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Original Research Article

Zeolites Effects in Physical Characteristics of Low-Density Polyethylene (LDPE) and Polypropylene (PP) Pyrolysis into Liquid Fuel

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Abstract
The decline in the quality of waste management has generally started to occur since the prolonged economic crisis in Indonesia. Plastic waste includes inorganic waste, which is currently widely used by industry and households. Therefore, it is necessary to have an alternative recycling process, like converting plastic waste into liquid fuel. The research objective is to utilize LDPE plastic waste (Low-Density Polyethylene) and PP (Polypropylene) in liquid fuel utilizing pyrolysis to determine the effect of using a zeolite catalyst by comparing the results of the pyrolysis process. The investigation took place at the Wonosari landfill in Singkawang, where parameters such as density, viscosity, and color were examined. The pyrolysis results underwent consistency testing through the Mann-Whitney test. According to the study findings, the average physical parameter values for viscosity and density of LDPE pyrolysis liquid fuel were 0.302 cP, LDPE+catalyst was 0.114 cP, with densities of 767 kg/m^3 and 737 kg/m^3. For PP, the average viscosity was 2.812 cP, and PP+catalyst was 0.248 cP, with densities of 774 kg/m^3 and 735 kg/m^3. Samples of PP and LDPE with catalysts exhibited lower density values compared to those without catalysts.

Keywords: Low density polyethylene; plastic; pyrolysis; polypropylene

1. Introduction

The significant decline in the quality of waste management has generally started since the prolonged economic crisis hit all cities in IndoAia. The significant decrease in the quality of waste management naturally began to occur since the protracted financial crisis hit all cities in Indonesia (Ministry of Environment and Forestry, 2020). This condition decreases the performance of waste facilities and infrastructure, especially the quality of landfills. The poor performance of waste management results in serious problems that must be addressed immediately (Miskah et al., 2016). Like another, Singkawang City also faces many challenges in waste management. Data from the Badan Pusat Statistik (BPS) states that the volume of waste generated by Singkawang City in 2021 is 214,496 m^3 and the volume of waste that can be transported to the Wonosari landfill in Singkawang City is around 67,422 m^3 where the average amount of waste transported per day is 184.72 m^3 (Kota Singkawang dalam Angka, 2022). The volume and type of waste increase are not immediately anticipated with proper waste management planning, and it is feared that it will cause environmental impacts, such as pollution, health problems, and fires.

Plastic waste includes inorganic waste, widely used by industry and households. The use of plastic will continue to increase because of its advantages, including lightness and strength, resistance to corrosion, transparency, and easy coloring (Anggono et al., 2020). Behind all its benefits, plastic waste creates environmental problems because it cannot be decomposed in the soil. Hence, it is essential to explore alternative recycling methods with greater potential for the future, and one such approach involves transforming plastic waste into oil. (Istadi, 2011). Types of plastic waste such as LDPE (Low-Density Polyethylene) and PP (Polypropylene) can be processed into raw materials for the manufacture of fuel oil. LDPE is a type of plastic that is usually used as a raw material for making plastic bags, and PP is a type of plastic that is generally used as a raw material for mineral glass (Miandad et al., 2017).

Pyrolysis is a chemical decomposition process using heating without the presence of oxygen. Pyrolysis has the same working principle as the distillation process; that is, the raw material changes from solid to gas and is then passed through a condenser tube to be cooled so that the vapor turns into a liquid (Sharuddin et al., 2018a). The product of pyrolysis consists of gas, liquid, and solid residue. Furthermore, the cooling process is carried out on the pyrolysis gas and undergoes a condensation process to form a liquid (Blasi, 2008). Based on this, it is therefore necessary for this research to reduce LDPE and PP plastic waste by the pyrolysis process. This study aims to (i) identify the effect of zeolite catalysts in the pyrolysis of LDPE plastic waste (Low-Density Polyethylene) and PP type (Polypropylene) into liquid fuel using traditional fixed-bed reactors. This kind of reactor can be used to process a wide range of feedstocks and is a versatile and practical type of reactor for the pyrolysis of plastic waste with natural zeolite catalysts (Suárez-Toriello et al., 2021) and (ii) identify the physical quality of liquid fuel produced from the pyrolysis process of LDPE type plastic waste (Low-Density Polyethylene) and PP type (Polypropylene).

2. Methods

2.1. Equipment and Materials

Preparation of tools and materials was carried out by calibrating scales, collecting used wood and tires as pyrolysis fuel, 6000 grams of LDPE and PP waste, preparing 1800 grams of zeolite, which would be activated using an oven, and preparing pyrolysis equipment.

2.2. Preparation of Equipments and Materials

The equipment utilized in this investigation consisted of self-designed fixed-bed type pyrolysis reactors sourced from the Singkawang City landfill., condenser (Allihn), scales (Excellent), furnaces (Memmer), condensation containers, manometer (Wiebrock), pycnometer (Gratech), tubes, valve, stative, and 1000 ml measuring cup.

Materials needed in conducting this research included 6000 grams of LDPE plastic waste from transparent plastic bags, plastic clothes bags, and mineral water glasses, 6000 grams of PP plastic waste from bottled water, wood, used tires from waste processing sites, clean water, and 1800 grams of commercial natural zeolite (Bonzaz) for three repetitions.

2.3. Natural zeolite activation

Physical activation is done by heating 300 grams of natural zeolite for each waste at 200^{O}C using an oven in the Singkawang Laboratory. The zeolite heating process was carried out by keeping the temperature and time for 3 hours. Heating aims to evaporate the water trapped in the pores of the zeolite crystal so that the number of pores and the specific surface area increase (Rehan et al., 2017). The greater the surface area of the catalyst, the bigger the cracks form and the reaction gets easier. The large size of the pore radius allows the catalyst to enter the pore. The large surface area allows the catalyst's performance as a reactant to be maximized and effective.

2.4. Cleaning and Drying LDPE and PP Plastic Waste

Plastic waste is washed with water for up to three repetitions to remove dirt that sticks to the surface of the plastic from the landfill so that the oil produced in the pyrolysis process is clean and free from other materials. After washing, the plastic waste is dried using the sun's heat until it is scorched for 3 hours.

2.5. Pyrolysis Process

Plastic waste of LDPE and PP has been cleaned and dried, then cut to a maximum size of 5 cm. The reactor was packed with the zeolite catalyst, where the catalyst bed should be loaded to ensure consistent flow of the plastic waste through the reactor. LDPE and PP plastic waste is put into the pyrolysis reactor as much as 6000 grams according to capacity. Then, wood and used tires are put into the furnace with a heat shield around the furnace to start the fire until it reaches a temperature of 400 ^{O}C for 180 minutes. The heat shield can reflect the heat back into the furnace to keep the temperature more consistent. The pyrolysis occurs until the oil comes from the pipe oil outlet. Pyrolysis oil dripped the fastest on average of all reactors at 9 minutes. The volume of oil formed after the pyrolysis process is measured and placed in a measuring container and then set aside.

2.6. Analysis Procedures

2.6.1. Density measurement

Density is measured using a pycnometer made from glass, and the capillary tube in the middle of the lid allows bubbles to escape from the device. The way to measure using a pycnometer is to clean the pycnometer until there is no liquid and dirt left. After that, weigh the empty pycnometer on an analytical balance and record it as "a" gram. The sample is inserted into the pycnometer up to the top of the neck, and then the lid is put on until the sample can fill the capillary tube without air bubbles. The pycnometer containing the sample is weighed with an analytical balance and recorded as "b" grams. Determining the density of a substance can be determined using the following equation (1):

$$\rho = \frac{m_b - m_a}{v} \qquad (1)$$

ρ	= density (g/cm³)	ma	= empty pycnometer mass (g)
mb	= filled pycnometer mass (g)	v	= pycnometer volume (cm³)

2.6.2. Viscosity measurement

The viscometer used is an Ostwald viscometer. The Ostwald viscometer requires less sample than other viscometers. The principle is to measure the time needed for a liquid to pass through two predetermined points on a vertical capillary tube. This value is determined by comparing the viscosity value of a comparison liquid whose value is already known with another liquid whose viscosity value is not yet known. This viscosity calculation can be determined using the following equation (2):

$$v_x = \frac{t_x \rho_x}{t_a \rho_a} v_a \qquad (2)$$

v_x	= oil viscosity (cP)	v_a	= water viscosity (cP)
t_x	= oil flow time (s)	t_a	= water flow time (s)
ρ_x	= oil density (kg/m³)	ρ_a	= water density (kg/m³)

After obtaining oil samples resulting from the pyrolysis of LDPE waste and PP, the volume of oil is calculated by holding the resulting product in a measuring cup container. Next, the samples were analyzed based on viscosity and density parameters at the Chemical Research and Biotechnology Laboratory, Universitas Tanjungpura. Color testing was visually done by comparing the resulting oil's color with the existing fuel's color. The volume of the residue remaining in the combustion tube is also measured.

2.6.3. Analysis Statistics Analysis of Classification Consistency

The data analysis used was a nonparametric statistical test using the Mann-Whitney test method using Minitab18 software. The Mann-Whitney tests two independent samples from the same population.

In this research, the Mann-Whitney test was used to determine how much influence the catalyst in the pyrolysis process has on the consistency of the quality of LDPE and PP plastic waste. If the Mann-Whitney test results are accepted, the results will be compared with the research hypothesis to decide which is better in terms of quality.

The hypothesis is:

Ho: if the significance value is more than the critical limit of 0.05 (P>0.05), then Ho is accepted
H1: if the significance value is smaller than the critical limit (P<0.05), then Ho is rejected

3. Result and Discussion

3.1. Natural Zeolite Activation

Natural zeolite is a porous mineral that has a unique cage-like structure. This structure gives zeolites a large surface area and a high affinity for cations. Zeolites are found naturally in all parts of the world, and they have been used for centuries in various applications, including agriculture, water treatment, and catalysis. Natural zeolite can be activated by various methods, including acid washing, thermal, and chemical activation. Zeolites are excellent catalysts for various chemical reactions, including cracking, reforming, and isomerization. Activated zeolite catalysts are used in the petroleum industry to produce high-octane gasoline and other valuable products.

The acidity of natural zeolite was documented as 1.576 g/mol, and it exhibited a Si/Al ratio of 1.576 g/mol, along with a surface area ranging from 20.8 to 23.2 m2/g. (Cahyono et al., 2014 & Santoso et al., 2020). Scanning electron microscopy with energy dispersive X-ray spectroscopy (SEM-EDS) and Brunauer–Emmett–Teller (BET) measurements showed that the pore size ranged from 7.73 to 11.4 Å. X-ray diffraction (XRD) examination indicated that the mineralogical composition consisted of the mordenite phase, characterized by lattice parameters a = 18.115(8) Å, b = 20.520(9) Å, and c = 7.515(2) Å. (Suminta, 2006). Based on the research, physical activation is primarily used to modify the properties of natural zeolite by removing impurities, enlarging pores, and expanding the surface (Marcilla et al., 2009 & Sumari et al., 2019).

3.2. Pyrolysis of LDPE and PP with Activated Natural Zeolite

Pyrolysis is a thermochemical decomposition of a more useful product substance without oxygen as a fixed oxidizing agent. It is a complex mixture of organic compounds, including oxygenates, hydrocarbons, and char (Zadeh et al., 2020). The reaction pathway of pyrolysis can be shown in **Figure 1**.

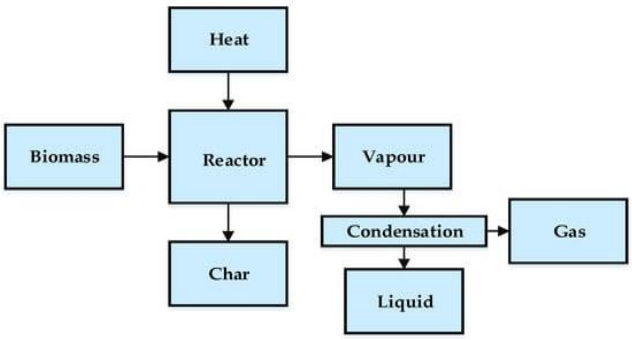

Figure 1. Pyrolysis pathway of reaction
Source: (Zadeh et al., 2020)

Pyrolysis oil can be used as a fuel, a feedstock for chemical production, or a blending agent for petroleum fuels. The pyrolysis oil can be used directly in internal combustion engines, boilers, and turbines. It can also be upgraded to produce higher-quality fuels and chemicals (Park et al., 2020). The upgrading process can be carried out using various methods, such as hydrotreating, catalytic cracking, and reforming (Ancheyta et al., 2016). The substance that is decomposed in this process is plastic waste from LDPE (Low-Density Polyethylene) and PP (Polypropylene). The pyrolysis oil obtained from LDPE and PP is a complex mixture of hydrocarbons, including alkanes, alkenes, and aromatics (Pan et al., 2022) that depends on the type of plastic waste used and the pyrolysis conditions. The series of pyrolysis equipment used in this research can be seen in **Figure 2**.

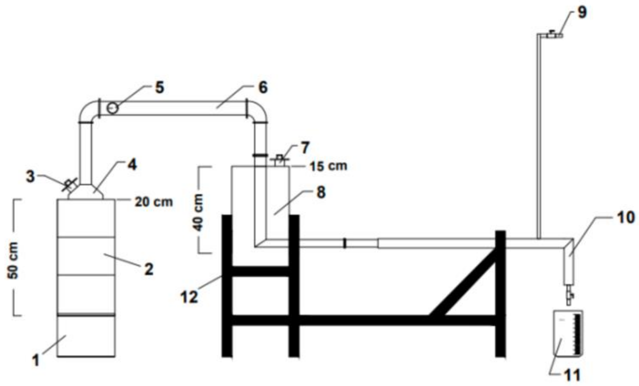

Figure 2. The design of pyrolysis equipment

3.3. Visual Observation of Pyrolysis Liquid Fuel from LDPE and PP

After obtaining oil samples from the pyrolysis process using clear plastic bag waste and mineral water glasses with a catalyst, visual observations were made of the four oil samples regarding the color and clarity of the oil. The visual observations of pyrolysis oil based on the oil's color and clarity are shown in **Table 1** and **Figure 3**.

Table 1. Visual observation results

No.	Sample Name	Oil Color	Oil Clarity
1	PP + catalyst	yellow	slightly murky
2	PP	cloudy dark brown	lack and thick
3	LDPE	cloudy yellow	less clear
4	LDPE + catalyst	cloudy yellow	less clear

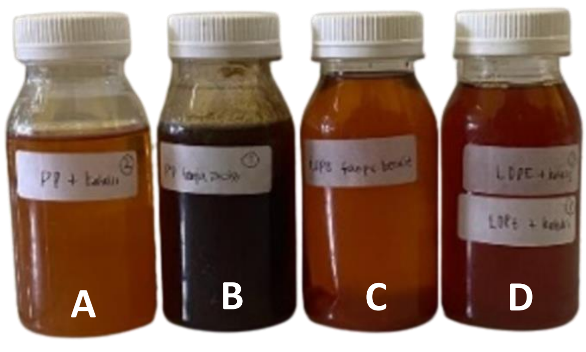

Figure 3. Oil produced from the pyrolysis process: (A) PP+catalyst, (B) PP, (C) LDPE, (D) LDPE+catalyst

The LDPE+catalyst sample has a cloudy yellow color and poor clarity, and the LDPE sample has a yellow, cloudy, and less clear oil color and clarity. PP+catalyst has a yellow and slightly clear oil color. PP has a dark brown oil color, cloudy and unclear. There is a difference in color and clarity in plastic waste that uses and does not use zeolite. The pyrolysis results on LDPE and LDPE waste using a catalyst obtained in this study were cloudy yellow and less clear. There was a difference in previous studies where the addition of a zeolite catalyst obtained clearer results than those without using a zeolite catalyst (Hendrawati et al., 2023 & Santoso et al., 2022). The oil obtained from plastic pyrolysis can be turbid and not clear for several reasons, including incomplete pyrolysis, presence of impurities, water presence in the oil, and containing high molecular weight compounds. Some steps that can be done to clarify the oil filter (Brueckner et al., 2020), liquid-liquid extraction (Fardhyanti et al., 2020), and treat the oil with some chemicals, such as acid, base, and sawdust (Wang et al., 2014). However, it doesn't rule out the possibility that the oil may still be slightly turbid after those treatments. This condition is because the pyrolysis oil is a complex mixture of hydrocarbons, and some of these hydrocarbons may not be very soluble in oil. While PP and PP waste used a catalyst, this study showed that the use of a catalyst resulted in an increase in the quality obtained and produced slightly clear oil from PP waste, which did not use a zeolite catalyst.

3.4. Time Required and Amount of Oil Yield

Data on the recovery of pyrolysis oil using a catalyst are different from the results of obtaining pyrolysis oil without a catalyst, as seen in **Table 2**.

Table 2. Pyrolysis process data

No	Sample name	Waste weight (kg)	Temperature (°C)	Lasting time (hours)	Oil amount (liter)
1	LDPE	6	400	3	4,2
2	LDPE + catalyst				4,8
3	PP				3,8
4	PP + catalyst				4,1

The use of catalysts is expected to increase the quality and quantity. This study shows that the use of a catalyst can provide more amount. The LDPE waste sample produced 4.2 liters of oil with a yield of 70%, while the LDPE waste sample using a catalyst produced 4.8 liters of oil with an 80% yield. The PP waste sample produced 3.8 liters of oil with a yield of 63%, and the PP waste sample using a catalyst produced 4.1 liters of oil with a yield of 68%. The effect of using a zeolite catalyst on the pyrolysis process of LDPE waste experienced an increase of 14%, whereas, in the pyrolysis process of PP waste, it experienced a rise of 7.3%. The use of a catalyst will increase its quantity because the efficiency in the pyrolysis process will result in more pieces of carbon chains (Al-Salem et al., 2017 & Anuar Sharuddin et al., 2016).

Factors that affect the amount of oil output and the time needed in one pyrolysis process in this study are the temperature stability that affects the time and production of the resulting oil. The unstable heating temperature in the pyrolysis process will affect the pressure inside the reactor, resulting in an unstable pressure (Obeid et al., 2014). As the reactor wall's temperature increases, the reaction rate for the formation of smaller molecules also increases. The results obtained for the pyrolysis time can be seen in **Figure 4.**

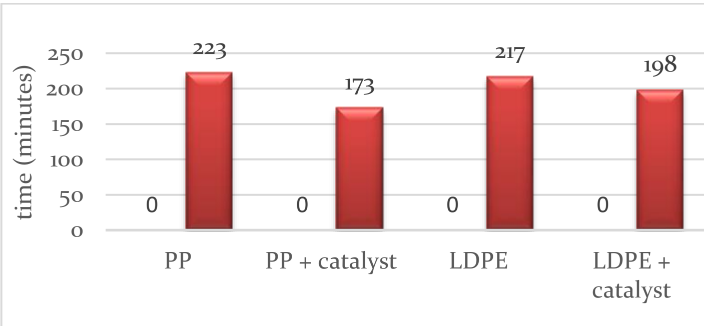

Figure 4. The pyrolysis reaction time required for LDPE and PP with and without catalyst to obtain oil

Based on **Figure 4**, the time required for the pyrolysis process without a catalyst is longer than that using a catalyst. This condition can happen because no reaction occurs with the catalyst, so the results come out without any residue left behind. Meanwhile, pyrolysis with the addition of a catalyst will leave the pyrolysis liquid in the catalyst column, which is not hot enough to evaporate until it leaves the condenser (Syamsiro et al., 2014).

Utilizing natural zeolite as a catalyst in the pyrolysis of LDPE and PP facilitates the breakdown of lengthy polymer chains into smaller molecules. This process lowers the energy demand for completing the pyrolysis reaction, consequently reducing the reaction time (Xue et al., 2015). In addition to reducing the reaction time, natural zeolite can also improve the yield and quality of the pyrolysis products because natural zeolite can help to suppress the formation of coke, which is a byproduct of the pyrolysis reaction that can reduce the yield and quality of the pyrolysis products (FakhrHoseini and Dastanian, 2013). Activated natural zeolite made many active sites on the surface of the zeolite where the pyrolysis reaction can occur. Hence, the more active sites there are, the faster the reaction will proceed. Acidic natural zeolite can also donate protons to the LDPE and PP molecules, which helps to break down the polymer chains. The more acidic the zeolite is, the faster the reaction will proceed. The porous structure of natural zeolite makes LDPE and PP molecules diffuse into the pores of the zeolite, where they can be more easily broken down by the acidic sites on the surface of the zeolite (Rehan et al., 2017 & Setiawan et al., 2022).

3.5. Testing the Characteristics of Pyrolysis Oil

After carrying out the pyrolysis process on LDPE and PP plastic samples, the next step is to test the characteristics of the pyrolysis oil, the results of which are as follows:

3.5.1. Density measurement

Density is a measurement of mass per unit volume unit. The density of a substance generally depends on the pressure and temperature of the liquid. Density testing in this study aims to test how much the density value of the oil produced because each substance has a different density value (Kusrini et al., 2018). Density measurements were carried out in this study using a pycnometer with a volume of 10 ml and were carried out in triplicate. The resulting density test results can be seen in **Table 3** below.

Table 3. Sample Oil Density

Sample variation	Sample code	Equipment & sample weight	Empty pycnometer weight	Density	Density	Average density	Average density
		(gr)	(gr)	(gr/ml)	(kg/m³)	(gr/ml)	(kg/m³)
PP	I	24.0767		0.77392	773.92	0.77390	774
	II	24.0766	16.3375	0.77391	773.91		
	III	24.0764		0.77389	773.89		
PP+catalyst	I	23.6921		0.73546	735.46	0.73548	735
	II	23.6923		0.73548	735.48		
	III	23.6925		0.7355	735.5		
LDPE	I	24.0006		0.76631	766.31	0.76628	767
	II	24.0004		0.76629	766.29		
	III	24.0001		0.76626	766.26		
LDPE+catalyst	I	23.7116		0.73741	737.41	0.73739	73
	II	23.7114		0.73739	737.39		
	III	23.7114		0.73739	737.39		

It can be seen that the catalyst used in pyrolysis can affect the density obtained. PP and LDPE waste samples that used a catalyst had a lower density value than PP and LDPE waste samples that did not use a catalyst. The density was affected because natural zeolite can help to break down the long polymer chains of LDPE and PP into smaller molecules, resulting in a higher yield of lighter hydrocarbons, which have a lower density than heavier hydrocarbons (Santoso et al., 2022 & Sharuddin et al., 2018).

Natural zeolite also can help suppress coke formation during pyrolysis, a byproduct of the pyrolysis reaction that has a high density. Therefore, reducing coke formation can also reduce the thickness of the pyrolysis oil. Natural zeolite can also help to remove impurities from the pyrolysis oil, which can sometimes increase the density of the oil (Sharuddin et al., 2018 & Tulashie et al., 2019). After laboratory testing, the pyrolysis oil from LDPE and PP can be analyzed, and the pyrolysis oil in PP has an average density value of 774 kg/m^3. The PP+catalyst sample code has an average density value of 735 kg/m3^3. Then, the LDPE waste code has an average density value of 767 kg/m^3, while the LDPE+catalyst sample code has an average density value of 737 kg/m^3.

The lowest oil density was found in the PP+catalyst sample, which was 735 kg/m^3. The highest oil density was obtained in the PP sample, which was 774 kg/m^3. The density produced in the pyrolysis process was more significant than the oil that did not use the addition of a zeolite catalyst. The results of the average density test show that pyrolysis results enter into the type of gasoline density according to **Table 4** of standards and quality (specifications) of fuel oil.

Table 4. Standards and Quality (Specifications) of fuel oil

No	Fuel Type	Parameters	Value
1	Diesel oil*	Viscosity (cP)	2-4.5
		Density (kg/m^3)	820-850
		Calorific value (J)	7,020
2	Diesel oil 48**	Viscosity (cP)	2.5-5
		Density (kg/m^3)	815-870
3	Diesel oil 48**	Viscosity (cP)	2-4.5
		Density (kg/m^3)	820-860
4	Gasoline*	Viscosity (cP)	0.652
		Density (kg/m^3)	715-850
		Calorific value (J)	47.3
5	Gasoline 88***	Density (kg/m^3)	715-770
6	Diesel oil 1**	Viscosity (cP)	2.5-11
		Density (kg/m^3)	900
7	Diesel oil 2**	Viscosity (cP)	24
		Density (kg/m^3)	920
8	Kerosene*	Viscosity (cP)	0.294-3.34
		Density (kg/m^3)	780-810
		Calorific value (J)	43
9	Kerosene**	Density (kg/m^3)	835

Source: * SNI 7390-2008
** Kep. DJM No.14499K/14/DJM/2008
*** SNI 3506-2017

The density value in this study is the same as Syamsiro's research (2015), which used LDPE-type plastic that obtained a density of 0.77 gr/cm^3. If the density value of the fuel is lower, it will easily burn because it is easy to evaporate (Santoso et al., 2022). Research conducted by Rahman (2017) showed pyrolysis of PP plastic waste (polypropylene) using a zeolite catalyst at 400°C. The pyrolysis process produces a density value of 0.85 grams/cm^3. These results are more applicable because they comply with quality standards when compared to the density of this study, which only reached 0.735 gram/cm^3 at its smallest value and 0.774 gram/cm^3 at its most significant value.

Wahyudi et al. (2018) stated that pyrolysis of plastic waste at 400°C will produce a lot of C9 carbon compounds, which can be condensed at room temperature. The results of this test density test concluded that the density of oil obtained by pyrolysis of PP is close to the density of diesel fuel. Research conducted by (Miandad, M.A. Barakat, M. Rehan, A.S. Aburiazaiza, I.M.I. Ismail, 2017) showed that the results of GC-MS carried out on polypropylene and various types of hydrocarbon fraction content including alpha-methyl styrene, benzene, xylene, methylnaphthalene, phenanthrene, ethylbenzene, propylbenzene, naphthalene, biphenyl, 2- phenylnapthalene. This composition is one of the factors why the density of polypropylene pyrolysis oil is relatively high.

3.5.2. Oil Viscosity Testing

Pyrolysis oil testing aims to test the viscosity value of the oil produced. Viscosity is a measure of the resistance of a liquid to flow. The greater the viscosity value of the liquid, the more difficult it is for the liquid to flow, and vice versa; if the viscosity value is low, the liquid will flow more easily (Wicaksana and Rachman, 2018). In this study, the Ostwald viscometer was used. The Ostwald viscometer is an alternative that can determine the viscosity value of a liquid whose value is unknown. Determination of this value is done by comparing the viscosity value of a reference liquid whose value is known with other liquids whose viscosity value is not known (Sejati, 2009). The results of the resulting viscosity test can be seen in **Table 5.**

Table 5. Oil viscosity

Sample variation	Sample code	Flow time	Sample density	Viscosity	Average viscosity
		(S)	(gr/ml)	(cP)	(cP)
PP	I	120.17	0.77392	2.786	2.812
	II	122.25	077391	2.834	
	III	121.44	0.77389	2.816	
PP+catalyst	I	10.33	0.73546	0.228	0.248
	II	12.10	0.73548	0.267	
	III	11.30	0.73555	0.249	
LDPE	I	14.29	0.76631	0.328	0.302
	II	13.01	0.76629	0.299	
	III	12.07	0.76626	0.278	
LDPE+catalyst	I	05.32	0.73741	0.118	0.114
	II	05.09	0.73739	0.112	
	III	05.02	0.73739	0.111	

Based on **Table 4** above, the highest average viscosity value of the 3 times oil testing was produced by the PP sample oil of 2.812, while the lowest average viscosity of oil was produced by the LDPE+catalyst sample of 0.114. This study used a reference fluid in the form of distilled water. The density of distilled water used was 0.9863 gr/ml obtained from direct calculations using a pycnometer, the water flow time was calculated directly, which was 28.29 seconds, and the viscosity used was 0.836 cP. The viscosity value is taken from international water viscosity standards based on liquid temperature. Based on ISO/TR 3666:1998 about the *Viscosity of Water,* the viscosity value used at the liquid temperature is 28^{O}C of 0.836 cP.

Where the average value of PP is 2.812 cP, PP+catalyst is 0.248 cP, LDPE is 0.302 cP, and LDPE+catalyst is 0.114 cP (Purwanto and Istiqlaliyah, 2018) explained that the small viscosity also affects the quality of a liquid, the smaller the viscosity, the thinner and more transparent the liquid will be. Pyrolysis oil has turbid physical properties and still has residual deposits. According to the research results of Anuar et al. (2016), the lower the viscosity value, the better the quality of the fuel oil because the thinner the oil, the easier it flows. It can be concluded from **Table 4** that the use of a catalyst affects the pyrolysis process to obtain a lower viscosity value than the pyrolysis process that does not use a catalyst when compared (Rahman et al., 2017), with a density value of 1.82 cP. This research has a viscosity value that reaches 0.114 cP at the lowest value and 2.812 cP at the largest.

The characteristics of the oil in the PP plastic pyrolysis process without using a catalyst has a viscosity of 2.812 cP at 400^{O}C, which is the standard for diesel oil, while the PP plastic pyrolysis process using a catalyst has a viscosity of 0.248 cP which is the standard for kerosene. The LDPE plastic pyrolysis process without a catalyst of 0.302 cP belongs to the kerosene standard, while LDPE using a catalyst has a viscosity of 0.114 cP.

3.5 Test Results *Mann Whitney*

The independent samples in this study are the types of LDPE and PP plastics that will be analyzed with Mann-Whitney. The test method used is an exact likelihood test to test nonparametric statistics. It tested the consistency of the physical parameter values of pyrolysis alternative fuel with Mann Whitney using the Minitab software because it provides various commands that allow data entry, data manipulation, graphing, and various statistical analyses. Mann Whitney for the parameter values of density and viscosity using the software MiniTab 18. The data simulation of the Mann-Whitney test can be shown in **Figure 5.**

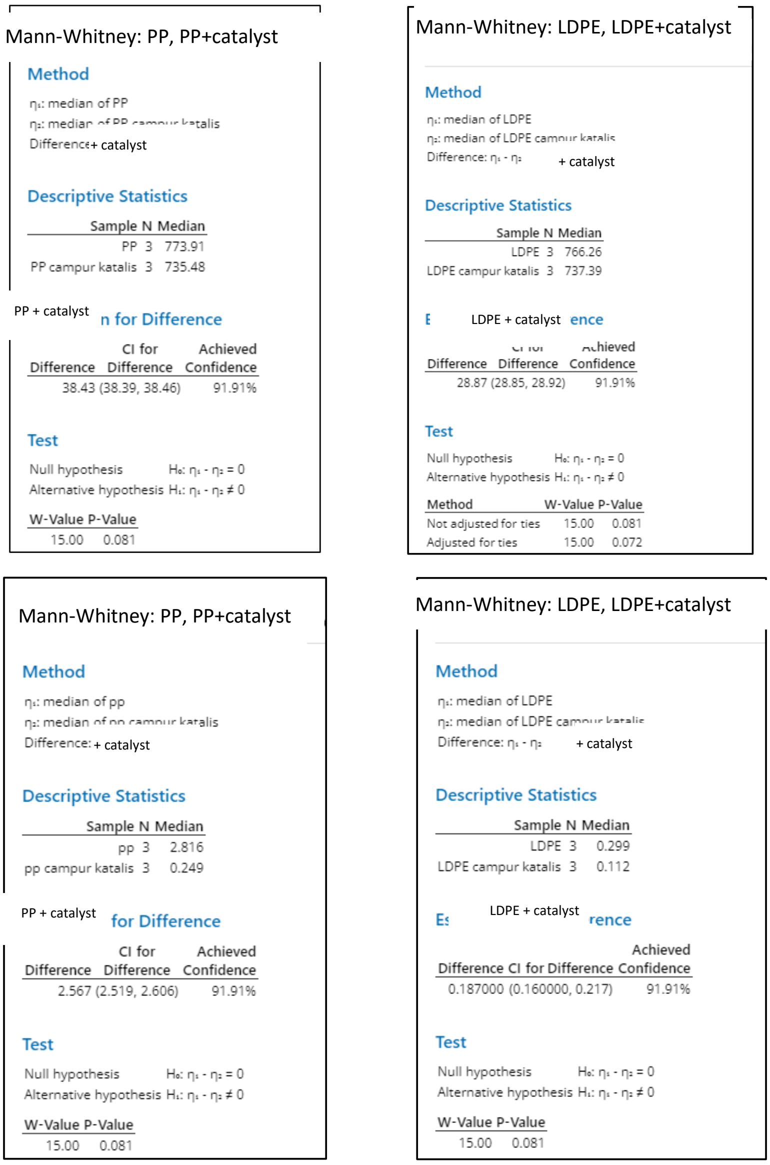

Figure 5. The data simulation showed that there was no significant difference between the PP, PP catalyst, and LDPE samples (p>0.05)

Based on the test results of Mann Whitney for the density parameter, a significance value of 0.081 was obtained. The significant value between PP, PP+catalyst, and LDPE, LDPE+catalyst variables due to P-Value (values sig) is more than the critical limit (α) of 0.05, then Ho is accepted. So, it can be concluded that there is no significant difference between PP and PP+catalyst samples based on quality and density parameters. The results of this statistical test are the same as the test results, which show that the sample values of PP and PP+catalyst are close to the gasoline density value of 88 (SNI 3506-2017) with a range of 715-850 kg/m³. Test result Mann Whitney for the viscosity parameter, a significance value of 0.081 was obtained, where the value was more significant than the critical limit of 0.05 so that the decision to accept the hypothesis Ho concluded that there was no significant difference between the PP, PP+catalyst and LDPE samples.

4. Conclusions

In conclusion, the study highlights the positive impact of using a catalyst in pyrolysis for LDPE and PP waste. The addition of a catalyst increased the quantity of oil produced, from 4.2 L to 4.8 L for LDPE and from 3.8 L to 4.1 L for PP plastic waste, enhancing efficiency in breaking down the polymer chains. Visual observations revealed differences in the color and clarity of the resulting oils, with catalyst-assisted samples exhibiting variations compared to non-catalyst samples. Furthermore, the catalyst influenced the density of the pyrolysis oil, with lower density values observed in samples treated with the catalyst compared to those without. The oil obtained from the pyrolysis of PP has an average density value of 774 kg/m³, while PP+catalyst is 735 kg/m3³. The oil obtained from LDPE pyrolysis has an average density value of 767 kg/m3³, while LDPE+catalyst has an average density value of 737 kg/m³. These findings underscore the catalytic effect on the quantity and quality of the pyrolysis products, emphasizing the importance of catalyst selection in optimizing plastic waste conversion processes. Based on the test results Mann Whitney for the density and viscosity parameters of each type of waste, a significance value of 0.081 was obtained where the value was more significant than the critical limit of 0.05 so that the hypothesis decision to accept Ho, explained that there was no significant difference between oil pyrolysis LDPE and PP with or without catalyst based on its density and pyrolysis, but the physical appearance and the oil obtained is different significantly.

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