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Pyrolysis of palm oil using zeolite catalyst and characterization of the boil-oil

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Abstract: Pyrolysis of palm oil is one of the most potential methods to obtain bio-oil. In this study, pyrolysis of palm oil was carried out by using zeolites as a catalyst. The use of HCl and NaOH as activating agents of the zeolites prior to its use in the pyrolysis process was investigated. The result showed that a 1 M concentration of either HCl or NaOH gave an optimum result when the zeolites were used to absorb methylene blue. When 1 M of HCl was used as the activating agent, a more uniform pore size of the zeolites was obtained, along with a more opened pore structure. A GC-MS analysis showed that by using zeolites which was activated using HCl or NaOH, the pyrolysis of palm oil yielded bio-oil with a high content of organic compounds.

Keywords: palm oil; zeolite; pyrolysis; bio-oil

1 Introduction

Indonesia is one of the largest producer of palm oil in the world, coming at the second position after Malaysia. In 2014, it was recorded that the 10,754,801 hectares of palm oil plantation in Indonesia produced 29,278,189 tons of palm oil, which increased to 31,244,306 tons in 2015. In 2020 it is estimated that palm oil plantation will cover an area of 22 million hectares; projected to produce 52 million tons of palm oil per year [1].

Palm oil is a potential biomass considering its abundant availaibility. Palm oil contains triglycerides, compounds that are convertible into bio-oil, which is rich in hydrocarbon compounds [2]. In general, bio-oil is volatile substance [3,4] with a similar composition to diesel oil [5], and it has been proposed as a promising fuel source in the future [6]. Bio-oil is a dark brown liquid with a smoke-like smell, and it has a different composition from petroleum-derived fuels [4,7,8]. Bio-oil is acidic, corrosive, polar, thermally unstable, and highly oxygenated [9]. A common method to produce bio-oil is pyrolysis, a popular technique due to its simple process and economic feasibility. Another advantage of this method is its ability to process a wide variety of feedstocks. In pyrolysis, the biomass being processed is decomposed through heating process with a very low level of oxygen, or even none at all [6]. It should be noted that in addition to bio-oil, pyrolysis process often also produces bio-char dan non-condensable gas [3,10].

Thangalazhy-Gopakumar et al. [11] have studied the pyrolysis sludge palm oil which was carried out at 550°C without using catalyst. The amount of bio-oil produced was 27.4 ± 1.7 wt%, with a high content of carboxylic and ester acid compounds [12]. Kabira et al. [13] reported that pyrolysis of palm oil from mesocarp fiber at 550°C using steel slag-derived zeolite as a catalyst produced bio-oil as much as 47 wt%. This significant difference in the yield of bio-oil produced from those reports implied that pyrolysis of palm oil to obtain a high yield of bio-oil would require a catalyst in the process.

Natural zeolite, with its active sites is a promising catalyst to be used for pyrolysis process, especially since it is naturally available in a plentiful amount. Before being used as a catalyst, natural zeolite would need to be activated first to remove impurities that come in the form of Na, K, Ca, Mg, and Fe; increase crystallinity; enlarge its pores, increase surface area, increase acidity, and increase the Si/Al ratio [14,15].

Activation of natural zeolite from Ponorogo-Indonesia has been carried out by Heraldy et al. [16] by using a number of acids (H_2SO_4, HNO_3, and H_3PO_4, and HCl). They reported that zeolit activation using 1 N HCl solution gave a catalyst with higher absorption ability compared with activation by using other acid solutions. The effectivity of HCl as an activating agent for natural zeolite is due to its ability to dissolve metal oxides [17]. In

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a study conducted by Hernawan et al. [18], natural zeolite from Gunungkidul-Indonesia which was activated by using a 3 N HCl solution had larger surface area compared to natural zeolites without activation. In another research done by Ngapa [19], activation of natural zeolite from Ende-Indonesia by using HCl and NaOH solutions with a concentration range varied from 0.5 to 3.0 M increased the capability of the zeolite to absorb methylene blue, indicating an increase in the zeolite surface area. From these studies, it can be inferred that zeolite activation would increase its surface area and hence, improving its absorption capacity.

This research investigated the effect of HCl and NaOH concentrations on their performance as activating agents for natural zeolite from Klaten, Indonesia. Characterization of the activated zeolite comprised of its morphology and constituents. Its adsorption capacity on methylene blue was also observed. Finally, the capability of the activated zeolite as a catalyst in the pyrolysis process of palm oil was examined. The intended purpose of this research is to find the most suitable activating agent and its optimum concentration for a natural zeolite that would further be used as a catalyst in the pyrolysis of palm oil.

2 Experimental

2.1 Preparation of catalyst

The natural zeolite used in this study was from Klaten, Indonesia. Fifty grams of the natural zeolite were washed with 1000 mL distilled water, then refluxed for 4 h in 1 M HCl solution as the activating agent. The zeolite was washed with distilled water and heated using furnace at 400°C for 3 h. The same procedure was repeated by using different concentration of HCl, with a variation of 2, 3, 4 and 5 M. Another set of experiment was also conducted by using NaOH as the activating agent, where the concentration was also varied to 1, 2, 3, 4 and 5 M. Morphological and elemental analysis of the activated zeolite was conducted with Scanning Electron Microscopy technique, using SEM-EDX JED 2300 from JEOL Ltd. Tokyo-Japan (voltage: 1200 KV, pixel: 512x384).

2.2 Methylene blue absorption

Solutions of 5 ppm methylene blue with different concentrations were prepared in conical flasks, and 2.50 g of the activated zeolite was added into each flask. The mixtures were shaken for 3 min, and then allowed to settle for 24 h. The adsorption capacity of the activated zeolite was examined by determining the amount of the remaining methylene blue in the solution using a UV-Vis spectrophotometer (Gold Spectrum Lab 53, BEL Photonics Do Brasil Ltda, Brasil), wavelength range: 200-1000 nm, light source: lamp combination, receiver: Hamamatsu 1226 UV receiver, wavelength accuracy: 2 nm, wavelength repeatability: 0.5 nm, spectrum bandwidth: 4 nm, power source: 220v/110V, at a wavelength of 665 nm.

2.3 Palm oil pyrolysis

Pyrolysis of palm oil was performed by introducing 25 mL of palm oil (Salim Ivomas Pratama Tbk Ltd.) and 2.5 g of the activated zeolite as a catalyst introduced into the pyrolysis reactor. The tubular reactor used in this experiment was made of stainless steel plate, with a diameter of 5 cm and 30 cm in height; the reactor was also equipped with a thermometer to observe the temperature of pyrolysis. The heating system of the reactor used a bunsen burner fuelled by liquid petroleum gas (LPG). The produced bio-oil was collected in canonical flasks. One gram of Na_2SO_4 was added into each flask, and the mixture was then filtered using filter papers. The bio-oil product was further characterized to determine its yield, specific gravity, viscosity, acid number, and calorific value. The compound composition of the obtained bio-oil was identified by using GC-MS. The sample was injected into an Rtx 5 MS column, where the temperature of the column was programmed to have a constant temperature of 50°C for 5 min, before it was gradually increased to 300°C in 10 min). The temperatures of the injector and the GC-MS interface were constantly kept at 310 and 305°C, respectively. The compounds were analysed over its mass per charge (m/z) ratio, ranged of 28-600, and identified by comparing the mass spectra with the NIST (National Institute of Standards and Technology) mass spectral library. Figure 1 showed a schematic diagram of the pyrolysis process.

3 Results and discussion

3.1 Characterization of catalyst

In this study, HCl and NaOH were used as activating agents of zeolite in preparing the zeolite as a catalyst. The variations of concentrations of the activating agents

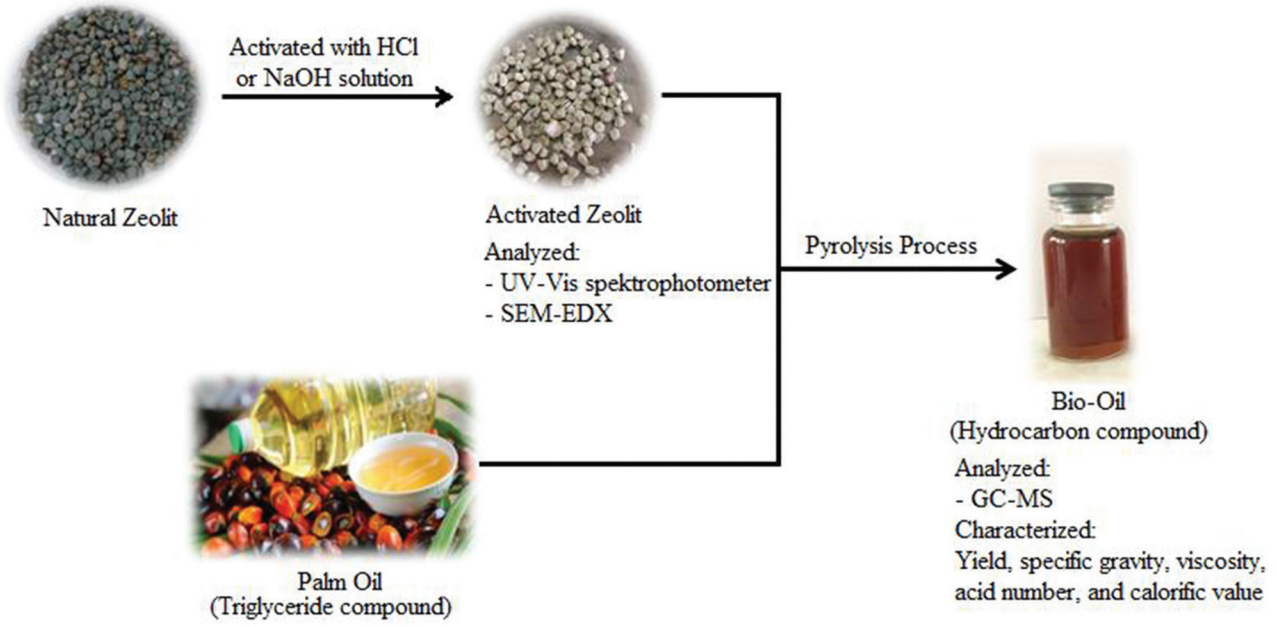

Figure 1: A schematic diagram of the pyrolysis process.

were 1, 2, 3, 4, and 5 M. As a comparison, another set of experiment was also conducted where the zeolite was activated by using distilled water. After the activation process, the zeolite was used as an absorbent for methylene blue (MB). The percent of absorbed MB as a function of the activating agent concentration is presented in Figure 2.

When distilled water was used as its activating agent, 15.72% of MB was absorbed by the zeolite. From Figure 2, it was evident that activation of zeolite using either HCl or NaOH as an activating agent has significantly increased the amount of MB absorbed by the zeolite compared to activation using distilled water. The use of HCl in the activation process was intended to remove the impurities, i.e. aluminium and other cations. Activation using NaOH removed the cations from the zeolite frame and replaced them with Na^+ ions. Hence, the zeolite would have a homo-ionic form with a similar pore size [20]. Interaction of zeolite and NaOH caused a partial dissolution of the silica compounds outside of the zeolite framework, which would be dissolved during the washing process.

As shown in Figure 2, the highest capability of catalysts in absorbing MB was 44.25%, which was a result when the zeolite was activated using 1M of HCl. On the other hand, using the same concentration of NaOH as an activating agent gave a lower absorption capacity, i.e. 43.04%. Figure 2 also showed that increasing HCl and NaOH concentrations appeared to decrease the absorption capability. This result comes in agreement with a study

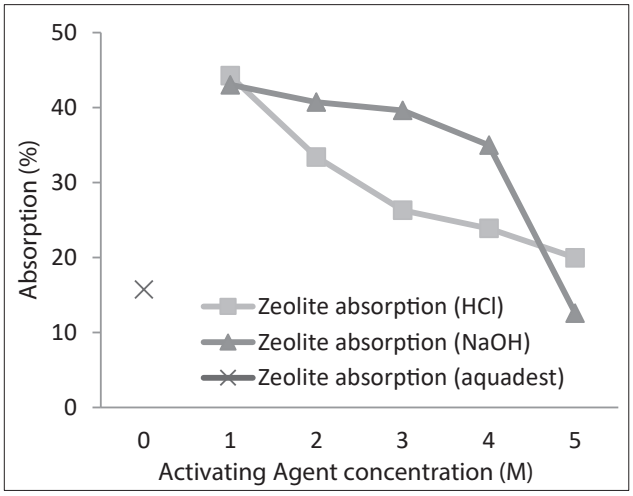

Figure 2: Graph of the relationship between the concentration of activator versus of the zeolite catalyst absorption to methylene blue.

from Pardoyo et al. [21], who reported that increasing the concentration of HCl from 4-10 M would cause a decrease the crystallinity of zeolite.

Zeolites activated with 1 M HCl solution (KZ-HCl-1), NaOH 1 M (KZ-NaOH-1), and distilled water (KZ-DW) were analysed by SEM to observe the morphology of the surface. The result of the analysis is shown on Figure 3. Based on Figure 3, it is evident that the type of activating agent would affect the morphology of the zeolites surface. While KZ-HCL 1 zeolite appeared to have a more uniform crystalline size with open pores (Figure 3a), KZ-NaOH-1

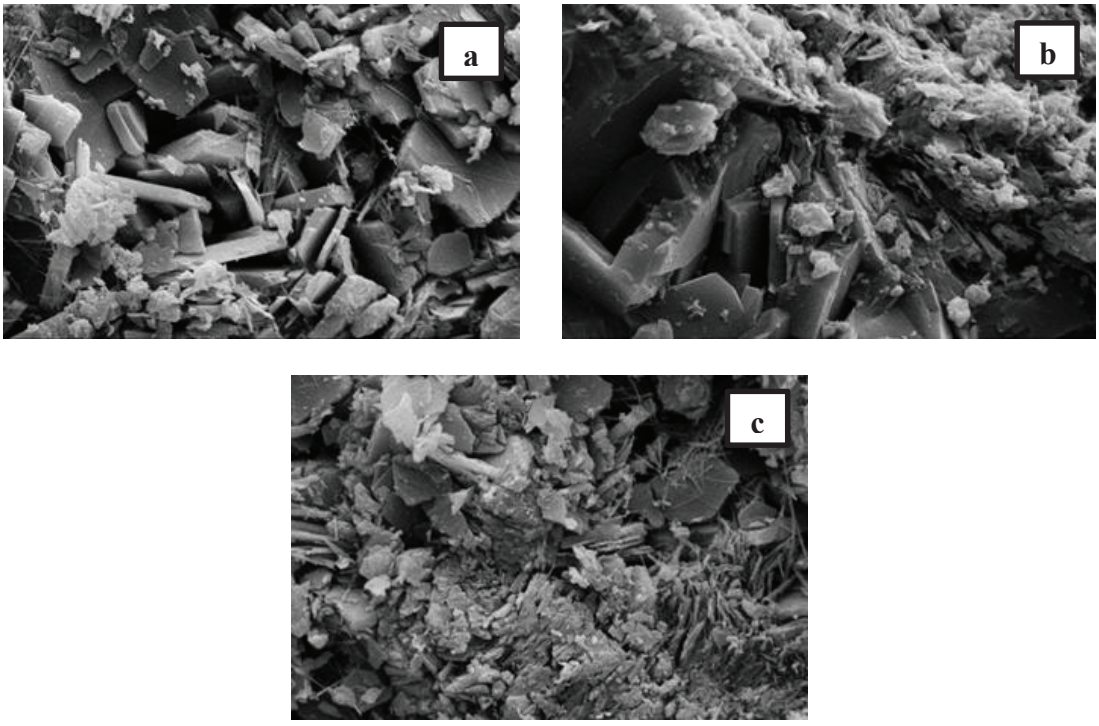

Figure 3: Surface cross-section of catalysts with magnification 5000x: (a) KZ-HCl-1 catalyst surface cross-section, (b) KZ-NaOH-1 catalyst surface cross section, (c) KZ-DW catalyst surface cross-section.

zeolites tend to have a less uniform one (Figure 3b). In comparison, KZ-DW zeolite appeared to have dense pores with non-uniform crystal size (Figure 3c).

The pore size of the activated zeolites can be estimated from the SEM images by using the *Analyze Particles* feature in Image-J software [22]. The pore size determination is necessary considering it is one of the factors affecting the adsorption capacity of catalyst [23]. Table 1 presents the pore area and the average of pore diameter for each of the activated zeolites being analysed.

Based on Table 1, zeolites activated using distilled water had an average pore area and pore diameters of 4.424 nm^2 and 2.374 nm, respectively. These were significantly lower than the other two activated zeolites, indicating that activation using HCl and NaOH has successfully increased the area and pore diameter of the zeolites. This increase of pore area pore diameter came in a good agreement with the capability of zeolites in absorbing MB.

Figure 4 shows the EDX spectrum for each of the activated zeolites, while Table 2 presents a quantitative data from the elemental composition of the zeolites.

As shown in Table 2, all of the zeolites contain Si, O, Al, K, Ca, and Na; and the Al content in the zeolites decreased after activation with HCl or NaOH.

While KZ-HCl-1 zeolite has the highest Si content, it has the lowest content of Al. KZ-NaOH-1 zeolite appeared to have a lower content of Si and Al compared to KZ-DW. These data indicated that both HCl and NaOH were able to dealuminate the zeolite. The decrease of Al content in both KZ-HCl-1 and KZ-NaOH-1 led to an increased Si/Al ratio, as shown in Table 2. It is very likely that the increasing Na content in KZ-NaOH-1 was due to the substitution of cations (K^+ and Ca^{2+}) by Na^+ derived from the NaOH solution. After the activation process, calcium ions were still found in KZ-DW, which was deactivated using NaOH. This indicated that NaOH was unable to remove calcium ions from zeolite.

Table 1: Pore area and pore diameter average.

Catalyst	Average pore area (nm^2)	Average pore diameter (nm)
KZ-HCl-1	8.466	3.284
KZ-NaOH-1	7.033	2.993
KZ-DW	4.424	2.374

The change of the Si/Al ratio in zeolite will have an impact on its ability as a catalyst. Heraldy et al. [16] reported that activation of natural zeolite from Ponorogo-Indonesia using HCl could increase the Si/Al ratio from 3.95 to 4.78. Similarly, an increased in Si/Al ratio (4.40 to 4.63) was also reported by Wirawan et al. [24] on natural zeolite from Klaten-Indonesia. Catalysts with a low Si/Al ratio have a higher affinity to interact with polar

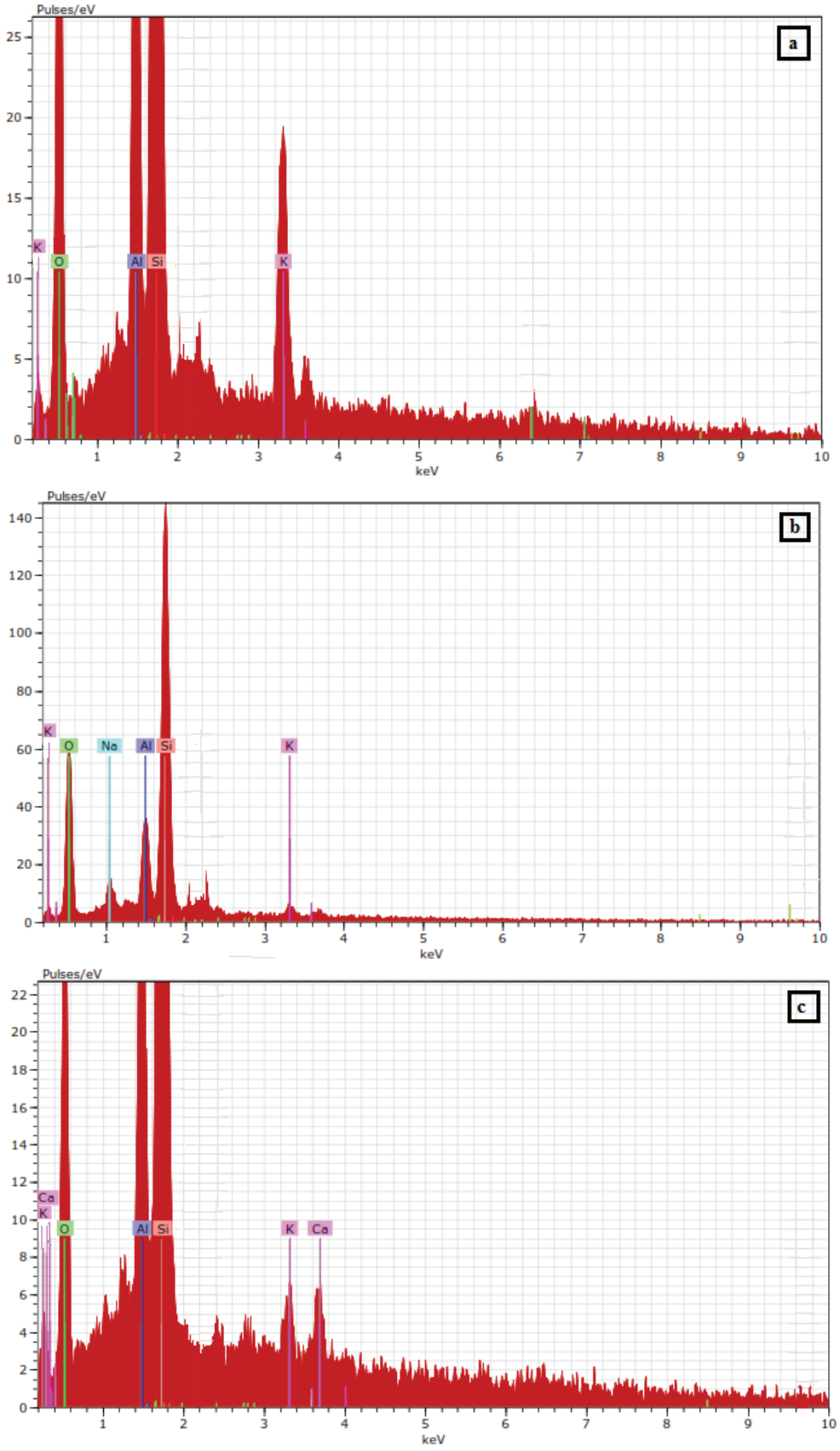

Figure 4: EDX spectra: (a) EDX spectra of KZ-HCl-1, (b) EDX spectra of KZ-NaOH-1, (c) EDX spectra of KZ-DW.

compounds. Conversely, a catalyst with a high Si/Al ratio would be more suitable to be used with non-polar compounds [25].

From Table 2, the Si/Al ratio for KZ-DW zeolite was 3.74, which was a lower value when compared to the other activated zeolites. The Si/Al ratio tends to increase along the presence of acid or base from the zeolite activation. On the other hand, KZ-HCl-1 zeolite has the highest Si/Al ratio, which was probably the result of dealumination caused by the presence of HCl as an activating agent [16,24]. When NaOH was used as an activating agent, it caused silica dissolution that lead to changes in the zeolite structure, reducing the silica content in the zeolite framework and thus, decreasing the Si/Al ratio.

3.2 Characterization of bio-oil

Figure 5 presents the yields of bio-oil obtained from pyrolysis using each of the zeolites as catalysts, where KZ-HCl-1 gave the highest yield. This came as a result from zeolite activation using HCl, which according to Windarti and Suseno [26], would cause an increase in Si/Al ratio due to dealumination that took place, along with an increase in the zeolite surface area.

Catalysts with a high surface area have a great catalytic activity. The ability of the zeolite as a catalyst corresponds to the availability of active centres in the zeolite channel, so the active sites on the catalyst can be utilized during the cracking process. The more active sites on the catalyst surface would give an increase in the volume of bio-oil produced.

Table 2: The composition of elements in the catalysts.

Catalysts	% element						Ratio Si/Al
	Si	O	Al	K	Ca	Na	
KZ-HCl-1	47.18	39.95	7.11	5.73	-	-	6.74
KZ-NaOH-1	37.90	45.50	9.86	2.62	-	4.09	4.15
KZ-Distilled water	42.42	35.20	12.25	5.34	4.65	-	3.74

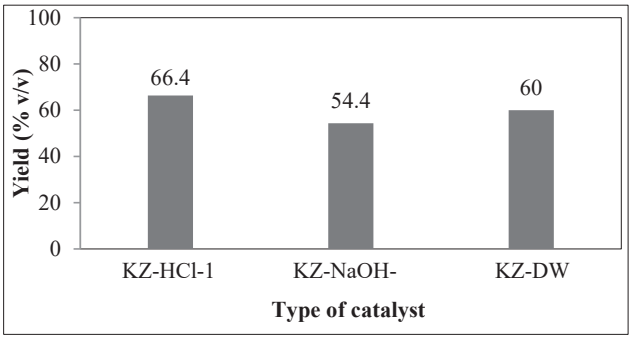

Figure 5: Yield of bio-oil produced for each type of catalyst.

The specific gravity for each bio-oil produced is shown in Figure 6. This specific gravity is lower than what has been reported by previous researchers, which might be due to the different raw materials used to produce bio-oil.

According to Mohan et al. [6], the specific gravity of bio-oil is 1.2 g/mL, which was within the range of 1.1-1.4 g/mL as proposed by Yu et al. [27]. Bardalai and Mahanta [28] reported that the specific gravity of bio-oil was 1-1.24 g/mL. The specific gravity of bio-oil in this study was 0.84-0.85 g/mL, which still falls within the range suggested by The European Committee for Standardization. According to the committee, as stated in EN 590:2004, the range for the specific gravity for crude petroleum products is 0.820-0.845 g/mL [29].

The specific gravity of fluid is related to the mass of the fluid, affecting its viscosity. Viscosity itself is highly dependent on friction taking place within the fluid. Bio-oil with high viscosity would have difficulty to flow, making it unsuitable to be used as fuel oil. The viscosity for each of the bio-oils produced with different types of zeolites as catalysts is shown in Figure 7.

As can be seen from Figure 7, the viscosity of the bio-oil obtained in this study was ranged between 4.72-5.21 cSt. These values fit within the standard range category for biodiesel as stated in ASTM D6751-12, i.e., 1.9-6.0 cSt [30]. It is worth to point out that based on the properties of this viscosity, the bio-oil produced in this study is a promising alternative of fuel oil.

Acid number indicates the amount of free fatty acids in oil. Acid number is also an important parameter in determining the quality of bio-oil. The acidity of the bio-oil

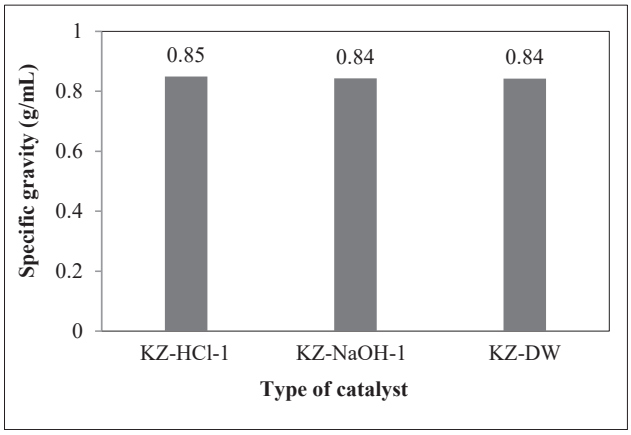

Figure 6: The specific gravity of bio-oil produced for each type of catalyst.

obtained in in this study were 27.67-84.15 mg KOH/g samples. Figure 8 shows the acid number for bio-oil obtained from pyrolysis process for each different type of zeolites used as the catalyst. From this figure, it can be seen that the lowest acid number was for the bio-oil which was produced from a process using KZ-DW as a catalyst, i.e., 27.67 mg KOH/g sample. Meanwhile, bio-oil produced by using KZ-NaOH-1 as a catalyst showed the highest acid number, i.e., 84.15 mg KOH/g sample. From these results, it can be inferred that different types of activating agents significantly affect the acid number of bio-oil. According to Mohan et al. [6], the acid number of bio-oil generally ranged between 35.1 to 50 mg NaOH/g sample, due to its carboxylic acid content. In another study, Azri [31] proposed a much higher value where he reported that the acid number of bio-oil produced from empty palm fruit bunches oil was 62.19-92.30 mg KOH/g sample. The high acidic number of bio-oil produced from pyrolysis signified the need of more treatment on bio-oil before it can be used as biofuel.

A calorific value is the amount of energy released when a certain fuel is completely burned; and it is an important parameter of fuel [33-35]. Figure 9 presents the calorific values of the bio-oil produced in this study, where the highest and lowest calorific values of bio-oil were 10570.06 cal/g and 7852.24 cal/g, respectively. In a study conducted by Kaisan et al. [36], the calorific value of diesel oil was 45.6 Mj/Kg (10898.66 cal/g), which was slightly higher than the calorific value obtained in this study. This difference might be due to the oxygen content in bio-oil, as what have been suggested by Mansourpoor et al. [37], that a chemical compound would have a low calorific value if it contained an oxygen atom.

From Figure 9, one could see that the bio-oil produced from the pyrolysis of palm oil using KZ-DW catalyst had the highest calorific value. This result implied that the bio-oil mainly contains long chain hydrocarbon compounds.

3.3 Chemical content analysis of bio-oil

Bio-oil produced from pyrolysis of palm oil with KZ-DW, KZ-HCl-1, and KZ-NaOH-1 catalysts were then analysed using GC-MS to investigate the chemical composition of the compounds. Table 3 presents the major compounds of bio-oil for each catalyst. The analysis showed that bio-oil produced from pyrolysis of palm oil using KZ-DW, KZ-HCl-1, and KZ-NaOH-1 catalysts contained 56, 56, and 41 compounds, respectively. This result confirmed the implication from the previous discussion about the calorific value that the bio-oil mainly consists of long chain hydrocarbon compounds.

Based on the result from GC-MS data analysis, the bio-oil produced from pyrolysis of palm oil using KZ-DW catalyst contained 72.02% hydrocarbon compound. Its content of carboxylic acid, ketones, alcohols, ester, and

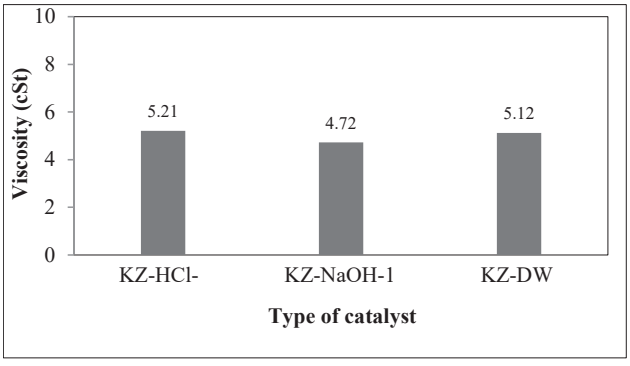

Figure 7: The relationship between catalyst type and bio-oil viscosity.

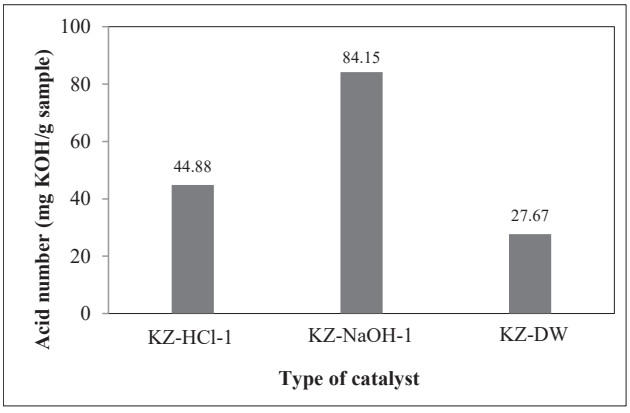

Figure 8: Bio-acid acid number of each bio-oil produced with different types of catalyst.

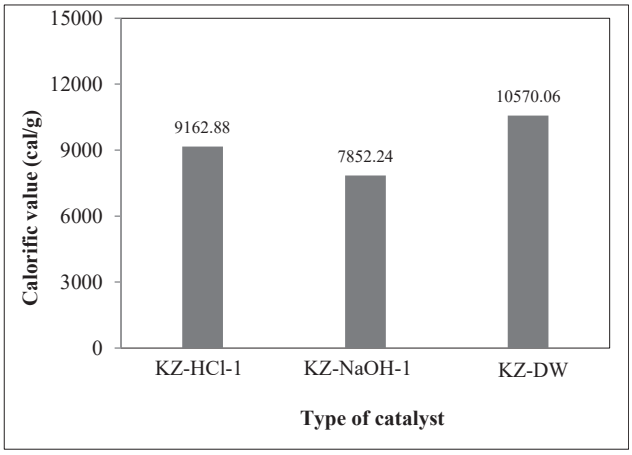

Figure 9: Calorific values of each bio-oil produced with different types of catalyst.

other class compounds were 1.76%, 5.73%, 1.62%, 18.39%, and 0.50%, respectively. The bio-oil produced from pyrolysis of palm oil with KZ-HCl-1 catalyst also contained hydrocarbon compound as much as 84.55%. Tridecane is the predominant hydrocarbon compound in the bio-oil, with a percentage of 32.65%. Several other compounds that were also found in the bio-oil were ketones (9.45%), alcohol (1.22%), ester (2.05%), carboxylic acid (0.86%), and other compounds (1.89%). As for the bio-oil produced from pyrolysis of palm oil using KZ-NaOH-1 catalyst, the hydrocarbon content was 84.21%. The most dominant hydrocarbon content in this bio-oil was also tridecane (29.71%). The other compounds found in the bio-oil were ketones (12.21%) and ester (3.1%). A high content of hydrocarbon in bio-fuel showed the potential of it as a fuel oil alternative.

Similar with the result of this study, Supriyanto et al. [38] also reported a high content of hydrocarbon in bio-oil. In their study, the chemical compounds found in bio-oil from the pyrolysis of sludge palm oil consisted of hydrocarbons (76%), esters (8%), alcohols (13%), and ketones (3%). A very different result in terms of the hydrocarbons content of the bio-oil came from another study [39], where it was found that the hydrocarbon content of bio-oil produced by pyrolysis of pine sawdust was 16.94%. It was very likely that this significant difference in the hydrocarbon content of the two studies was due to the different raw materials used to produce bio-oil.

Table 4 shows the fraction of compounds in bio-oil based on the number of carbon atoms. Compounds with less than five carbon atoms were found in small quantity as these compounds were in their gaseous phase at room temperature, and hence, they were more difficult to be condensed.

As can be observed in Table 4, the predominant hydrocarbon fraction found in the bio-oils from this work were mostly C_{11}-C_{15} compounds, which are the main components in kerosene fuel types [40,41]. Table 4 shows that both of the bio-oil produced using either KZ-HCl-1 or KZ-NaOH-1 as a catalyst had a high content of C_{11}-C_{15} compounds. On the other hand, when KZ-DW was used as a catalyst, the bio-oil produced had a low content of C_{11}-C_{15} compounds. This can be an indication that KZ-DW as a catalyst had a low capability in the cracking process, especially compared to the other catalysts. This indication was also apparent from the content of high C_x fraction ($x \geq 16$) in the bio-oil. Considering that pyrolysis of palm oil using KZ-HCl-1 and KZ-NaOH-1 catalysts produced a high quantity bio-oil with similar characteristics as kerosene,

Table 3: Some major compounds in bio-oil.

Atom C number	Compound	Percentage (%)		
		KZ-distilled water	KZ-HCl-1	KZ-NaOH-1
C_8H_{18}	Octane	1.14	0.83	1.05
C_9H_{20}	Nonane	1.56	1.2	1.55
$C_{10}H_{20}O_2$	Decanoic acid	1.57	0.41	-
$C_{11}H_{22}$	1-undecene	3.6	1.13	-
$C_{11}H_{24}$	Undecane	2.56	2.51	4.37
$C_{12}H_{24}$	1-dodecene	1.61	7.95	5.42
$C_{12}H_{24}$	5-dodecene	0.35	1.18	-
$C_{12}H_{26}$	Dodecane	7.89	3.46	7.28
$C_{13}H_{24}$	1,12-tridecadiene	1.17	1.43	0.95
$C_{13}H_{26}O$	2-tridecanone	-	-	9.56
$C_{13}H_{28}$	Tridecane	16.03	32.65	29.71
$C_{14}H_{28}$	Tetradecene	-	-	1.75
$C_{14}H_{28}$	1-tetradecene	-	10.66	2.34
$C_{14}H_{28}$	3-tetradecene	10.21	7.16	16.01
$C_{14}H_{28}$	Cyclohexane, 1,5-diisopropyl-2,3-dimethyl	1.15	-	-
$C_{16}H_{32}$	1-hexadecene	3.35	-	-
$C_{16}H_{32}$	7-hexadecene	4.43	-	-
$C_{16}H_{34}$	Hexadecane	5.12	-	-
$C_{17}H_{30}O_2$	Methyl-9,12-hexadecadienoate	-	0.78	1.01
$C_{17}H_{34}$	1-heptadecene	3.57	-	-
$C_{17}H_{34}$	8-heptadecene	-	5.03	7.71
$C_{17}H_{34}O$	2-heptadecanone	4.17	6.72	-
$C_{17}H_{34}O_2$	Isopropylmyristate	3.67	0.76	1.05
$C_{17}H_{34}O_2$	Methylpalmitate	3.82	0.51	-
$C_{18}H_{36}O$	3-octadecanone	0.72	1.62	1.61
$C_{18}H_{38}S$	1-octadecanethiol	-	1.26	-
$C_{19}H_{34}O_2$	Methyllinolelaidate	4.54	-	-
$C_{19}H_{36}O_2$	Methylelaidate	5.03	-	-
$C_{19}H_{36}O_2$	Methyl-11-octadecenoate	-	-	1.04
$C_{22}H_{44}$	1-docosene	1.03	-	-

Table 4: Classification of bio-oil based on the number of carbon atoms.

Sample	C_1-C_4 (%)	C_5-C_{10} (%)	C_{11}-C_{15} (%)	C_{16}-C_{20} (%)	> C_{20} (%)
Bio-oil KZ-HCl-1	0.58	7.08	71.78	19.36	1.22
Bio-oil KZ-NaOH-1	0.48	7.15	79.41	12.98	0
Bio-oil KZ-DW	0.64	8.49	47.11	40.02	3.76

it is worth to point out that the pyrolysis product from this study might be a potential alternative of renewable fuel.

3.4 Practical implications

The main challenge in this research is to prepare a catalyst with a high activity and selectivity for the pyrolysis process. The attempts of finding the most efficient catalyst should be continued in terms of trying to find efficient activating agents and appropriate activation processes. Considering that this research has shown the potentials of HCl and NaOH as activating agents to prepare natural zeolites as catalysts for a pyrolysis process, more in depth researches would need to be conducted

4 Conclusion

Natural zeolite which was activated using HCl and NaOH demonstrated a decrease in its ability to absorb methylene blue as the concentration of activating agent increases. The optimum concentration on both HCl and NaOH to be used as activating agent for natural zeolites was 1M. From the result of analysis using SEM-EDX, it can be concluded that the use of 1M HCl as an activating agent produced a catalyst with a larger pore area, pore diameter, and Si/Al ratio compared to the other catalysts prepared. In this research, pyrolysis of palm oil using activated zeolites as catalysts produced bio-oil that contained hydrocarbon compounds as its primary component (>70%). The predominant components of bio-oil were C_{11}-C_{15} compounds.

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