GOLDEN RATIO OF SOCIAL SCIENCE AND EDUCATION
VOLUME 5, ISSUE. 1 (2025)
Website: https://goldenratio.id/index.php/grsse/index

GOLDEN RATIO
ISSN [Online]: 2797-5827

SOCIAL SCIENCE AND EDUCATION | RESEARCH ARTICLE

The Effect of Pyrolysis Temperature and Amount of Zeolite Catalyst on Yield, Viscosity, and Cetane Index of Diesel Oil from LDPE Plastic Waste in The Process of Making Environmentally Friendly Diesel

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ARTICLE HISTORY

Received: February 04, 2025
Revised: March 01, 2025
Accepted: March 24, 2025

DOI
https://doi.org/10.52970/grsse.v5i1.1089

ABSTRACT
Indonesia's rapid population growth and industrial development have increased fuel oil consumption, mainly diesel fuel. The high diesel fuel consumption is feared to cause the depletion of diesel fuel reserves. To overcome this problem, it is time for Indonesia to examine the use of alternative energy sources to replace diesel fuel. The raw material for alternative energy sources is plastic waste. The amount of plastic waste in Indonesia is relatively abundant, so it has potential when utilized as an alternative energy source through pyrolysis. This study aimed to analyze the effect of pyrolysis temperature and the amount of zeolite catalyst on the yield, viscosity, and cetane index of diesel oil from LDPE plastic waste that produces environmentally friendly diesel. The LDPE plastic waste used was 40 kg of crackle plastic. The pyrolysis temperatures were 250 C, 300 (o)C, 350 C, and 400 C. The amount of zeolite catalyst used was 0%, 2.5%, and 5%. The characteristics of diesel oil tested were viscosity and cetane index. The results were compared with the quality standards of diesel oil based on the Decree of the Director General of Oil and Gas No. 146 of 2020. The results showed that the highest yield of diesel oil was 6.83%, the best viscosity was 2.645 mm2/s, and the best cetane index was 51.61. The viscosity and cetane index of diesel oil that meets the quality standards of environmentally friendly diesel fuel based on the Decree of the Director General of Oil and Gas No. 146 of 2020 are found in diesel oil with pyrolysis temperatures of 300 C, 350 C, and 400 oC at 5% catalyst use, namely 2.334 mm(2)/s; 2.165 mm(2)/s; and 2.035 mm2/s for viscosity values and 47.13; 48.97; and 51.61 for cetane index values. The potential use of LDPE plastic waste as a diesel oil producer in North Sumatra Province in 2021 is 5,340 tonnes/year; by 2030, it will be 5,424 tonnes/year.

Keywords: Pyrolysis, Catalyst, Yield, Viscosity, Cetane Index.

I. Introduction

Indonesia's rapid population growth and industrial development have increased fuel oil consumption, mainly diesel fuel. Various industrial, transport, and agricultural sectors rely heavily on diesel.

However, the high consumption of diesel fuel risks depleting diesel reserves. To overcome this problem, it is time for Indonesia to examine using alternative energy sources as a substitute for diesel. In addition, plastic waste is one of the environmental problems caused by rapid population growth in Indonesia. The increase in plastic consumption, coupled with people's indifference towards waste disposal and lack of knowledge about recycling, has caused the amount of plastic waste to increase. Among the various types of plastic waste, Polyethylene plastic (LDPE and HDPE) is the most abundant, contributing around 46% (Wahyudi et al., 2018). LDPE plastic is the most abundant because it is often used in everyday life, such as for food wrapping, garbage, shopping, and laundry bags.

Most of this plastic waste is dumped into landfills (Final Processing Sites), which does not provide a maximum solution because landfills can be complete, and plastics take a very long time to decompose, between 10 to 500 years. Handling plastic waste by burning is also considered less effective because it can cause exhaust emissions (CO2, CO, NOx, SOx) and other particulates (Nindita, 2015). One effective way to deal with plastic waste is to convert it into fuel through pyrolysis. Pyrolysis is cracking polymer chains into simpler compounds through heating at 300-600°C without oxygen (Sangpatch et al., 2019). In some cases, higher temperatures, up to 900°C, are also used to produce better pyrolysis products (Shoaib et al., 2021). Pyrolysis products consist of carbon residue (char), pyrolysis oil (tar), and gas (pyro-gas) (Nuryosuwito et al., 2018).

Research on the effect of pyrolysis temperature on the yield (oil) of various plastics has been conducted. Thahir et al. (2019) examined the effect of temperature on the pyrolysis oil yield of PP plastic waste at 500-650°C and found varying results, with the highest oil yield at 580°C of 88%. Panda (2018) conducted research on the effect of temperature on pyrolysis oil recovery from PP plastic, LDPE, HDPE, and a mixture of both at 400-550°C using Calcium bentonite catalyst, with the highest oil yield at 500°C, which is 80-90%. Anene et al. (2018) found that the pyrolysis oil of LDPE plastic reached 94% at 300-500°C. In addition to temperature, using catalysts can also affect pyrolysis results. A catalyst is a substance added to accelerate a reaction without undergoing chemical changes (Dewi et al., 2016). Catalysts can accelerate oil formation and improve quality (Sari, 2017). Zeolite, one type of catalyst, is highly effective because it can provide fast and stable temperature propagation (Kumara et al., 2015).

Research on the effect of pyrolysis temperature and catalyst on oil recovery has also been conducted. Balasundram et al. (2021) examined the effect of temperature and Ni/Ce/Al2O3 catalyst on the pyrolysis of HDPE plastic waste at 500-800°C, with the highest oil yield at 700°C. Panda et al. (2018) examined the effect of the amount of Calcium bentonite catalyst composition on the pyrolysis oil recovery of PP, LDPE, and HDPE plastics, with the highest oil yield at 33% composition of 80-90%. Anene et al. (2018) examined the effect of temperature and CAT-2 catalyst on oil recovery from PP and LDPE plastics, resulting in oil equivalent to petrol and diesel fuel. Based on these studies, it can be concluded that the use of high temperatures can increase pyrolysis oil recovery. In contrast, using catalysts can accelerate the plastic degradation process at lower temperatures, as shown in the studies of Balasundram et al. (2021) and Anene et al. (2018). In addition, increasing the amount of catalyst can also increase oil recovery, as found by Panda et al. (2018), and improve the quality of the oil produced. Diesel is a diesel engine fuel that produces exhaust emissions, including CO2, CO, NOx, SOx, and particulates. The combustion quality of diesel is strongly influenced by cetane number, which can be tested using Cooperative Fuel Research (CFR) engines (Asngari et al., 2019). However, this test is time-consuming, expensive, and requires large samples. To overcome this, the Calculated Cetane Index (CCI) test was developed as an alternative to calculate the diesel cetane index (Tomo, 2015). In addition, viscosity also affects the quality of diesel combustion, as diesel must have sufficient viscosity to be sprayed into the injector engine (Cappenberg, 2017).

Based on this background, the researcher plans to conduct a study entitled "Effect of Pyrolysis Temperature and Number of Zeolite Catalysts on Yield, Viscosity, and Cetane Index of Solar Oil from LDPE Type Plastic Waste in the Process of Making Environmentally Friendly Solar."

ISSN [Online]: 2797-5827

II. Research Method

2.1. Time and Site of Research

This research was conducted from February to July 2022 at the Gampong Jawa landfill in Banda Aceh, the Renewable Energy Laboratory of Medan State Polytechnic, and the Chemical Engineering Research Laboratory and Physical Chemistry of USU Chemical Engineering.

2.2. Equipment Used

1. Pyrolysis Reactor: A device for breaking down organic compounds through heating without direct contact with outside air.
2. Stabinger Viscometer SVM 3001 Anton Paar: Used to measure the viscosity and density of diesel oil based on the ASTM method.
3. Distillation Device: Used to separate components based on boiling point through heating.
4. Materials Used:
5. LDPE Plastic Waste: Crackle plastic waste is used as raw material for plastics.
6. Zeolite Catalyst: Fine zeolite is used as a catalyst in the pyrolysis process.

2.3. Research Procedures

1. Preparation of Plastic Raw Materials: LDPE plastic waste was cleaned, washed, and dried in the sun.
2. Activation of Zeolite Catalyst: Zeolite was activated by heating at 300°C for 2 hours in a furnace and cooling in a desiccator.
3. Pyrolysis Process: Crackle plastic and zeolite catalyst were put into a pyrolysis reactor heated at 250°C to 400°C. The pyrolysis oil is collected and weighed after reaching the specified temperature.
4. Calculation of Pyrolysis Oil Yield: Yield was calculated by comparing the mass of pyrolysis oil to the mass of crackle plastic used.
5. Viscosity and Density Test of Solar Oil: Using a Stabinger Viscometer to measure the viscosity and density of diesel oil.
6. Observation of Solar Oil Temperature during Distillation: Temperature observations were made when the distillate volume reached 10%, 50%, and 90% of the initial volume.
7. Calculation of Cetane Index of Solar Oil: After measuring the density and temperature, the cetane index is calculated using the CCI (Calculated Cetane Index) formula.

2.4. Data Analysis Method

Pyrolysis oil yield analysis

Yield analysis was conducted to determine the effect of pyrolysis temperature and catalyst amount on the yield of each pyrolysis oil produced. The following formula determines the yield:

$$\%\ yield = \frac{pyrolysis\ oil\ mass(g)}{plastic\ bag\ mass\ (g)} \times 100\%$$

Viscosity analysis of diesel oil

Viscosity analysis was conducted to determine the viscosity value of diesel oil. Viscosity was tested using a Stabinger Viscometer SVM 3001 Anton Paar at 40° Celcius with the ASTM D7042 test method.

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Cetane index analysis of diesel oil

1. The cetane index of diesel oil was analyzed using the ASTM D4737 test method with the following steps:
2. The density of diesel oil was first tested using a Stabinger Viscometer SVM 3001 Anton Paar at 15^0 Celcius with the ASTM D4052 test method;
3. Diesel oil was distilled using a distillation apparatus, and the temperature was recorded when the volume of distillate formed was 10%, 50%, and 90% of the initial volume of diesel oil when heated;
4. After knowing the density and temperature of diesel oil, the cetane index value can then be calculated using the following equation:

$$CCI = 45.2 + 0.0892T_{10N} + (0.131 + 0.901B)T_{50N} + (0.0523 - 0.42B)T(_{90N)} + 0.00049(T(^2)_{(10N)} - T(^2)_{(90N)}) + 107B + 60B(^{2)}$$

Description:

CCI = Calculated Cetane Index
T10 = temperature when 10% distillate is formed
T10N = T10 - 215
T50 = temperature when 50% distillate is formed
T50N = T50 - 260
T90 = temperature when 90% distillate is formed
T90N = T90 - 310
B = [e^(-3.5)(D-0.85)] - 1
D = density at 15 C (g/ml)

III. Results and Discussion

3.1. Pyrolysis Oil Yield Analysis of LDPE Plastic Waste

The yield produced in the pyrolysis process of LDPE plastic waste consists of diesel oil, kerosene, and gasoline. The pyrolysis results of LDPE plastic waste can be seen in the following table 1.

Figure 1. Solar oil, kerosene, and petrol from pyrolysis of LDPE plastic waste

The mass of diesel oil produced in the pyrolysis process can be seen in Table 1.

Table 1. Mass of Solar Oil

Amount of Zeolite Catalyst	Mass of Solar Oil at Pyrolysis Temperature (g)
	250 °C
Without Catalyst	208,72
2.5% catalyst	275,64
5% catalyst	311,87

Once the mass of diesel oil is known, the yield can be calculated by comparing the mass of diesel oil with the mass of LDPE plastic (40 kg). The yield value of diesel oil can be seen in Table 2.

Table 2. Yield of diesel oil

Amount of Zeolite Catalyst	Yield of Solar Oil at Pyrolysis Temperature (%)
	250 °C
Without Catalyst	0,52
2.5% catalyst	0,69
5% catalyst	0,78

Based on Table 2 and Figure 2, it can be seen that the diesel oil yield increases with the increase in pyrolysis temperature and the amount of zeolite catalyst. The lowest diesel oil yield occurred at a pyrolysis temperature of 250 °C without a catalyst, while the highest yield occurred at a pyrolysis temperature of 400 °C using a 5% catalyst.

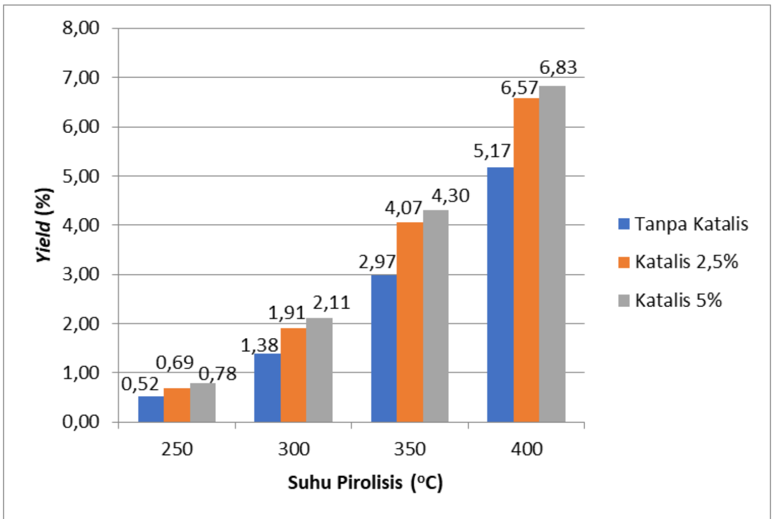

Figure 2. Effect of Pyrolysis Temperature and Number of Zeolite Catalysts on Solar Oil Yield

The mass of kerosene produced in the pyrolysis process can be seen in Table 3.

Table 3. Mass of Kerosene

Amount of Zeolite Catalyst	Mass of Kerosene at Pyrolysis Temperature (g)
	250 °C
Without Catalyst	0
2.5% catalyst	0
5% catalyst	0

Once the mass of kerosene is known, the yield can be calculated by comparing the mass of kerosene with the mass of LDPE plastic (40 kg). The yield value of kerosene can be seen in Table 4.

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Table 4. Kerosene Yield

Amount of Zeolite Catalyst	Kerosene Yield at Pyrolysis Temperature (%)
	250 °C
Without Catalyst	0
2.5% catalyst	0
5% catalyst	0

The mass of gasoline produced in the pyrolysis process can be seen in Table 5.

Table 5. Mass of Petrol

Amount of Zeolite Catalyst	Mass of Gasoline at Pyrolysis Temperature (g)
	250 °C
Without Catalyst	0
2.5% catalyst	0
5% catalyst	0

Once the mass of gasoline is known, the yield can be calculated by comparing the mass of gasoline with the mass of LDPE plastic (40 kg). The gasoline yield value can be seen in Table 6.

Table 6. Gasoline Yield

Amount of Zeolite Catalyst	Gasoline Yield at Pyrolysis Temperature (%)
	250 °C
Without Catalyst	0
2.5% catalyst	0
5% catalyst	0

3.2. Viscosity Analysis of Solar Oil

The viscosity of diesel oil was tested using a Stabinger Viscometer SVM 3001 Anton Paar at 40°C using the ASTM D7042 test method. Table 7 shows the results of the diesel oil viscosity analysis.

Table 7. Results of Viscosity Analysis of Solar Oil

Sample Name	Viscosity (mm^2/s)	Decree of the Director General of Oil and Gas No. 146 Year 2020
	I	II
250°C (No Catalyst)	0	0
300°C (No Catalyst)	0	0
350°C (No Catalyst)	0	0
400°C (No Catalyst)	0	0
250°C (2.5% catalyst)	2,666	2,624
300°C (2.5% catalyst)	2,536	2,485
350°C (2.5% catalyst)	2,238	2,274
400°C (2.5% catalyst)	2,136	2,150
250°C (5% Catalyst)	2,497	2,508
300°C (5% Catalyst)	2,362	2,307
350°C (5% Catalyst)	2,172	2,158
400°C (5% Catalyst)	2,025	2,046

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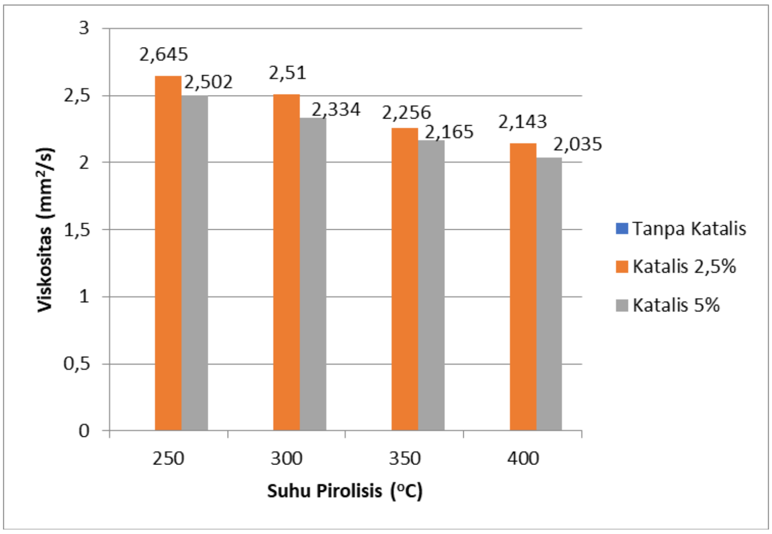

Figure 3. Effect of Pyrolysis Temperature and Amount of Zeolite Catalyst on Viscosity of Solar Oil

The viscosity of diesel oil decreased as the pyrolysis temperature and the amount of zeolite catalyst increased, according to the research of Damayanti et al. (2018), which showed that viscosity is inversely proportional to temperature. The highest decrease occurred at 350°C with 2.5% catalyst, reaching a decrease of 0.254 mm^2/s. The viscosity of the resulting diesel oil is in the range of 2.035 - 2.645 mm^2/s, meeting the quality standards of environmentally friendly diesel fuel set out in the Decree of the Director General of Oil and Gas No. 146 of 2020, which is between 2 mm^2/s to 4.5 mm^2/s.

3.3. Cetane Index Analysis of Solar Oil

The cetane index of diesel oil was analyzed using the ASTM D4737 test method. Table 8 shows the results of the diesel oil density analysis. The density of diesel oil was first tested using Anton Paar's Stabbing Viscometer SVM 3001 at 15 C with the ASTM D4052 test method. From the results of the analysis that was carried out, the density of diesel oil is obtained, as shown in Table 8.

Table 8. Density Analysis Results of Solar Oil

Sample Name	Density (kg/m^3)			Decree of the Director General of Oil and Gas No. 146 Year 2020
	I	II	Average	
250 ^{C} (No Catalyst)	0	0	0	Minimum 815 kg/m^3 Maximum 870 kg/m^3
300 °C (No Catalyst)	0	0	0	
350 ^{C} (No Catalyst)	0	0	0	
400 ^{C} (No Catalyst)	0	0	0	
250 °C (2.5% Catalyst)	877,2	877,4	877,30	
300 °C (2.5% Catalyst)	867,4	866,9	867,15	
350 °C (2.5% Catalyst)	869,3	870,1	869,70	
400 °C (2.5% Catalyst)	868,2	867,5	867,85	
250 °C (5% Catalyst)	856,7	856,4	856,55	
300 °C (5% Catalyst)	847,3	847,2	847,25	
350 °C (5% Catalyst)	846,9	846,8	846,85	
400 °C (5% Catalyst)	833,6	834,0	833,80	

The effect of pyrolysis temperature and amount of zeolite catalyst on diesel oil density is shown in Figure 4 below

ISSN [Online]: 2797-5827

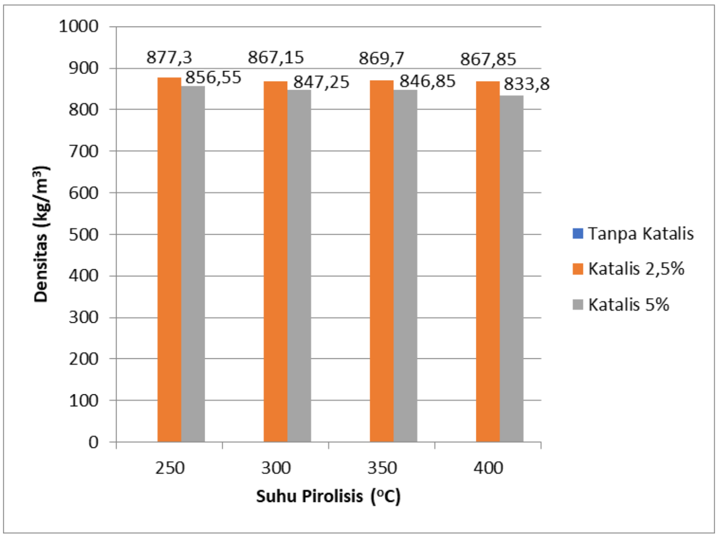

Figure 4. Effect of pyrolysis temperature and amount of zeolite catalyst on diesel oil density.

The density of diesel oil decreases as the pyrolysis temperature and the amount of zeolite catalyst increase, according to the research of Selpiana et al. (2019) showed that the higher the temperature, the density tends to decrease. This is due to the forming of compounds with shorter carbon chains at high temperatures. The density of the diesel oil produced ranged from 833.80 - 877.30 kg/m^3, meeting the quality standards of environmentally friendly diesel fuel stipulated in the Decree of the Director General of Oil and Gas No. 146 of 2020, which is between 815 kg/m^3 to 870 kg/m^3, except for the density of the pyrolysis results at 250°C with 2.5% catalyst, which was 877.30 kg/m^3. Diesel oil was distilled using a distillation apparatus, and the temperature was recorded when the volume of distillate formed was 10%, 50%, and 90% of the initial volume of diesel oil when heated, as shown in Table 9.

Table 9. Temperature of diesel oil at the time of distillation

Sample Name	Solar Oil Temperature at Destillate Volume formed (°C)					
	10%		50%		90%	
	I	II	I	II	I	II
250 ^{C} (No Catalyst)	326	324	347	346	363	363
300 °C (No Catalyst)	290	296	314	315	348	350
350 ^{C} (No Catalyst)	326	320	340	338	358	355
400 ^{C} (No Catalyst)	316	318	330	326	346	344
250 °C (2.5% Catalyst)	312	314	329	328	338	338
300 °C (2.5% Catalyst)	285	279	314	310	347	345
350 °C (2.5% Catalyst)	283	280	318	321	334	334
400 °C (2.5% Catalyst)	278	278	312	310	324	325
250 °C (5% Catalyst)	239	236	284	280	318	316
300 °C (5% Catalyst)	224	222	262	252	302	298
350 °C (5% Catalyst)	240	241	256	258	286	286
400 °C (5% Catalyst)	218	220	245	246	267	270

Based on Table 9 above, the temperature of diesel oil during distillation decreased as the pyrolysis temperature and the amount of zeolite catalyst increased. This is related to the viscosity of diesel oil. The higher the viscosity of diesel oil, the higher the temperature required to boil the diesel oil. The cetane index is then calculated using the following equation:

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$$CCI = 45.2 + 0.0892T_{10N} + (0.131 + 0.901B)T_{50N} + (0.0523 - 0.42B)T_{(90N)} + 0.00049(T^{2}_{(10N)} - T^{2}_{(90N)}) + 107B + 60B^{2}$$

Description:

CCI = Calculated Cetane Index
T10 = temperature when 10% distillate is formed
T10N = T10 - 215
T50 = temperature when 50% distillate is formed
T50N = T50 - 260
T90 = temperature when 90% distillate is formed
T90N = T90 - 310
B = $[e^{(-3,5)(D-0,85)}] - 1$
D = density at 15 C (g/ml)

From the analyses carried out, the cetane index of diesel oil was obtained, as shown in Table 10 below.

Table 10. Cetane Index (CCI) values of diesel oil

Sample Name	Cetane Index (CCI)			Decree of the Director General of Oil and Gas No. 146 Year 2020
	I	II	Average	
250 c (No Catalyst)	0	0	0	Minimum 45
300 °C (No Catalyst)	0	0	0	
350 c (No Catalyst)	0	0	0	
400 c (No Catalyst)	0	0	0	
250 °C (2.5% Catalyst)	44,46	44,82	44,64	
300 °C (2.5% Catalyst)	44,97	44,81	44,89	
350 °C (2.5% Catalyst)	43,77	42,93	43,35	
400 °C (2.5% Catalyst)	43,95	44,39	44,17	
250 °C (5% Catalyst)	44,90	44,77	44,84	
300 °C (5% Catalyst)	47,26	47,00	47,13	
350 °C (5% Catalyst)	48,88	49,06	48,97	
400 °C (5% Catalyst)	51,55	51,66	51,61	

Description:

= Does not meet the standard of Cetane Index value based on the Decree of the Director General of Oil and Gas No. 146 of 2020

The effect of pyrolysis temperature and the amount of zeolite catalyst on the diesel cetane index is shown in Figure 5. Based on Table 10 and Figure 5, it can be seen that the cetane index of diesel oil increases with the increase in pyrolysis temperature and the amount of zeolite catalyst. This is based on the research of Setyopratomo et al. (2008), which states that the higher the temperature, the higher the cetane index. The diesel oil produced has a cetane index between 43.35 and 51.61. The highest increase in the cetane index occurred at 400 C using a 5% catalyst with an increase of 2.64. The cetane index that meets the quality standards of environmentally friendly diesel fuel as stipulated in the Decree of the Director General of Oil and Gas No. 146 of 2020, which is a minimum of 45, is only found at pyrolysis temperatures of 300 C, 350 oC, and 400 oC at the use of 5% catalyst.

ISSN [Online]: 2797-5827

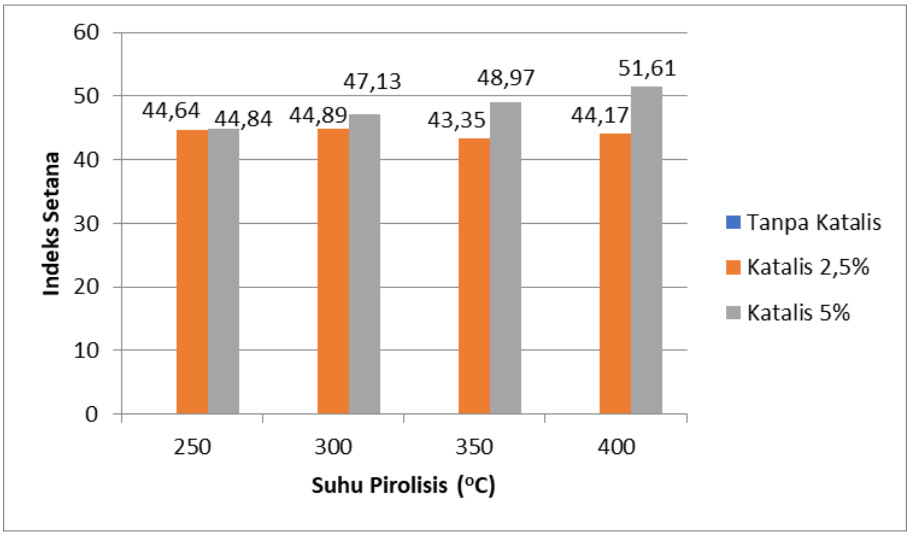

Figure 5. Effect of Pyrolysis Temperature and Amount of Zeolite Catalyst on Cetane Index of Solar Oil

3.4. Statistical Analysis

3.4.1. Analysis of the effect of pyrolysis temperature and the amount of zeolite catalyst on the viscosity of diesel oil

Based on the results of ANOVA analysis, the interaction between pyrolysis temperature and the amount of catalyst affects viscosity. There are differences in the viscosity value of diesel oil in each interaction of pyrolysis temperature and the amount of catalyst. After the ANOVA analysis, a further test (Tukey) was conducted to determine the temperature and amount of zeolite catalyst that produced the best viscosity, as shown in Figure 6 below.

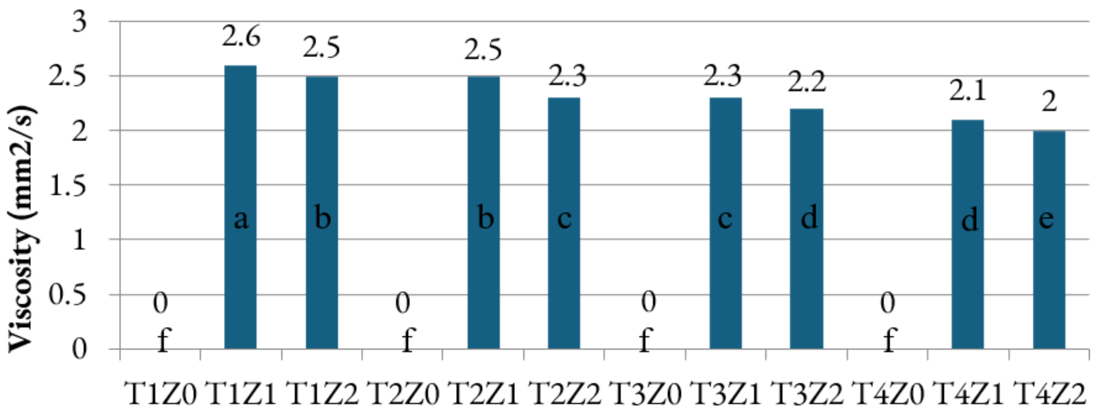

Figure 6. Interaction of Pyrolysis Temperature and Amount of Zeolite Catalyst on Viscosity of Solar Oil

Based on Figure 6, the interaction between pyrolysis temperature and the amount of zeolite catalyst that produces the best viscosity occurs at 250 C using 2.5% catalyst (T1Z1) with a value of 2.645 mm2/s.

3.4.2. Analysis of the effect of pyrolysis temperature and the amount of zeolite catalyst on the cetane index of diesel oil

Based on the results of ANOVA analysis, the interaction between pyrolysis temperature and the amount of catalyst affects the cetane index, and there is a difference in the cetane index value of diesel oil in each interaction of pyrolysis temperature and the amount of catalyst. After the ANOVA analysis, a further test (Tukey) was conducted to determine the temperature and amount of zeolite catalyst that produced the best cetane index, as shown in Figure 7 below.

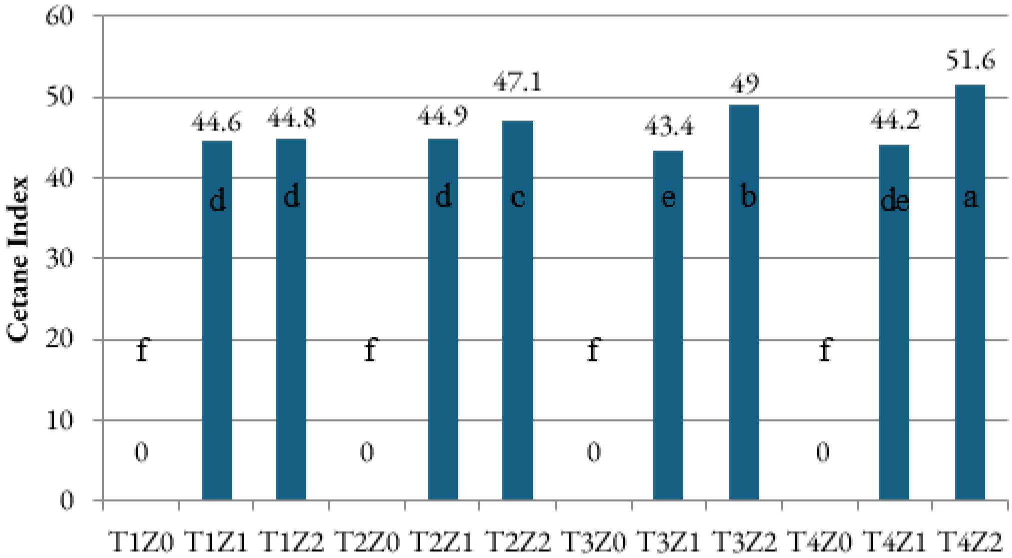

Figure 7. Interaction of Pyrolysis Temperature and Amount of Zeolite Catalyst on Cetane Index of Solar Oil

Based on Figure 7 above, the interaction between pyrolysis temperature and the amount of zeolite catalyst that produces the best cetane index occurs at 400 C using 5% catalyst (T4Z2) with a value of 51.6.

3.4.3. Potential Utilisation of LDPE Plastic Waste as Solar Oil Producer in North Sumatra Province

Based on data from the National Waste Management Information System (SIPSN) of the Ministry of Environment and Forestry of the Republic of Indonesia, the amount of waste generation in North Sumatra in 2021 was 2,039,438.93 tonnes/year, and the waste composition can be seen in Table 11. below.

Table 11. Waste Composition by Waste Type in North Sumatra Province in 2021 (SIPSN)

No.	Type of Waste	Composition
1.	Leftovers	28,86%
2.	Wood/Twigs	13,08%
3.	Paper/Carton	14,10%
4.	Plastic	16,67%
5.	More	14,09%

Based on Table 11, the composition of plastic waste in North Sumatra in 2021 is 16.67%. Meanwhile, based on data from the Disaster Management Center (DMC), the amount of waste generated in North Sumatra in 2021 is 1.9 million tonnes/year; the waste composition can be seen in Table 12 below.

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Table 12. Waste Composition by Waste Type in North Sumatra Province in 2021 (DMC)

No.	Type of Waste	Composition
1.	Leftovers	35,39%
2.	Wood/Twigs	15,50%
3.	Paper/Carton	13,71%
4.	Plastic	13,90%
5.	More	21,50%

Based on Table 12, the composition of plastic waste in North Sumatra in 2021 is 13.90%. When compared with the data from the National Waste Management Information System, the amount of plastic waste composition does not differ much from the data from the Disaster Management Centre, so the figure that will be used in calculating the potential utilization of plastic waste uses data from the National Waste Management Information System. According to Wahyudi et al. (2018), plastic waste generally has a composition of 46% Polyethylene (LDPE and HDPE), 16% Polypropylene (PP), 16% Polystyrene (PS), 7% Polyvinyl Chloride (PVC), 5% Polyethylene Terephthalate (PET), 5% Acrylonitrile-Butadiene-Styrene (ABS), and other polymers. Based on the data above, the amount of LDPE plastic waste in North Sumatra Province can be calculated as follows:

Assumed composition of LDPE plastic waste	= 23% (half of Polyethylene plastic composition)
Total waste generation in 2021	= 2,039,438.93 tonnes/year
Composition of plastic waste in 2021	= 16,67%
Amount of LDPE plastic waste	= 23% x (16.67% x 2,039,438.93 tonnes/year)
	= 78,194 tonnes/year
	= 78,194,000 kg/year

Based on the study's results, the highest mass of diesel oil was obtained with the use of 5% catalyst, which was 2.73167 kg. That much diesel oil was obtained from the pyrolysis of 40 kg of LDPE plastic waste. Based on the amount of LDPE plastic waste from the calculation of 78,194,000 kg/year above, the potential diesel oil that can be produced from the use of LDPE plastic waste in North Sumatra Province in 2021 is (78,194,000 kg/year: 40 kg) x 2.73167 kg = 5,340,005 kg/year or 5,340 tonnes/year. The potential utilization of LDPE plastic waste as a diesel oil producer in North Sumatra Province until 2030 can be determined based on data on the population and the amount of waste generated in North Sumatra Province until 2030, as shown in Table 13.

Table 13. Potential Solar Oil from LDPE Plastic Waste Utilisation in North Sumatra Province until 2030

Year	Total Population	Waste generation (tonnes/year)	Solar Oil Potential (tonnes/year)
2021	14.936.148	2.039.438,93	5340
2023	15.386.640	2.047.132,25	5360
2025	15.837.132	2.055.050,82	5381
2027	16.287.624	2.063.194,63	5402
2030	17.009.550	2.071.699,40	5424

Based on Table 13, the potential use of LDPE plastic waste as a diesel oil producer in North Sumatra Province in 2021 is 5,340 tonnes/year until 2030 is 5,424 tonnes/year.

IV. Conclusion

Based on the results, it can be concluded that increasing the pyrolysis temperature has a positive effect on diesel oil yield, with the highest increase of 2.53%, a decrease in viscosity of 0.254 mm^2/s, and an increase in cetane index of 2.64. In addition, increasing the amount of zeolite catalyst also increased diesel oil

ISSN [Online]: 2797-5827

yield with the highest increase of 1.4%, decreased viscosity by 0.176 mm^2/s, and increased cetane index by 7.44. The optimal combination of pyrolysis temperature and zeolite catalyst amount produced the highest diesel oil yield of 6.83%, the best viscosity of 2.645 mm^2/s, and the best cetane index of 51.61. The viscosity and cetane index of diesel oil that meets the quality standards of environmentally friendly diesel fuel based on the Decree of the Directorate General of Oil and Gas No. 146 of 2020 was recorded at pyrolysis temperatures of 300°C, 350°C, and 400°C with 5% catalyst, with viscosity values of 2.334 mm^2/s, 2.165 mm^2/s, and 2.035 mm^2/s, respectively, and cetane index of 47.13, 48.97, and 51.61. In addition, the potential use of LDPE plastic waste as a diesel oil producer in North Sumatra Province in 2021 reached 5,340 tonnes/year and is estimated to increase to 5,424 tonnes/year in 2030. As a suggestion, pyrolysis should be carried out at temperatures above 250°C to avoid producing diesel oil yields that are too thick, which can interfere with viscosity and density measurements. In addition, to ensure the accuracy of the results, it is recommended that the analysis be conducted with a minimum of three repetitions to minimize data errors.

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