/MS, respectively. The catalysts were characterized by XRD, FTIR, SAA, and AAS.

#### 2.3.3 Catalytic Activity Test

The catalysts and the waste cooking oil were put into the vessel. The vessel was put into the hydrocracking reactor that uses a fixedbed system with the catalyst/feed weight ratio was 1/50 (w/w). The variation of hydrocracking conditions was thermal (without catalyst) and catalytic with Ni(4)/MS, Ni(6)/MS, Ni(8)/MS catalysts. After that, the reactor was heated at 450 °C with a temperature increment of 10 °C/minute with the H<sub>2</sub> gas flow rate of 15 mL/minute for 2.5 h. The liquid product of hydrocracking was flowed through the cooler and placed into the flask. The result of the hydrocracking process was determined by the percentage (%) of the conversion by using Eqs. (1), (2), and (3):

Liquid product (wt%) = 
$$\frac{W_L}{W_F} \times 100\%$$
 (1)

$$Coke(wt\%) = \frac{W_C}{W_F} \times 100\% \tag{2}$$

$$Gas(wt\%) = \frac{W_F - (W_L + W_C)}{W_F} \times 100\%$$
 (3)

The liquid products were analyzed by GC-MS. The chromatogram showed the relative percentages for each compound contained in the liquid product. Gasoline fraction was a hydrocarbon compound composed of alkanes with  $C_5$ – $C_{12}$  carbon chains and diesel oil fractions composed of  $C_{13}$ – $C_{17}$  carbon chains. The organic fraction consists of alcohol, ether, aldehyde, ketone, carboxylic acid, and ester compounds. Determination of percent selectivity of gasoline, diesel, and organic fractions to liquid products from waste cooking oil can be determined by using Eqs. (5), (6), and (7):

Gasoline fraction (wt%) = 
$$\frac{relative \ E\% \ of \ C_5 - C_{12}}{\% total \ relative} \times liquid \ product \ \ \textbf{(5)}$$

Diesel fraction(wt%) = 
$$\frac{relative\ E\% of\ C_{13} - C_{17}}{\%total\ relative} \times liquid\ product$$
 (6)

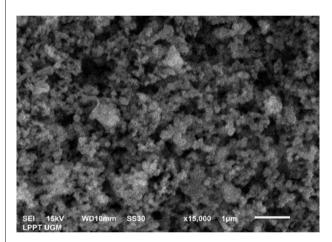
$$Organic(wt\%) = liquid\ product - (gasoline + diesel\ fractions)$$
 (7)

where, E% is %area of a compound from GC data,  $W_F$  is the weight of feed (g),  $W_L$  is the weight of the liquid product (g),  $W_C$  is the weight of coke (g),  $W_R$  is the weight of residue (g)

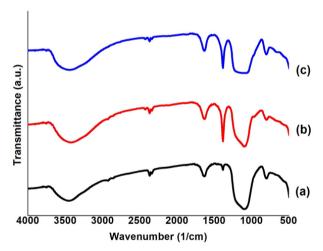
#### 3. Results and Discussions

# 3.1 Characterization of Mesoporous Silica

Analysis by using Scanning Electron Microscope (SEM) used to know the topography and morphological character of MS catalyst. The SEM uses a focused beam of high energy electrons to generate a variety of signals at the surface of solid specimens. MS with CTAB template characterization results using SEM is shown in Figure 1. It was shown that the MS has a porous structure with an irregular pore shape. The pores are visible in the image. Based on the theory, the shape should be hexagonal rods with a thick wall. But in this case, the hexagonal shape cannot be seen due to the less magnification of the image.



**Figure 1.** Morphology of mesoporous silica by SEM.



**Figure 2.** FT-IR Spectra (a) Ni(4)/MS, (b) Ni(6)/MS, and (c) Ni(8)/MS.

3.2 Characterization of Mesoporous Silica after Impregnation of Nickel Metal

Metal content played an important role in the catalyst system. This is because metal can contribute a large acid site to the catalyst system as a whole, through the contribution of the Lewis acid site. High metal content will also provide a high acidity value. In this experiment, the metal content was analyzed by Atomic Absorption Spectrophotometer (AAS) which is commonly used to analyze monometallic catalyst samples. The result can be seen in Table 1. The results obtain the composition of Ni elements in the whole catalysts. In this case, the amount of Ni metal that is carried is greater than that included in the synthesis, this is maybe because the silica support is extracted from natural materials such as Lapindo mud so that it has the potential to contain other metals in a very small percentage.

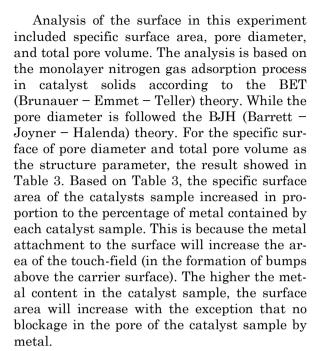
Characterization by using FTIR spectra is aimed to know the functional groups of Ni/MS catalysts in various metal concentrations. FTIR spectra based on Figure 2 showed the similarity between (a) Ni(4)/MS (ratio 1:4) (b) Ni(6)/MS (ratio 1:6) and (c) Ni(8)/MS (ratio 1:8). All three samples show similar features of FT-IR spectra of silica material and there were four highest peaks for each catalyst. The absorption peaks at 3448.72 cm<sup>-1</sup> and 3425.58 cm<sup>-1</sup> were assigned to the stretching vibration of Si-OH. The absorption peaks at 1635.64 cm<sup>-1</sup> were assigned to the bending vibration of Si-OH. The absorption peak at 1095.57 cm<sup>-1</sup> and 1080.14 cm<sup>-1</sup> were assigned to asymmetric stretching of Si-O-Si. The absorption peaks at 470.63 cm<sup>-1</sup> were assigned Si-O-Si, which indicated the formation of the silica network. The absorption peaks at 1391.03 cm<sup>-1</sup> were assigned to the C-H deformation. These results are following previous studies [21].

**Table 1.** Atomic Absorption Spectrophotometer data for nickel.

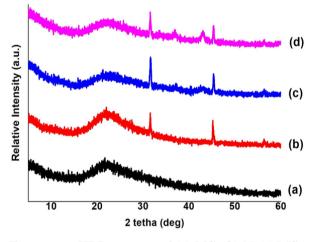
Catalyst	Nickel Content (wt%)*
Ni(4)/MS	4.40
Ni(6)/MS	6.97
Ni(8)/MS	9.57

<sup>\*</sup>The linear equation of the Ni calibration curve was used to find the Ni concentration of each catalyst. The concentration was converted to weight Ni then divided by the weight of the catalyst. The result was multiplied by 100% to get the percentage of Ni metal content in the catalyst.

The MS which has been impregnated by nickel-metal is characterized by XRD to be seen qualitatively and quantitatively in the state or crystal system of the metal formed for the carrier material. Based on Figure 3, nickel-metal was successfully added to the catalyst. It could be seen that each spectrum of the Ni/MS catalyst appears 4 distinct main peaks. First, peak at 23° shows the amorphous structure of the silica support material according to JCPDS card no. 01-086-1561 [22]. A peak of 31° with high intensity indicates a crystal plane (111) of NiO, indicating the sample is not completely reduced. Peaks at 45° and 56°, both representing fcc metallic Ni with crystal planes (111) and (200), respectively following JCPDS card no. 01-087-0712 [23]. Based on these results, it can be concluded that the calcination and reduction processes produce a mixed crystal structure of NiO/fcc Ni. Based on calculations using the Scherrer equation in Table 2, it can be seen that the Ni(4)/MS catalyst at 20 31.54° experienced the greatest aggregation of all catalysts with a size of 165.04 nm. This is indicated that Ni(4)/MS catalyst has the greatest aggregation that has occurred on the external surface or in the mesoporous.



The pore diameter was measured by the BJH desorption method where the diameter size showed the highest pore distribution. The pore diameter curve of each catalyst can be seen in Figure 4. The pore diameter can increase with the specific surface area from every



**Figure 3.** XRD spectra of (a) MS, (b) Ni(4)/MS, (c) Ni(6)/MS, and (d) Ni(8)/MS.

Table 2. Crystallite size of MS and Ni/MS.

Catalyst	2θ (°)	FWHM	Crystallite Size (nm)*
MS	21.69	0.09	89.84
Ni(4)/MS	31.54	0.05	165.04
	45.17	0.07	122.87
	56.43	0.33	27.31
Ni(6)/MS	31.73	0.23	35.89
	45.35	0.20	43.03
	56.41	0.20	45.06
Ni(8)/MS	31.58	0.23	35.88
	45.30	0.20	43.02
	56.35	0.27	33.37

<sup>\*</sup>Crystallite size = ((0.9 x 1.54)/(FWHM (rad) x cos  $\theta$  (rad))) x 0.1.

Table 3. Parameter of MS and Ni/MS structure.

Catalyst	Specific Surface Area (m²/g) <sup>a</sup>	Pore Diameter (nm)b	Total Pore Volume (cm³/g)c
Ni(4)/MS	63.05	3.26	0.16
Ni(6)/MS	91.45	3.22	0.15
Ni(8)/MS	120.45	3.59	0.17

Note: a Specific Surface Area measured by BET

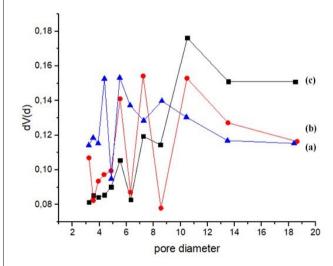
<sup>&</sup>lt;sup>b</sup> Pore diameter measured by BJH desorption

<sup>&</sup>lt;sup>c</sup>Total Pore Volume determined from nitrogen adsorption in relative pressure (0.99)

catalyst. This is because the pore diameter from the catalyst sample is measured based on the BJH desorption where the actual radius of the pore is the radius of the calculation according to the Kelvin equation and the thickness of the adsorbate which is attached to the surface of the sample. The higher the metal content of the catalyst sample, the more likely the adsorbate to be absorbed on the surface and increasing as well so that the thickness of the adsorbate increased and if it calculated based on the BJH principle, the diameter of the catalyst sample will be increased. Only the Ni(6)/MS catalyst did not follow the rule. Ni(6)/MS catalyst diameter is smaller than Ni(8)/MS catalyst. This is indicated that there was a blockage by the metal in the surface of the pore of the catalyst sample thereby inhibiting N<sub>2</sub> as an adsorbate to enter the pore and adsorbed the porous

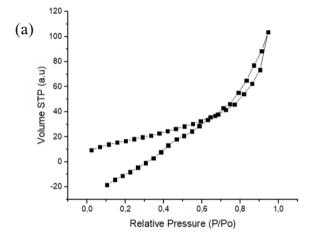
In general, the catalyst sample volume has increment and decrement which is not so far compared to MS. In calculations based on the BET principle, the volume is the space in the catalyst pore that can be filled by adsorbate. Insignificant increment and decrement indicated that there are not so many changes that occurred in the pore sample of the catalyst that metal has been exposed to with MS. This also indicated that there is no blockage of the pore by the metal. The Ni/MS catalyst showed a decrement in volume due to its smaller diameter compared to other catalyst samples so that the chance of adsorbate entering and the analyzed volume was smaller.

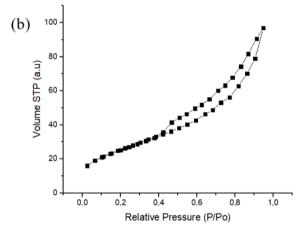
Pore type is also an important character in the catalyst. Pore types were analyzed from linear isotherm data of each catalyst. The re-

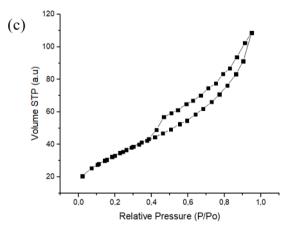


**Figure 4.** Pore distribution curve of; (a) Ni(4)/MS (b) Ni(6)/MS; and (c) Ni(8)/MS.

sults can be seen in Figure 4. From the curve, it can be seen that all catalysts have type IV adsorption patterns. Type IV isotherms are generally adsorbents that tend to occur through multilayer formation followed by capillary condensation and usually occurred in mesoporous material. This is evidenced by an increase in the adsorbed volume at several pressures. At low pressure, the adsorbent and ad-







**Figure 5.** Nitrogen gas adsorption desorption isotherm of; (a) Ni(4)/MS, (b) Ni(6)/MS, and (c) Ni(8)/MS.

sorbates interact with each other to form a monolayer. At medium pressure, the adsorbates interact to form a multilayer. At pressures close to 1, there is condensation in the catalyst capillaries.

From Figure 5, the three types of catalysts meet these requirements. Besides, nitrogen gas pressure on hysteresis loops around  $P/P_0$  0.4 indicates that all four types of catalysts are mesosized material. The hysteresis loops pattern also gives a certain meaning, all three types of catalysts have H2 type based on classification according to IUPAC. Type H2 indicates that the material usually has a pore distribution and shape that cannot be known with certainty the shape and distribution and usually has a bottle-neck pore constriction.

#### 3.3 Catalytic Activity Test

The activity and selectivity of Ni/MS catalysts with various concentrations were tested in a hydrocracking reaction. The quantitative analysis where used for determining the percentage of the products from the hydrocracking process were calculated. The products include the main product (liquid), coke, and gas. The obtained liquid products were analyzed using GC-MS to determine the selectivity of the catalyst. The catalyst is activated in-situ in the process of calcination and hydrogenation of used

cooking oil without undergoing additional treatment.

Hydrocracking of used cooking oil using a catalyst produces more liquid product than using without catalyst (thermal) as shown in Table 4. In thermal hydrocracking, the liquid product that is produced is 76.67 wt%. The use of MS catalyst, the liquid product of 63.95 wt% was produced 21]. Meanwhile in the use of Ni(4)/MS, Ni(6)/MS, and Ni(8)/MS, the liquid product were 80.57, 74.63, and 75.77 wt%, respectively. The Ni(4)/MS shows the highest catalytic activity which is certainly greatly influenced by optimal conditions where the right combination of acidity, specific surface area, pore-volume, and pore diameter.

This experiment can also be given the fact that the thickening of the pore wall increases the percentage of coke fraction. This is because the small pores size will increase the rate of coke formation resulting in deactivation of the catalyst. The hydrocracking of liquid products is then analyzed by using GC-MS to find out the estimated compounds produced in the waste cooking oil of the hydrocracking process. The content of each gasoline fraction (C<sub>5</sub>-C<sub>12</sub>), diesel fraction (C<sub>13</sub>-C<sub>17</sub>), and organic in the hydrocracking liquid product can be known from the percentage of peak area of the GC-MS test results. Table 5 showed the fractions of liquid products produced in the hydrocracking of

**Table 4.** Distribution of product of waste cooking oil hydrocracking.

0 + 1 +	Product Yield (wt%)		
Catalyst	Liquid Fraction	Gas Fraction	Coke
Thermal	76.67	23.33	0
$MS^a$	63.95	30.33	5.72
Ni(4)/MS	80.57	16.75	2.68
Ni(6)/MS	74.63	23.02	2.35
Ni(8)/MS	75.77	22.14	2.09

Note: aData were taken from Trisunaryanti et al. [21].

**Table 5.** Data of hydrocracking liquid product based on the fractions.

C-4-1	The fraction in a liquid product (wt%)			
Catalyst	Gasoline fraction (C <sub>5</sub> -C <sub>12</sub> )	Diesel Oil fraction ( $C_{13}$ – $C_{17}$ )	Organic	
Thermal	49.32	6.66	20.69	
$MS^{\mathrm{a}}$	20.96	1.52	41.47	
Ni(4)/MS	54.22	1.24	25.11	
Ni(6)/MS	49.98	0.95	23.70	
Ni(8)/MS	45.68	8.37	21.72	

Note: aData were taken from Trisunaryanti et al. [21].

waste cooking oil. Table 5 showed that the result of the catalytic activity test by heating at the temperature of 450 °C on the hydrocracking of waste cooking oil into shorter hydrocarbon chains. Liquid product of hydrocarbon compounds produced from the Ni/MS with three concentration of catalysts are at (C<sub>5</sub>-C<sub>12</sub>) chains (gasoline fraction). Based on Table 5, the selectivity of Ni(4)/MS catalyst in the hydrocracking of waste cooking oil produced a dominant gasoline fraction of 54.22 wt%, while the highest diesel fraction selectivity that is produced from Ni(8)/MS catalyst is 8.37 wt%. This indicates that the Ni(4)/MS catalyst has an ability to captured (binding) the free fatty acid (FFA) as well as it can make cracking into shorter hydrocarbons. Thus, the type of catalyst in the hydrocracking of waste cooking oil can affect the selectivity of liquid products to the gasoline fraction and the diesel fraction that is produced.

Based on the explanation, it showed that the Ni(4)/MS catalyst has the highest catalytic activity (80.57 wt%), because almost a big part of the hydrocracking of waste cooking oil process is produced hydrocarbon compounds (55.46 wt%). The results of this study are lower than the study of Nurmalasari et al. who used Ni/MS in waste lubricant hydrocracking [24]. The result obtained from that study has 99.95% of hydrocarbons in the liquid products. This is because the feed utilized is different, where waste cooking oil comes from nature which still contains a lot of organic material, while lubricating oil consists of the long-chain hydrocarbon compounds as the largest constituent component. Therefore, Ni(4)/MS material was a potential catalyst in the hydrocracking of waste cooking oil into the hydrocarbons (biofuel).

# 4. Conclusion

The specific surface area of Ni(4)/MS, Ni(6)/MS, and Ni(8)/MS catalysts are 63.08, 91.45, and 120.45 m<sup>2</sup>/g, where the pore diameters are 3.26, 3.22, and 3.59 (nm), and the total volumes are 0.16, 0.15 and 0.17, respectively. The liquid product of waste cooking oil hydrocracking by using Ni(4)/MS, Ni(6)/MS, and Ni(8)/MS catalysts were 80.57, 74.63, and 75.77 wt%, respectively. The highest selectivity of the gasoline fraction (54.22 wt%) was produced by Ni(4)/MS catalyst and the highest diesel fraction (8.37 wt%) was produced by Ni(8)/MS catalyst. Ni(4)/MS material was successfully used as the most potent catalyst in the hydrocracking of waste cooking oil into the hydrocarbons with the highest amount of biofuel (55.46 wt%).

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