

The Effect of Catalyst Amount and Time on the Results of Converting Rubber Wood Chip Waste by Catalytic Pyrolysis into Alternative Energy

Aditia Patrio^{1*}, Irawan Rusnadi², Aida Syarif³

^{1,2,3}Energy Engineering Study Program, Chemical Engineering Department, Sriwijaya State Polytechnic
Jl. Sriwijaya Negara, Bukit Lama, Kec. Ilir Barat, Kota Palembang, Sumatera Selatan 30128

ARTICLE INFO

Article history

Received : 15 August 2023

Revised : 05 December 2023

Accepted : 06 December 2023

Available online:

14 December 2023;

Published Regularly:

September 2023

DOI :

<https://doi.org/10.33366/rekabuar.v8i2.5063>

Keywords: *alternative energy; catalyst; pyrolysis; rubberwood chips; time*

*e-mail corresponding author :
apatrio19@gmail.com

ABSTRACT

In the rubber plantations of South Sumatra, covering an area of 1,013,969 hectares, there exists an underutilized waste stream known as rubber wood waste. This waste can be subjected to pyrolysis to Yield char, bio-oil, and syngas products. This research is centred on pyrolyzing rubber wood waste, employing various zeolite catalysts and time durations, to explore the potential of alternative energy sources and calculate the Specific Energy Consumption (SEC). The pyrolysis results, with variations in catalysts and time, indicate that the optimal combination is at a temperature of 390°C, using 6% zeolite catalyst, and a duration of 70 minutes. The resultant Yields comprise char at 21.73% with a calorific value of 6264.87 kcal/g, bio-oil at 22.50%, and syngas at 45.28% with a CH₄ content of 55.52%. The most SEC-optimal variation is at a temperature of 390°C, using a 6% zeolite catalyst, and 30 minutes, with an SEC value of 3.25 kWh/L.

PENERBIT :

UNITRI PRESS

Jl. Telagawarna, Tlogomas-
Malang, 65144, Telp/Fax:
0341-565500



This is an open access article under the [Creative Commons Attribution-ShareAlike 4.0 International License](https://creativecommons.org/licenses/by-sa/4.0/). Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI. [CC-BY-SA](https://creativecommons.org/licenses/by-sa/4.0/)

Cara Mengutip : Pario, A., Rusnadi, I., Syarif, A. (2023). The Effect of Catalyst Amount and Time on the Results of Converting Rubber Wood Chip Waste by Catalytic Pyrolysis into Alternative Energy. *Reka Buana : Jurnal Ilmiah Teknik Sipil dan Teknik Kimia*, 8(2), 164-182. doi: <https://doi.org/10.33366/rekabuana.v8i2.5063>

1. INTRODUCTION

To live life, humans need an energy source. Alternative or renewable energy comes from biomass, a renewable resource. The biomass-burning cycle produces organic materials such as products and waste [1]. Solar radiation then converts carbon dioxide emissions into additional biomass formation. Replacing fossil fuels with biomass can help reduce carbon dioxide emissions. Biomass usually consists of three main compounds: lignin, hemicellulose, and cellulose. Each compound has a different composition.

According to data from the South Sumatra Province Plantation Service in 2021 [2], the area of rubber plantations in South Sumatra reached 1,013,969 hectares. The plantation produces around 500 rubber trees per hectare, producing around 25 kilograms of rubber wood waste per hectare. Rubber wood chips are wood residues produced from stripping the bark of rubber trees. It is also a byproduct of extracting rubber sap. The lignocellulosic content of rubber wood chips, an organic material with a complex chemical structure that can be broken down through the pyrolysis process into simpler compounds, is the reason why rubber wood chips have the ability to pyrolysis. The three main components of lignocellulose are lignin, cellulose, and hemicellulose. Research on the characteristics of rubber wood [3], [4], [5], [6] is as follows: Cellulose (20.13 - 50.26%), Hemicellulose (39.97 - 77.04%), Lignin (2.63 - 33.49%), Ash Content (0.60 - 2.40%), Water Content (7.34 - 9.98%), Density (607 - 644.98 kg/m³), Fixed Carbon (13.81 - 16.8%), Volatile Content (74.40 - 86.30%).

Pyrolysis is a thermochemical decomposition process in which organic materials are heated without air or oxygen to decompose into more straightforward chemical products. This prevents the complete combustion of organic materials. Materials such as plastic and biomass are usually involved in the pyrolysis process. Pyrolysis of biomass produces non-condensable gases, liquids, and solids. Biomass pyrolysis usually occurs at 300–600°C [7]. In the passive pyrolysis phase, hemicellulose and cellulose tend to decompose more at low temperatures (150–350°C), while hemicellulose and cellulose decompose at 220–320°C, cellulose at 250–360°C, and lignin at 180– 500°C [8]. Starting with the decomposition of hemicellulose and cellulose during the active pyrolysis phase, CO₂ and CO gas formation occur.

On the other hand, during the passive pyrolysis phase, lignin decomposition produces CO gas. Hemicellulose and cellulose are more likely to decompose at low temperatures (150°C to 350°C), and CO₂ production stops when they are completely decomposed. At the same time, lignin decomposes at higher temperatures, producing CH₄ and H₂ gas components [9]. The type of raw material, temperature, time, and amount or type of catalyst are some of the variables that influence pyrolysis results. Higher pyrolysis temperature increases the amount of bio-gas and Syngas but reduces char production [10]. More intense thermal decomposition of rice straw causes a simultaneous increase in bio-oil and Syngas [11]. High temperatures and longer operating times can produce bio-oil without oxygen [12]. Additional operating time and zeolite catalyst increase bio-oil yield. The amount of zeolite catalyst present in the reactor also influences the amount of liquid produced from pyrolysis; the more catalyst in the reactor, the more liquid is produced [14].

By using a zeolite catalyst for biomass pyrolysis, the phenol content in the bio-oil produced is lower [15]. The catalyst-to-biomass ratio also influences results. For example, when zinc oxide was used as a catalyst, bio-oil production decreased by approximately 6 wt%, while gas production increased from 21.38% to 28.74 wt% [16]. Another study showed that when pyrolysis of pine wood was carried out without a catalyst at 390 °C, Baggase material produced 33.67% char, 27.11% bio-oil, and 26.43% syngas [17]. With a zeolite catalyst, bio-oil production reaches its peak. As a result of the use of zeolite catalysts for the pyrolysis of pine wood, bio-oil production reached its peak at 4% of the amount of catalyst, namely 43.78% [18].

This research focuses on the pyrolysis of rubber wood chip waste with several zeolite catalysts and time variations to obtain alternative energy potential and find the optimal Specific Energy Consumption (SEC) value. The yield of char, bio-oil, and syngas from the pyrolysis of rubber wood chip waste was reviewed based on variations in the amount of catalyst and time as well as analysis of each product. The urgency of this research for the development of science is to take advantage of the opportunity for rubber wood chip waste, which was previously thrown away and burned by rubber farmers, to become a pyrolysis product with alternative energy value where non-renewable energy reserves are decreasing over the years. Meanwhile, the impact is that the results of this research can be a reference for further research in the field of chemistry of pyrolysis processes with catalysts and alternative energy, which is hoped will create opportunities for the development of new technology and increased understanding of biomass pyrolysis.

2. METHOD

The materials used in this research were rubber wood chips and natural zeolite. The equipment used is a series of pyrolysis equipment (consisting of a pyrolysis reactor, separator, condenser, 500 mL Erlenmeyer, condenser hose, gas hose, vacuum pump, small water pump, stove.), key equipment, 100 mL measuring cup, 500 mL beaker, mercury thermometer, wattmeter, porcelain cup, ruler, urine bag, paper duct tape, char holding plastic, bio-oil and tar holding bottles, analytical balance, desiccator, clamping forceps, aluminium foil paper, filter paper, ice cubes, funnel, pycnometer, viscometer, pH meter, oven, furnace, sieve shaker, stone mortar, and match. The following is a series of pyrolysis equipment in Figure 1.

When the pyrolysis experiment began, the raw materials for rubber wood chips and natural zeolite were first prepared as materials in this research. A series of pyrolysis equipment used includes a bandheater biomass pyrolysis reactor tube, separator, 40 cm glass condenser, 1/2 L Erlenmeyer, water hose for condenser, gas stove hose, 1/4 HP vacuum pump, small water pump, and stove. Apart from that, other important equipment is a mercury thermometer, electric power meter, 100 mL measuring cup, 1/2 L beaker, laboratory crucible cup, ruler, plastic container for syngas, paper duct tape, plastic bottles to hold oil and tar, laboratory scales, desiccator, laboratory crucible forceps, aluminium foil, Whatman filter paper, ice cubes, glass funnel, Brookfield viscometer, pH meter, dryer oven, furnace, shaker, pestle, and match.

After operating and cooling the device for about two hours, the sample product consisted of char inside the pyrolysis reactor, bio-oil collected in a vacuum Erlenmeyer, and tar from the bottom of the separator. The char mass bio-oil and tar volume were measured using a measuring cup. While the char is put into thick plastic, the bio-oil and tar are put into a sample container bottle. The experimental flow diagram is in Figure 2. Next, the pyrolysis product is analyzed using various types of analysis to determine its characteristics, namely:

a. Quantitative Analysis:

Calculating the yield of pyrolysis products uses the following equation from equations (1) to (4) [19]:

1). *Yield on char*

$$\text{Char Yield (\%)} = \frac{\text{char mass}}{\text{raw material mass}} \times 100\% \quad (1)$$

2). *Yield on bio-oil*

$$\text{Bio-oil Yield (\%)} = \frac{\text{char mass}}{\text{raw material mass}} \times 100\% \quad (2)$$

3). *Yield on tar*

$$\text{Tar Yield (\%)} = \frac{\text{char mass}}{\text{raw material mass}} \times 100\% \quad (3)$$

4). *Yield on syngas*

$$\text{Syngas Yield (\%)} = 1 - y_{\text{char}} - y_{\text{bio-oil}} - y_{\text{tar}} \quad (4)$$

In the analysis of the characteristics of each biomass pyrolysis product, they are as follows:

- 5). The Char product is an analysis of calorific value, water content, ash content, volatile matter content and fixed carbon content, which is based on the wood charcoal standard in SNI 1683:2021.
- 6). Bio-oil products include testing the pH value, viscosity/viscosity, and density/density, as well as the compound content in the bio-oil product.
- 7). The Syngas product is a CH₄ composition. Apart from that, the length of the flame and the length of time the flame burns are also measured.
- 8). Calculation of Specific Energy Consumption (SEC) by measuring the electrical power used during the pyrolysis process (kWh), whose value is divided by the total product produced (L). SEC Formula [20]:

$$SEC = \frac{\text{Total Energy Consumption}}{\text{measurable product}} \quad (5)$$

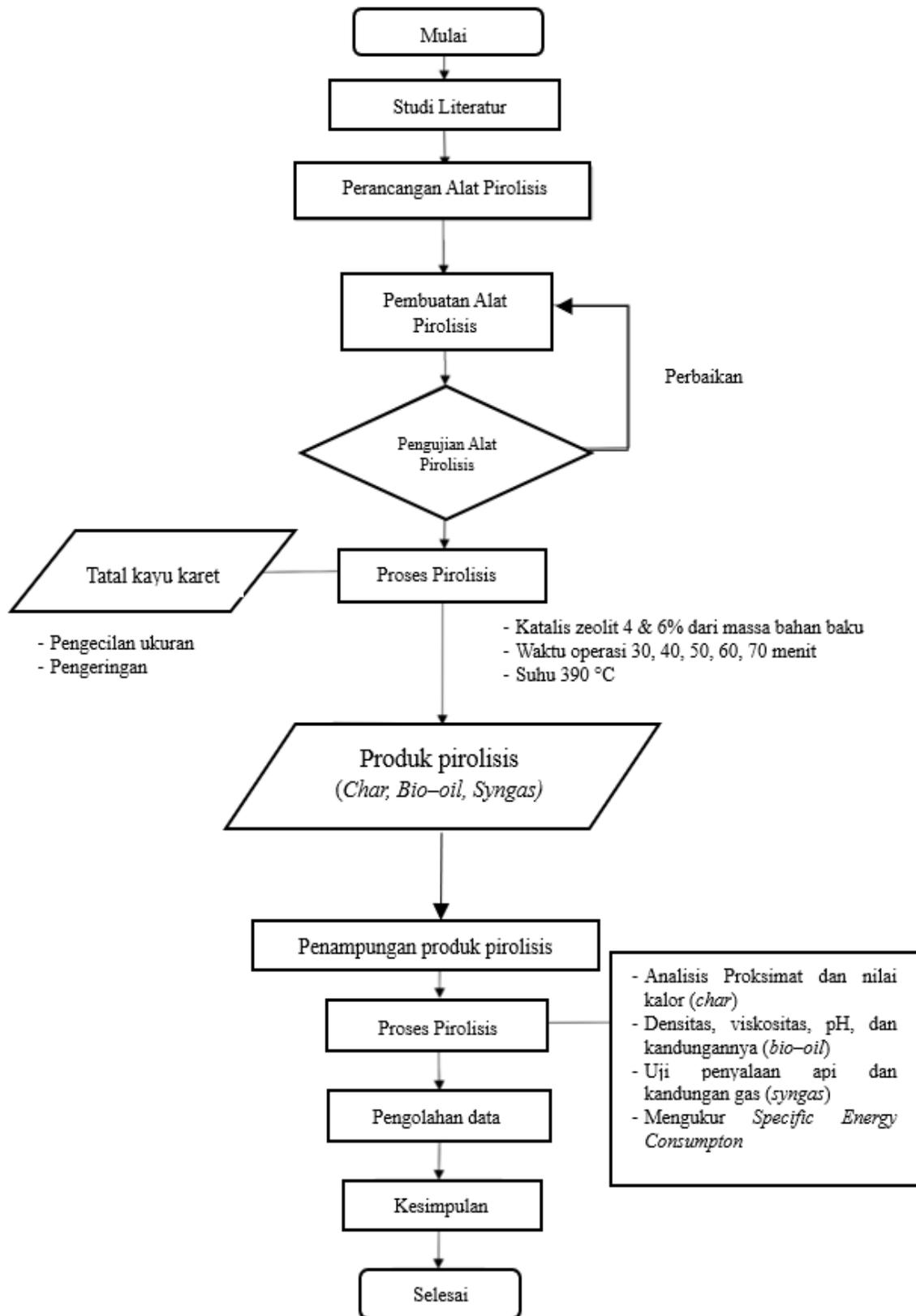


Figure 2. Process Flow Diagram

3. RESULTS AND DISCUSSION

3.1 The Effect of the Amount of Catalyst and Operating Time on the Char Product

a. Char Yield.

The char yield graph is shown in Figure 3 as follows:

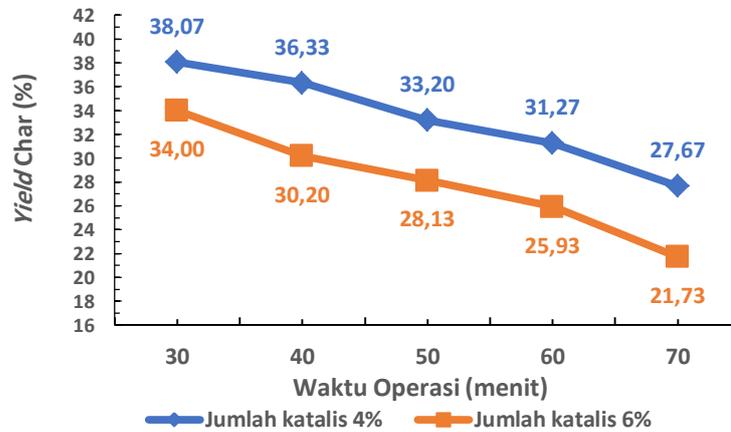


Figure 3. Char Yield from Experimental Variations in the Amount of Zeolite Catalyst and Time

Based on Figure 3 above, the yield of char products tends to decrease over time, and so does the use of a number of zeolite catalysts. This is caused by the increasing percentage of zeolite, which causes more biomass to decompose. As a result, biomass loses a lot of its volume [21]. In this research, the most significant amount of catalyst was 6%, and the operation was carried out for a maximum of 70 minutes, so there is a connection to the effect of reducing the char product produced.

b. Proximate Analysis of Char Products

Proximate analysis of char products is an analysis to determine the water content, ash content, volatile matter content and fixed carbon content in the char.

1) Moisture Content

Figure 4 below is a graph of the moisture content of the char product for each experimental sample:

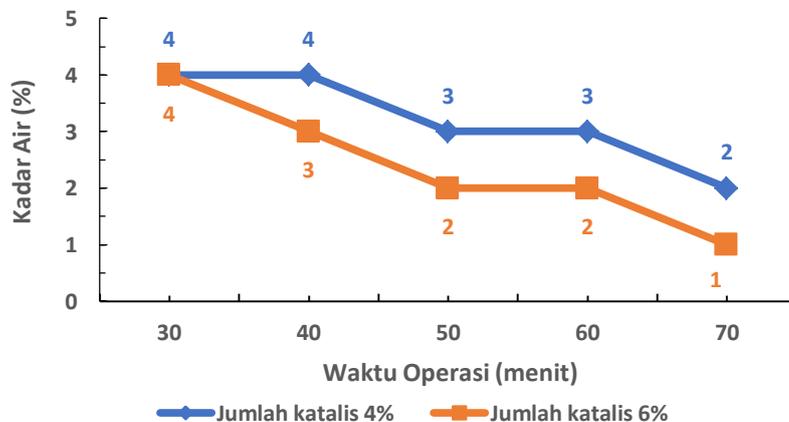


Fig. 4. Char Moisture Content (Experimental Variations) in the Amount of Zeolite Catalyst & Time

Based on Figure 4, the moisture content in the char product decreases with the length of operation time and the amount of catalyst. The lowest water content in samples varying in the amount of catalyst was 6% with an operating time of 70 minutes, namely 1%. This is caused by more prolonged heating and the use of a more significant number of zeolite catalysts, which can result in higher dehydration occurring so that more moisture content evaporates due to heating in the pyrolysis reactor. If viewed from SNI 1683:2021, the moisture content in all experimental variation samples is in accordance with the standard.

2) Ash Content

Figure 5 contains a graph of the ash content in the char product for each experimental sample.

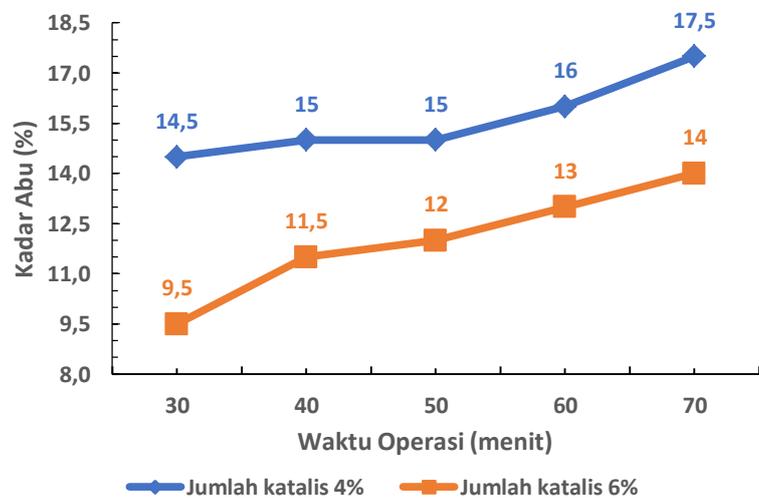


Fig. 5. Char Ash Content (Experimental Variations) in the Amount of Zeolite Catalyst & Time

Based on Figure 5, the ash content in the char product increases with the length of operation time, but the opposite is true for the amount of zeolite catalyst. This is because the accumulated components of inorganic or mineral substances in rubber wood chips increase with the length of the operation time, which also reduces the levels of volatile substances fixed to the charcoal and the longer the operation time, the more the ash content increases [22], [23]. If viewed from SNI 1683:2021, the ash content in all experimental variation samples still does not comply with this standard.

3) Volatile Matter Content

The graph of volatile matter levels can be seen in Figure 6. Based on Figure 6, the measured volatile matter levels decrease with the length of operation time and the increase in the number of zeolite catalysts. The longer the processing time, the lower the volatile matter levels [24]. This is due to the large number of zeolite catalysts, which are able to increase the heating process more quickly so that with the increase in the length of the operation time, the volatile matter contained

decreases because it is released as a result of the heating process and the operation time becomes longer. If viewed from SNI 1683:2021, then the levels of volatile substances in the samples at 4% zeolite catalyst amount variation were only 60 and 70 minutes and at 6% zeolite catalyst amount at 40, 50, 60 and 70 minutes, which was in accordance with this standard.

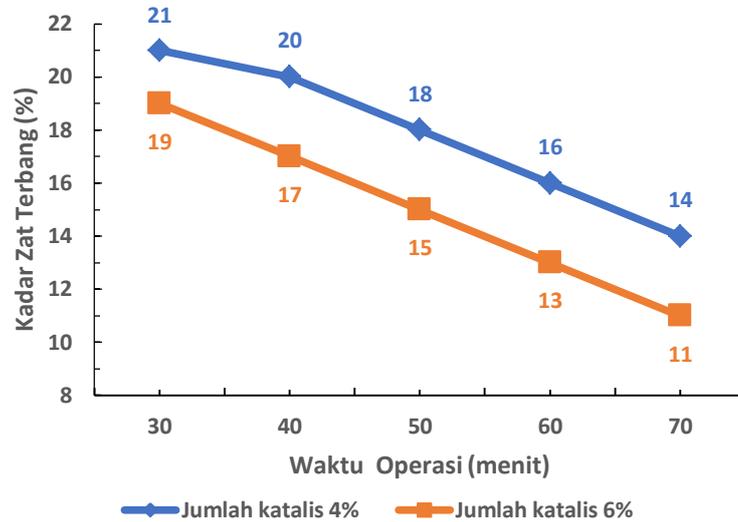


Figure 6. Char Volatile Matter Content from Experimental Variations in the Amount of Zeolite Catalyst and Time

4) Fixed Carbon Content

Fixed carbon content is the carbon content in charcoal, which is the main component of the charcoal structure and is still left in the charcoal itself. The graph of fixed carbon content can be seen in Figure 7.

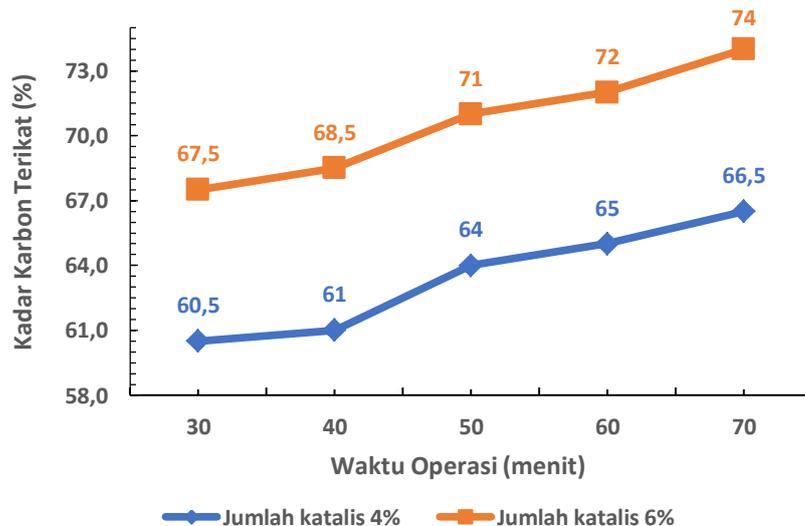


Figure 7. Char Fixed Carbon Content from Experimental Variations in the Amount of Zeolite Catalyst and Time

Based on Figure 7, the fixed carbon content increases with the large number of zeolite catalysts and the length of operation time. This is due to the accumulation of water content, ash content and volatile matter content, which have been calculated previously. In this study, what most influenced the fixed carbon content was the volatile matter content because it had the most significant changes compared to water content and ash content. If viewed from SNI 1683:2021, the fixed carbon content in all experimental variation samples still does not meet this standard.

c. Calorific Value of Char Products

The calorific value of the char product can be seen in Figure 8 below. Based on Figure 8, there is a constant increase along with increasing the number of zeolite catalysts and the length of operation time.

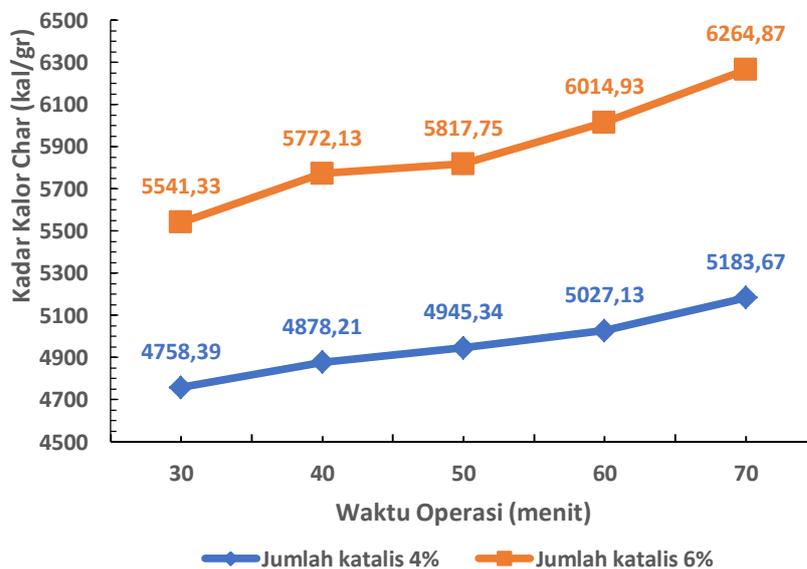


Figure 8. Calorific Value of Char from Experimental Variations in the Amount of Zeolite Catalyst and Time

This heating value is influenced by the amount of bound carbon content in the char sample because the large amount of bound carbon makes the char more efficient at releasing heat with less mass. If viewed from SNI 1683:2021, then the calorific value of char only in samples varying in the amount of 6% zeolite catalyst at an operating time of 60 and 70 minutes meets this standard.

3.2 Effect of Catalyst Amount and Operation Time on Bio-oil Products

a. Bio-oil Yield

The yield of bio-oil produced when using a number of catalysts and the length of operation time can be seen in Figure 9 below.

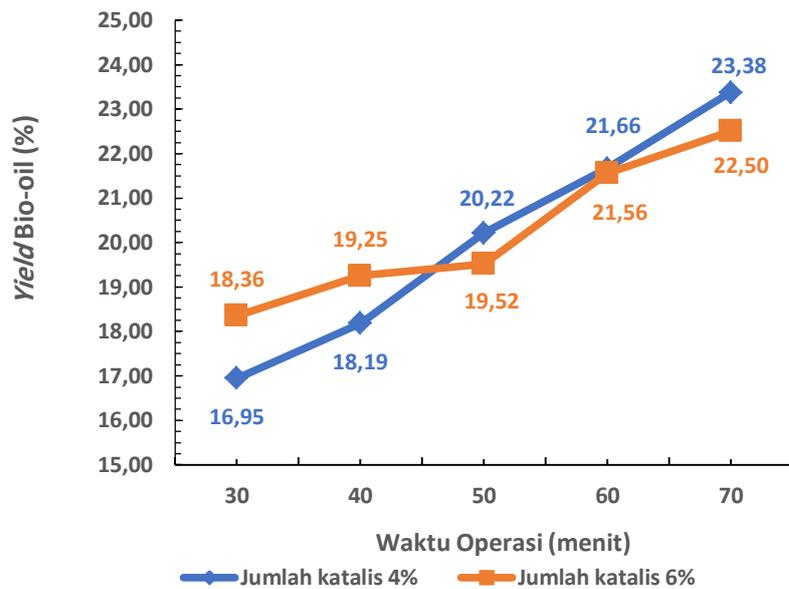


Figure 9. Bio-Oil Yield from Experimental Variations in the Amount of Zeolite Catalyst and Time

Bio-oil yield is calculated from the ratio of the mass of bio-oil to the mass of raw materials (one run). The amount of bio-oil is measured in volume; then, the density is measured using a pycnometer. After that, the mass of bio-oil is obtained by multiplying the calculated density by the volume of bio-oil measured in the observation data. It can be seen that the highest bio-oil yield was obtained in the experimental variation of 4% zeolite catalyst with an operating time of 70 minutes, amounting to 23.38%. This is due to the effect of using a catalyst amount of 4%, which tends to produce bio-oil quite slowly but consistently compared to a catalyst amount of 6%. As a result, the longer the operation time, the 4% catalyst amount can overtake the bio-oil yield from the 6% catalyst amount in the two initial experiments. Apart from that, the bio-oil yield is also influenced by the density of each bio-oil sample so that the mass of the bio-oil is lower than the volume and vice versa.

b. Bio-oil Density

The bio-oil density graph can be seen in Figure 10 below. Based on Figure 10, the density of the bio-oil obtained from the perspective of the amount of zeolite catalyst tends to decrease as the amount of catalyst is reduced, but over a long period of operation, the density tends to be unstable. This is because the cracking process is faster due to the large number of zeolite catalysts used, resulting in an increase in vapours with light and heavy compounds, which are also included in the bio-oil product due to condensation.

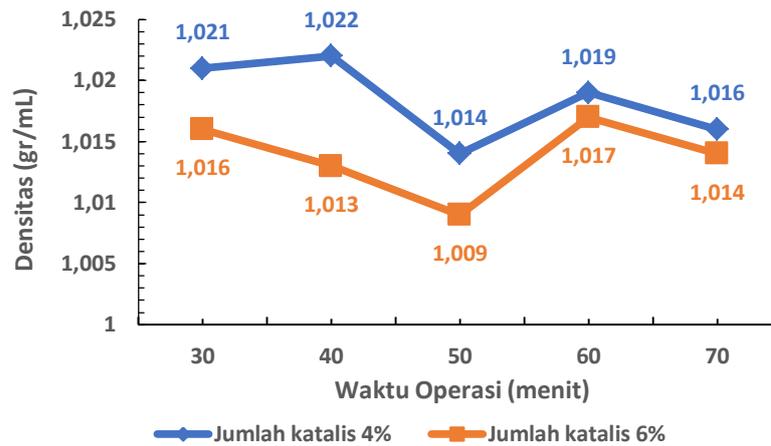


Figure 10. Bio-oil Density from Experimental Variations in the Amount of Zeolite Catalyst and Time

However, the long operating time does not cause a constant decrease or increase because the formation of heavy compounds can increase the density in the early stages of pyrolysis time. Further pyrolysis reactions can cause the decomposition or breakdown of these heavy compounds. This is in accordance with research [25], where the greater the number of zeolite catalysts, the more the density of the bio-oil produced decreases.

c. Bio-oil Viscosity

The dynamic viscosity sample data graph can be seen in Figure 11. Based on Figure 11, the dynamic viscosity decreases with the length of operation time and the large number of zeolite catalysts used. This is because many light compounds and volatile gases are formed during the pyrolysis process. These light compounds can have a lower viscosity compared to heavy compounds so that their contribution to the bio-oil viscosity becomes more dominant as the pyrolysis time increases. This is in accordance with research by [25], where there was a decrease as the amount of zeolite catalyst increased because the catalyst re-breaks down compounds with high molecular weights into alkene hydrocarbon compounds which have low molecular weights.

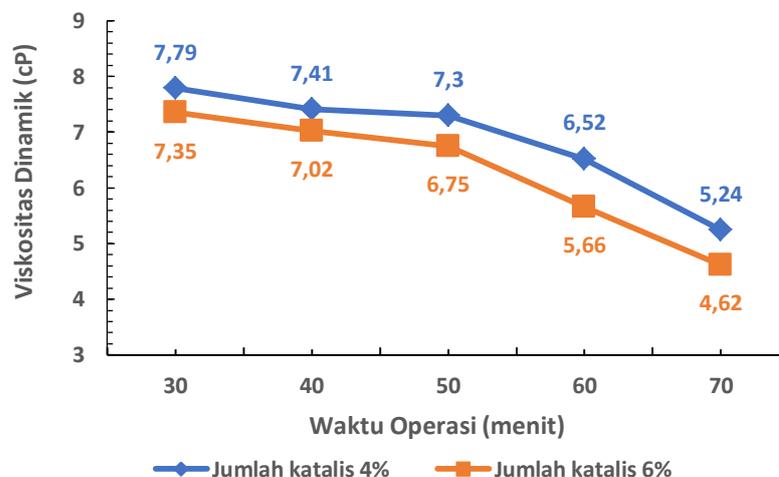


Figure 11. Bio-Oil Viscosity from Experimental Variations in the Amount of Zeolite Catalyst and Time

d. Bio-oil pH Value

The following is a graph of the pH value of bio-oil shown in Figure 12. Based on Figure 12, the more significant the amount of zeolite catalyst, the more acidic the bio-oil.

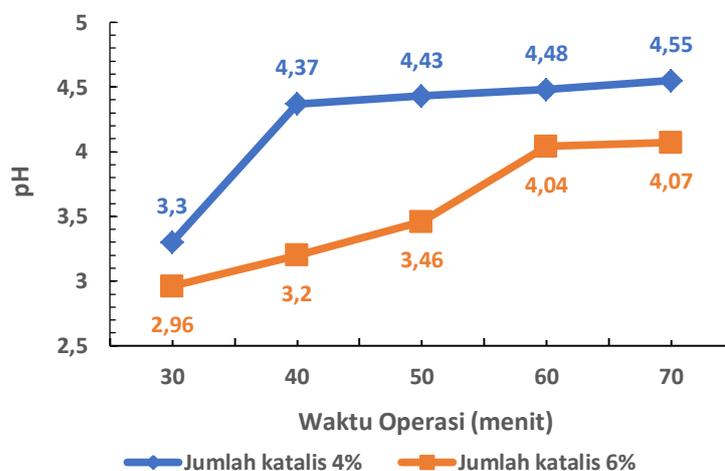


Figure 12. Bio-Oil pH from Experimental Variations in the Amount of Zeolite Catalyst and Time

The decomposition of acid compounds can cause a decrease in the concentration of acid compounds in the bio-oil. As a result, the pH of the bio-oil can increase (more alkaline) as pyrolysis time goes by. Meanwhile, regarding the effect of the amount of zeolite catalyst, this is not in accordance with research [25] where the use of increasing amounts of zeolite catalyst also increases the pH level, so what is appropriate from increasing the amount of zeolite catalyst is increasing the pH level in the bio-oil.

e. Bio-Oil Chemical Compound Content

After analyzing the bio-oil content using the GCMS tool at the South Sumatra Regional Police Forensic Laboratory, the dominant bio-oil content was obtained and then presented in Tables 1 and 2 as follows.

Table 1. Bio-Oil Content in The Pyrolysis Results of Rubber Wood Chips with 4%wt Zeolite Catalyst

No.	RT min.	Area	Compound Name	Qual. %
2	5,397	0,11	3-Ethoxy-1,1,1,5,5,5-hexamethyl-3-(trimethylsiloxy) trisiloxane	72
			1,1,1,3,3,5,5,7,7-Nomethyletrasiloxane	58
			Methyl 10-methoxycarbonyl-17-oxooctadecanoate	43
3	7,027	0,07	Cyclopentasiloxane, decamethyl-	62
			3-Amino-2-phenazinol ditms	43
8	8,695	0,11	Cyclohexasiloxane, dodecamethyl-	91
			2-phenyl-N-(4-[[E]]-phenyldiazenyl) phenyl) cyclopropanecarboxamide	89
17	10,203	0,10	Cycloheptasiloxane, tetradecamethyl-	93

No.	RT min.	Area	Compound Name	Qual. %
			3-(4-N,N-Dimethylaminophenyl) propenoic acid, 2-(diethoxyphosphinyl)-, ethyl ester	38
20	11,546	0,02	10-14-chlorophenyl)-8-fluoranyl-3-methyl-benzo[g]pteridine-2,4-dione	35
			3,4-Dihydroxyphenylglycol, 4TMS derivative	30
			5, 8-Epoxy-15-nor-labdane	
23	12,708	0,01	1-(3-Methylphenyl)-1H-indole	43
			t-Amyl-t-butyl-p-benzoquinone	

Table 2. Bio-Oil Content in The Pyrolysis Results of Rubber Wood Chips with 6%wt Zeolite Catalyst

No.	RT min.	Area	Compound Name	Qual. %
			1,2-Bis(trimethylsilyl) benzene	
1	3,506	0,27	Methyltris(trimethylsiloxy) silane	64
			Arsenous acid, tris(trimethylsilyl) ester	
2	5,404	0,08	3-Ethoxy-1,1,1,5,5,5-hexamethyl-3-(trimethylsiloxy) trisiloxane	72
			Cyclotetrasiloxane, octamethyl-	64
3	7,040	0,06	Cyclopentasiloxane, decamethyl-	64
4	8,698	0,08	Cyclohexasiloxane, dodecamethyl-	91
11	10,205	0,06	Cycloheptasiloxane, tetradecamethyl-	93

Based on Table 1, namely in the bio-oil sample, the amount of zeolite catalyst is 4%, and the dominant chemical compound content in the bio-oil is Cyclohexasiloxane Dodecamethyl- ($C_{12}H_{36}O_6Si_6$) with a flash point of >76 °C, Tetradecamethyl Cycloheptasiloxane ($C_{14}H_{42}O_7Si_7$) with a flash point of 150.7 °C, 3-Ethoxy-1,1,1,5,5,5-hexamethyl-3-(trimethyl siloxy) trisiloxane ($C_{11}H_{32}O_4Si_4$) with a flash point of 100.8 ± 23.0 °C (predicted), and 2-phenyl-N-(4-[[E]]-phenyldiazenyl) phenyl) cyclopropane carboxamide ($C_{12}H_{15}NO$) with a flash point of 145.0 ± 10.5 °C (predicted).

Meanwhile, in Table 2, in the bio-oil sample, the amount of zeolite catalyst is 6%, and the dominant chemical compound content in the bio-oil is Cyclohexasiloxane Dodecamethyl- ($C_{12}H_{36}O_6Si_6$) with a flash point of >76 °C, Tetradecamethyl Cycloheptasiloxane ($C_{14}H_{42}O_7Si_7$) with a flash point of 150.7 °C, 3-Ethoxy-1,1,1,5,5,5-hexamethyl-3-(trimethyl siloxy) trisiloxane ($C_{11}H_{32}O_4Si_4$) with a flash point of 100.8 ± 23.0 °C (predicted).

These compounds are compounds that are still difficult to burn in terms of their flash point. The presence of impurity elements in the compounds in the bio-oil content could also come from environmental contamination during the pyrolysis process because the suction of the operating vacuum pump may also bring these elements mixed into the bio-oil. Bio-oil needs to be upgraded by catalytic cracking, where high molecular weight compounds are broken down into alkanes [26].

3.3 Effect of Catalyst Amount and Operating Time on Syngas Products

a. Syngas Yield

It can be seen in Figure 13 below, which explains the syngas yield graph.

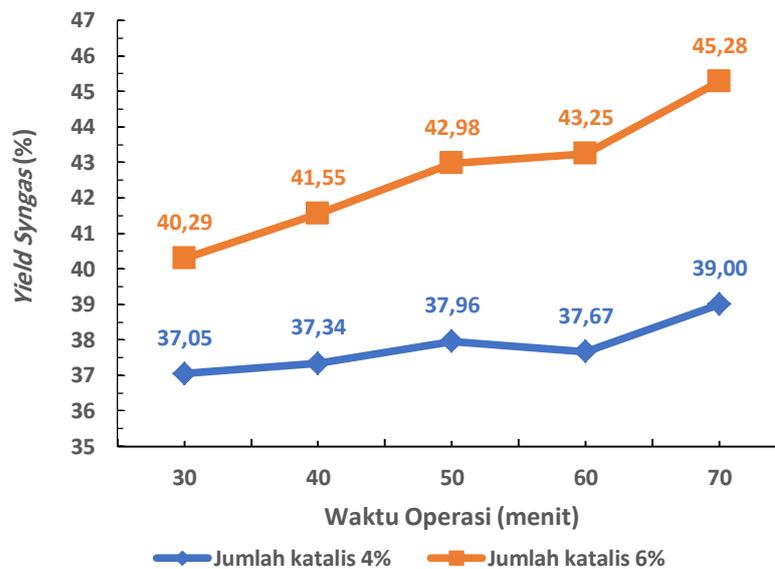


Figure 13. Syngas Yield from Experimental Variations in the Amount of Zeolite Catalyst and Time

Based on Figure 13, the yield on syngas products is more influenced by the large number of zeolite catalysts used rather than the length of pyrolysis operation time, which tends not to be constant. However, this shows that the syngas yield also tends to increase as the number of zeolite catalysts and operating time increases. The calculation of syngas yield is the accumulated reduction in the yield of char and bio-oil products as well as byproducts (tar).

b. CH₄ content in Syngas

The following Figure 14 shows the composition graph of CH₄. The CH₄ content in the resulting Syngas shows results that tend not to be constant. This is because the amount of zeolite catalyst, apart from accelerating the thermal decomposition reaction with increasing temperature, can also increase CH₄ production during pyrolysis. The effect of operating time on changes in CH₄ tends to be different because sampling is carried out when the blue flame first appears on the stove. The decrease in CH₄ composition was caused by impurity compounds such as N₂ and other gases such as methane, CO and H₂, which were not readable.

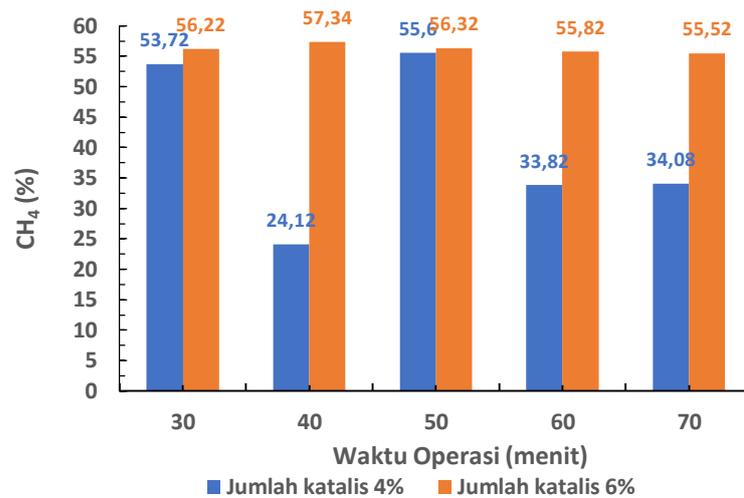


Figure 14. CH₄ Content from Experimental Variations in the Amount of Zeolite Catalyst and Time

3.4 Effect of Zeolite Catalyst Amount and Time on Specific Energy Consumption

The term that compares the energy consumption power used and the products produced is called Specific Energy Consumption (SEC). This calculation is to see how optimal the experiment is in terms of the large number of products produced with less energy consumption. Figure 15 displays the SEC graph for each variation sample experiment that has been determined as follows. Based on Figure 15, the SEC value for 6% zeolite catalyst is less than 4%. This is because electrical energy consumption is significantly influenced by operating time, and the resulting product is influenced by time and the amount of catalyst.

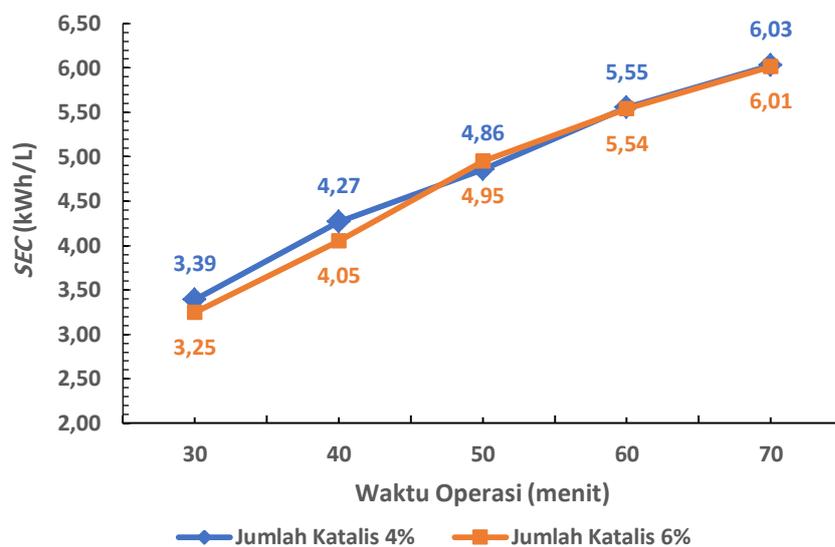


Figure 15. Specific Energy Consumption (SEC) from Experimental Variations in the Amount of Zeolite Catalyst and Time

The lowest SEC is an experimental variation that is capable of producing 0.391 L of liquid product with a power of 1.269 kW, as a comparison of previous research using 1-3 cm coconut shells as raw material for pyrolysis with Specific Energy Consumption (SEC) which consumes 5.68 kWh/L of energy [27]. In contrast, the product from 60 mesh coconut shells is 0.795 litres with energy small, namely 5.65 kWh/L and 5.68 kWh/L [28]. Compared with the two studies, this study has a lower SEC value, which means it is more efficient and optimal in terms of energy consumption.

4. CONCLUSION

From the experiments that have been carried out, it can be concluded that the amount of zeolite catalyst and operating time have a significant influence on the yield of char and Syngas, whereas they tend not to do so on bio-oil. For char, the greater the number of catalysts and the operating time, the better the char produced, except for the ash content. In bio-oil, the greater the number of zeolite catalysts and the operating time, the lower the pH, viscosity and density values. In Syngas, the influence of the amount of zeolite catalyst and operating time on the CH₄ content tends not to change consistently. Among all the variations in the number of zeolite catalysts and pyrolysis operation time, the most optimal in terms of its potential as alternative energy is at a temperature of 390°C, the amount of zeolite catalyst is 6%, and the operation time is 70 minutes, yielding a char yield of 21.73% with water content. 1%, ash content 14%, volatile matter content 11%, bound carbon 74%, and calorific value 6264.87 cal/gr; Bio-oil yield 22.50%, dynamic viscosity 4.62 cP, density 1.014 gr/mL, pH 4.07 but still requires distillation and cracking to be valuable as fuel oil; and syngas yield of 45.28% with CH₄ 55.52%. Meanwhile, if viewed from Specific Energy Consumption (SEC), the most optimal variation is 390°C with a 6% zeolite catalyst and an operating time of 30 minutes with an SEC value of 3.25 kWh/L. After obtaining results with optimal experimental variations, this can become a reference for further development and research related to this research.

5. REFERENCES

- [1] L. Parinduri and T. Parinduri, "Konversi Biomassa Sebagai Sumber Energi Terbarukan," *J. Electr. Technol.*, Vol. 5, No. 2, PP. 88–92, 2020.
- [2] Badan Pusat Statistik, "Luas Tanaman Perkebunan Tahun 2019-2021". *Badan Pusat Statistik Sumatera Selatan*, Indonesia, 2022.
- [3] R. Ali, U. H. Abdullah, Z. Ashaari, L. S. Hua, N. H. Hamid, and S. H. Kamarudin, "Physical Properties of Hydrothermally Treated Rubberwood [*Hevea brasiliensis* (Willd . ex A . Juss .) Müll . Arg .] in Different Buffered Media," *Forests*, vol. 13, no. 1052, pp. 1–14, 2022.
- [4] E. T. D. Severo, E. F. Oliveira, C. A. Sansigolo, C. D. Rocha, and F. W. Calonego, "Properties of juvenile and mature woods of *Hevea brasiliensis* untapped and with

- tapping panels,” *Eur. J. Wood Wood Prod.*, vol. 71, no. 6, pp. 815–818, 2013, doi: 10.1007/s00107-013-0731-2.
- [5] A. Shariff, R. Hakim, and N. Abdullah, “Rubber Wood as a Potential Biomass Feedstock for Biochar via Slow Pyrolysis,” *World Acad. Sci. Eng. Technol. Int. J. Chem. Mol. Enginnering*, vol. 10, no. 12, pp. 1415–1420, 2016.
- [6] S. H. Sultan, A. Palamanit, K. Techato, M. Amin, and K. A. Baloch, “Physiochemical Characterization and Potential of Synthesis Gas Production from Rubber Wood Biomass by Using Downdraft Gasifier,” *Mehran Univ. Res. J. Eng. Technol.*, vol. 40, no. 1, pp. 1–15, 2021, doi: 10.22581/muet1982.2101.01.
- [7] S. A. Novita, Santosa, Nofialdi, Andasuryani, and A. Fudholi, “Artikel Review: Parameter Operasional Pirolisis Biomassa Review,” *Agroteknika*, vol. 4, no. 1, pp. 53–67, 2021.
- [8] Y. Widiardi, P. Wiyoto, E. P. Budiana, and D. A. Himawanto, “Analisa thermogravimetry pada pirolisis limbah pertanian,” *J. Tek. Mesin Indones.*, vol. 11, no. 1, pp. 25–30, 2016.
- [9] J. Waluyo, I. G. B. N. Makertihartha, and H. Susanto, “Pyrolysis with intermediate heating rate of palm kernel shells: Effect temperature and catalyst on product distribution,” in *AIP Conference Proceedings 1977*, 2018, no. 020026, pp. 1–5. doi: 10.1063/1.5042882.
- [10] Qurat-ul-Ain, M. Shafiq, S. C. Capareda, and Firdaus-e-Bareen, “Effect of different temperatures on the properties of pyrolysis products of Parthenium hysterophorus,” *J. Saudi Chem. Soc.*, vol. 25, no. 3, pp. 1–13, 2021, doi: 10.1016/j.jscs.2021.101197.
- [11] A. K. Sakhiya, P. Baghel, S. Pathak, and V. K. Vijay, “Effect of Process Parameters on Slow Pyrolysis of Rice Straw : Product Yield and Energy Analysis,” no. January, 2021, doi: 10.1109/ICUE49301.2020.9306945.
- [12] R. E. Guedes, A. S. Luna, and A. R. Torres, “Operating parameters for bio-oil production in biomass pyrolysis: A Review,” *J. Anal. Appl. Pyrolysis*, no. 129, pp. 134–149, 2017, doi: 10.1016/j.jaap.2017.11.019.
- [13] R. A. Sari, S. Bahri, and Khairat, “Pirolisis Kulit Kayu Pinus (Pinus Merkussi) Menjadi Bio-Oil Menggunakan Katalis Nimo/NZA,” *Jom Fteknik*, vol. 2, no. 2, pp. 1–9, 2015.
- [14] Y. C. Danarto, P. B. Utomo, and F. Sasmita, “Pirolisis Limbah Serbuk Kayu dengan Katalisator Zeolit,” in *Prosiding Seminar Nasional Teknik Kimia “Kejuangan,”* 2010, pp. 1–6.
- [15] S. Wibowo, L. Efiyanti, and G. Pari, “Karakterisasi bio-oil tandan kosong kelapa sawit dengan penambahan katalis Ni/NZA menggunakan metode free fall pyrolysis,” *J. Penelit. Has. Hutan*, vol. 35, no. 2, pp. 83–100, 2017.

- [16] Kabakcı, S. B., & Hacıbektaşoğlu, Ş., “Catalytic Pyrolysis of Biomass. Pyrolysis”, 2017, doi: 10.5772/67569
- [17] Al Arni, S, “Comparison of slow and fast pyrolysis for converting biomass into fuel, Renewable Energy”, *Renewable Energy*, 2017, doi: 10.1016/j.renene.2017.04.060.
- [18] A. Kuntaarsa, “Tinjauan Titik Nyala Dari Pembuatan Bio Oil Dari Pirolisis Kayu Pinus Dengan Katalisator Zeolit Alam,” in *Simposium Nasional RAPI XVIII*, 2019, pp. 392–397.
- [19] A. Zulkania, “Pengaruh Temperatur Dan Ukuran Partikel Biomassa Terhadap Bio-Oilhasil Pirolisis Ampas Tebu/Baggase,” *J. Teknoin*, vol. 22, no. 5, pp. 328–336, 2016.
- [20] A. Lawrence, P. Thollander, M. Andrei, and M. Karlsson, “Specific Energy Consumption / Use (SEC) in Energy Industry: Meaning, Usage and Differences,” *Energies*, vol. 12, no. 247, pp. 1–22, 2019, doi: 10.3390/en12020247.
- [21] W. Wijayanti, “Efek Zeolit Untuk Produksi Tar Dan Char Pada Pirolisis Rotary Kiln,” *Rekayasa Mesin*, vol. 12, no. 1, pp. 51–58, 2021.
- [22] D. Purwanto and Sofyan, “Pengaruh suhu dan waktu pengarangan terhadap kualitas briket arang dari limbah tempurung kelapa sawit,” vol. 4, no. 1, pp. 29–38, 2014.
- [23] S. Siahaan, M. Hutapea, and R. Hasibuan, “Penentuan Kondisi Optimum Suhu Dan Waktu Karbonisasi,” *J. Tek. Kim. USU*, vol. 2, no. 1, pp. 26–30, 2013.
- [24] R. Salim, “Karakteristik dan Mutu Arang Kayu Jati (*Tectona grandis*) dengan Sistem Pengarangan Campuran pada Metode Tungku Drum,” *J. Ris. Ind. Has. Hutan*, vol. 8, no. 2, pp. 53–64, 2016.
- [25] S. Wibowo, L. Efiyanti, and G. Pari, “Karakterisasi bio-oil tandan kosong kelapa sawit dengan penambahan katalis Ni/NZA menggunakan metode free fall pyrolysis,” *J. Penelit. Has. Hutan*, vol. 35, no. 2, pp. 83–100, 2017.
- [26] H. Wijayanti, D. Ratnasari, and R. Hakim, “Studi Kinetika Pirolisis Sekam Padi untuk Menghasilkan Bio-oil sebagai Energi Alternatif,” vol. 3, no. 2, pp. 83–88, 2020.
- [27] M. P. Putri *et al.*, “Analisis Kinerja Unit Pirolisator Kondensor Ganda Guna Konversi Limbah Biomassa Menjadi Asap Cair Performance Analysis of Double Condenser Pyrolysis Unit for Conversion of Biomass Waste into Liquid Smoke,” *J. Pendidik. dan Teknol. Indones.*, vol. 2, no. 11, pp. 447–452, 2022.
- [28] I. Febriana, A. M. Putri, and I. Silviyati, “Analisis Konsumsi Energi Spesifik Pirolisator Double Kondensor Pada Konversi Limbah Biomassa,” *J. Redoks*, vol. 8, no. 1, pp. 7–12, 2023.