

The Influence of Particle Size and Fuel Consumption Rate on Oil Characteristics from Pyrolysis of Aluminum Foil Coated Polyethylene (Al-PE) Waste

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Abstract

The collection of oil and aluminum is an effort made in order to utilize waste from Aluminum Foil Coated Polyethylene (Al-PE). Meanwhile, pyrolysis is one of the conversion technologies that can be used to treat this waste. The materials that would be used in this research is Al-PE plastic waste. This research aims to determine the effect of fuel consumption rate and particle size on the oil characteristics from pyrolysis of aluminum foil coated polyethylene plastic (Al-pE) waste. The material used in this research is Al-PE plastic waste. The selected particle size variations were 50 × 50 mm and 100 × 100 mm for 130 minutes with variations in fuel consumption rate of 4.77 g / min, 377 g / min and 2.46 g / min. The resultant pyrolysis and aluminum oil is measured to obtain yield. The results showed that Al-PE pyrolysis oil has a brownish yellow color, distinctive odor, flammability and physical character close to kerosene even to gasoline. The oil yield is between 6.9% wt to 22.4% wt. The highest oil yield and highest heating value obtained from sample A with particle size 50 × 50 mm and fuel consumption rate 4.99 g / min (0.29 kg / h) per kg of Al-PE for 130 min with material density in reactor 27 kg / m³.

Keywords: Pyrolysis, Al-PE, heating rate, particle size

1. Introduction

Plastic as a kind of solid waste is difficult to decompose and at the same time, its volume continues to increase every year. Due to the prices, practicality, and flexibility of use, the plastics have more advantages than other materials, such as; lighter, insulators, hard to decompose and cheap in production prices [1]. In addition, population growth, lifestyle and increased of packaging products consumption also trigger the increase in the volume of waste plastic. Data from the Deputy of Pollution Control of State Ministry of

Environment [2] stated that each of the average society produces 0.8 kg of garbage and 15% is the plastic waste. The estimated amount of plastic waste from 240 million population of Indonesia is 28,800 Ton/day. The amount of plastic waste will continue to grow and will be a potential threat to the environment and human sustainability in the future.

Plastic is one type of polymer which generally use basic materials such as polypropylene (PP), polyethylene (PE), polystyrene (PS), poly methyl methacrylate (PMMA), high-density polyethylene (HDPE) and polyvinyl chloride (PVC). Up until now, plastic is still a material used by industry and households widely. Meanwhile, the most common type of plastic used in the community for aluminum foil-coated packaging is Polyethylene (PE). To do the calculation, the polyethylene chemical formula is $(-CH_2-)_n$, n is the degree of polymerization [3].

The formation reaction is as follows:

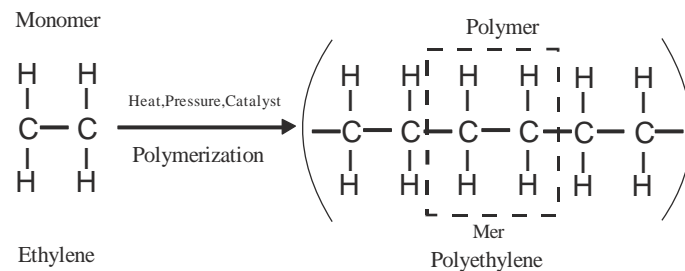


Figure 1. Polyethylene Formation Process

Some types of plastics can be recycled into plastic ores, but aluminum foil-coated plastic waste can not be processed with that technology. Based on the facts found in the field, both from studies/surveys and newspapers show that the garbage is not well managed by the authorities so it becomes an environmental issue. The aluminum foil coating of this type prevents it from being recycled as a pellet/plastic ore product. This condition causes aluminum foil coated plastic waste is not economical and pollute the environment, which makes this type of waste only piled up in various places or burned carelessly.

The removal of plastic waste using a burning method can create a dangerous pollutant. Landfill and open dumping methods in the final disposal site are no longer possible with the growing consumption of plastic packaging that continues to increase, while the plastics require a very long time to decompose. The disposal by burning process (incineration) risks generating pollutants from exhaust emissions ie CO_2 , CO , NO_x , HCN , SO_x and some other pollutant particulates. The finalization process of waste or plastic waste has not supported the concept of sustainable development (sustainable development).

Alternatives to the process of recycling plastic waste that can not be processed into plastic ores can be carried out by the following processes; pyrolysis, hydrocracking, and hydrogenation processes [1]. The pyrolysis

process is one option to recycle the polyethylene plastic waste with coated aluminum foil. The expected pyrolysis product is plastic oil, which can be used as an alternative fuel. Further processed plastic oil is expected to be an alternative fuel for combustion engines so it can be more useful.

Pyrolysis is the process of decomposition of a material at high temperatures in the absence of air or with limited air. The decomposition process in pyrolysis is also often called devolatilization. The main products of pyrolysis that can be produced are charcoal, oil, and gas. The formed charcoal can be used for fuel or as activated carbon and the resulting oil can be used as an additive or mixture in the fuel, while the formed gas can be burned directly [4]. Purwanti and Sumarni [3] have pyrolyzed LDPE plastic pieces with pyrolysis operating temperatures ranging from 400 ° C-600 ° C. The amount of the product is directly proportional to the temperature rise as well as the length of the process. The amount of solid or charcoal will be less with the increase in temperature and processing time. The effects of temperature and rate of warming on slow pyrolysis have been investigated by Williams [5], the heating rate used is between 5°C / min and 80°C / min with temperatures of 300°C and 750°C.

The pyrolysis process will produce condensed fumes called plastic oil and charcoal solids left in the reactor. Factors that may affect the process of pyrolysis are [6], [4], [7] The analysis of the physical properties of pyrolysis oils includes analysis of specific gravity, heat value, flash point, por point, and kinematic viscosity [8], [9], [10].

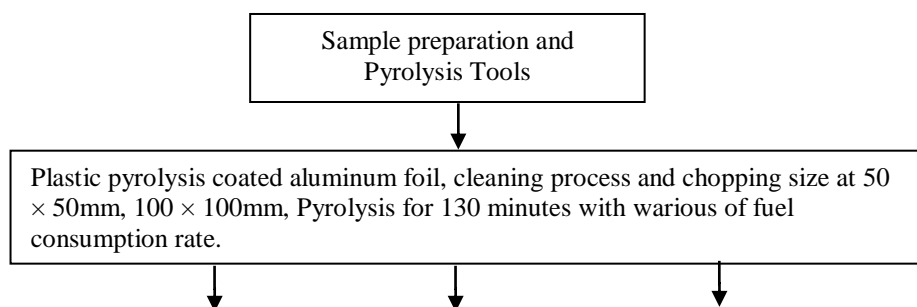
2. Materials and Methods

2.1 Research Locations

The research was conducted in Trayeman, Pleret, Bantul, Yogyakarta, CV. Harimukti Teknik, including design work, assembling tools and process of pyrolysis Al-PE. Testing of the characteristics of pyrolysis oil was conducted at the Petroleum, Coal and Gas Chemical Engineering Laboratory at UGM which has been cultivated ISO 17025: 2005.

2.2 Flowchart

The picture below presents the research flow diagram:



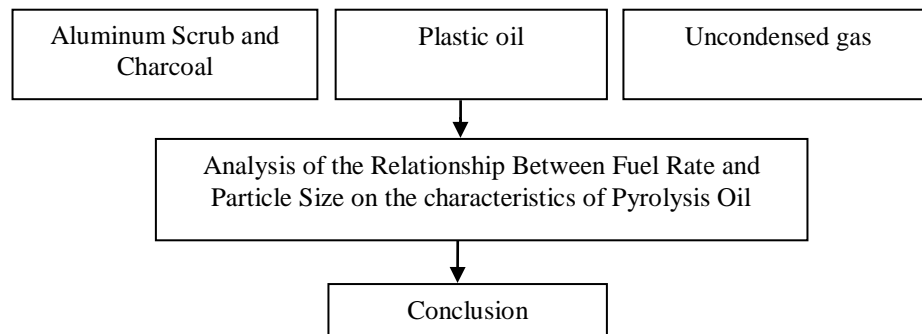


Figure 2. Research Flowchart

2.3 Research Materials

The raw material used in this research is aluminum foil-coated polyethylene waste from Final Disposal Site (TPA) in Piyungan, Bantul Yogyakarta and the water used in this research has a function as a coolant on the condenser.

2.4 Research Tools

The tools used in this research include 250ml measuring cylinders, stopwatch, glass bottles, one unit pyrolysis batch system capacity of 1000 grams of plastic. The pyrolysis reactor that has been used in this research is a prototype reactor with a diameter of 40 cm and a height of 30 cm. The length of the condenser is 1.5 meters and its diameter is 1 inch. The length of the outer tube of the reactor is 1.25 meters and 3 inches in diameter, while the pump used is a water pump with a discharge of 1m³ / h. A separator device is installed at the end of the condenser to separate the oil product and the non-condensable gas. A separator is installed to connect the gas output with a gas reservoir made of polypropylene plastic measuring 55 cm × 150 cm

Explanation:

1. Heater
 2. Pyrolysis reactor
 3. Condenser
 4. Separator
 5. Gas container
 6. Oil container
 7. Water reservoir
 8. Water pump
- T = Thermometer

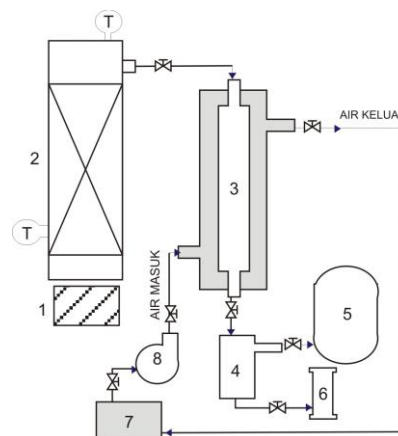


Figure 3. Scheme of pyrolysis tools

2.5 Research procedure

2.5.1 Preparation

Raw materials still in the form of aluminum foil-coated polyethylene plastic waste are cleaned to minimize impurities. This material is cut to size 50 × 50 mm and 100 × 100 mm, then measuring cups are prepared to accommodate pyrolysis oil. Water is prepared for the condenser and proceeds in the cooling basin.

2.5.2 Phase of pyrolysis process

Aluminum foil coated plastic that has been cleaned as much as 1000g with size 50 × 50 mm placed into the pyrolysis reactor. In preparation, the nuts and bolts must be sealed carefully to prevent a gas leak. Then, the reactor is coated with silicon with the temperature set at 450°C. The pyrolysis process lasted for 130 minutes with an average fuel consumption rate of 4.77 g / min, with a temperature achievement of ± 400 ° C - 450 ° C. This temperature is maintained until the entire process is over and the pyrolysis oil is then collected in a measuring cup.

The next experiment was carried out on materials measuring 100 × 100 mm with a consumption rate of 4.77g / min. Then with the same procedure, the experiment was carried out again on materials measuring 50 × 50 mm and 100 × 100 mm with a variation of fuel consumption rate of 2.46g / min.

The control variables in this research were at the time of pyrolysis; 130 min and the mass of Al-PE waste plastic waste; 1000 gram. Process variables (treatment) in this research is the size pyrolyzed Al-PE plastic of 50 mm × 50 mm and 100 mm × 100 mm. Another process variable is the heating (valve) using the control valve (valve) of the gas set at; maximum (100%), with a fuel consumption rate of 4.77 g / min, moderate (75%) with a fuel consumption rate of 3.77 g / min, and minimum (50%) with a fuel consumption rate of 2.46 g / min.

Control	Process		Sample
	Particle Size (mm)	Fuel consumption rate (g/minute)	
Pyrolysis reactors dimension	50 × 50	4,77	Sample A
130 minutes	50 × 50	3,77	Sample B
The mass of AL-PE is 100 grams	50 × 50	2,46	Sample C
Density of 0,035 g/cm ³	100 × 100	4,77	Sample D
	100 × 100	2,46	Sample E

Table 1. Varibel Bebas Penelitian

Results evaluation in this study, include:

1. Calculation of yield of oil produced (ml / g)

$$\text{Yield } \left(\frac{\text{ml}}{\text{g}}\right) = \frac{\text{Volume of pyrolysis oil}}{\text{mass of plastic}}$$

2. Calculation of aluminum (mg/g)

$$\text{Yield } \left(\frac{\text{mg}}{\text{g}}\right) = \frac{\text{mass of pyrolysis of aluminum}}{\text{mass of plastic}}$$

3. Tests on the characteristics of pyrolysis oil include specific gravity, gross heating value, kinematic viscosity, flash point, pour point and water content and aluminum rendement which includes microstructure.

3. Results and Discussion

3.1 Characteristics of Reactors and Research Variables

The pyrolysis reactor used in this research is prototype reactor with diameter 40 cm and height 30 cm, condenser length 1.5 meter with the 1-inch diameter, while the length of the outer tube is 1.25 meter with the 3-inch diameter. The water pump is a very important tool for the flow of cooling water with a discharge of 1m³ / h. The separator is deliberately installed on the end of the condenser to separate between the non-condensable oil and gas products. Meanwhile, for gas output, the separator end is connected to a gas container made of polypropylene plastic measuring 55 cm × 150 cm.

The Al-LE material of 1000 grams was then placed into a pyrolysis reactor with an Al-PE plastic density dimension in an average 0.027 g / cm³ pyrolysis reactor. During the pyrolysis process, the temperature changes are recorded for 130 minutes and temperature changes in oil and gas products are observed and recorded every 10 minutes.

3.2 Results and Characterization of Al-PE Plastic Wastewater pyrolysis

This research will measure the following variables: process temperature, volume, and yield of Al-PE pyrolysis oil, oil characteristics.

3.2.1 Temperature Profile

Gambar 4.1 menyajikan profil dari suhu proses pirolisis atas sampah plastik Al-PE, bukaan valve (laju konsumsi bahan bakar) dan suhu.

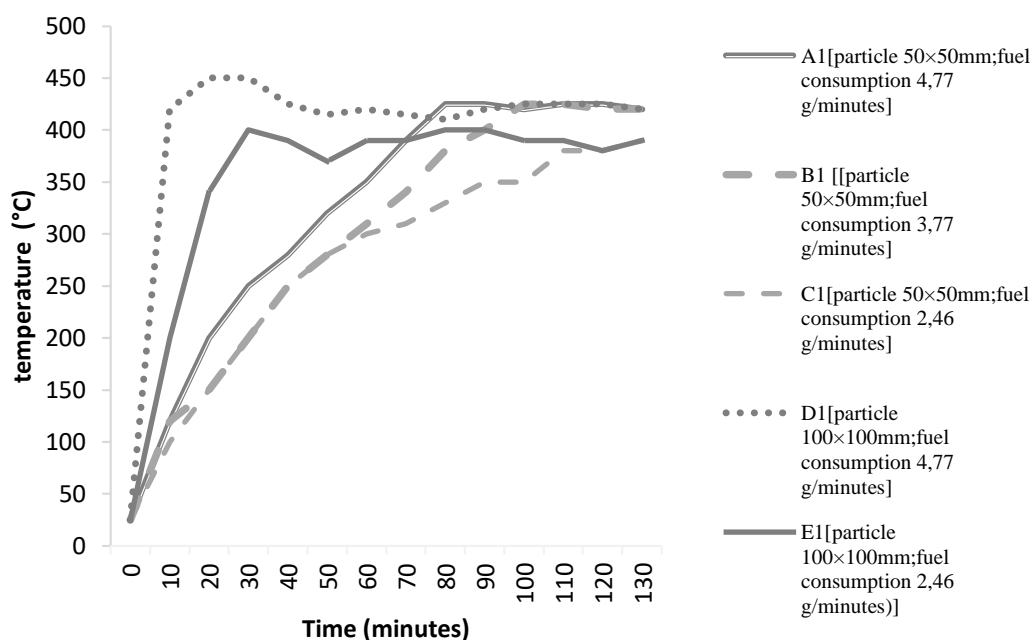


Figure 4. Pyrolysis Temperature Profile

As shown in Figure 4, the peak temperatures achieved by each process are varied. In addition, there was a time difference to reach the peak temperature at each treatment sample showing the difference in heating rate. The A1 sample reached a peak temperature of 425 ° C within 80 minutes, then the temperature was relatively stable until the 130th minute (holding time). Sample B1 has reached a peak temperature of 425 ° C within 100 minutes. The C1 sample reached a peak temperature of 390 ° C within 130 minutes. The D1 sample takes about 20 minutes to reach the peak temperature, but the temperature drop occurs up to 425 ° C and then relatively stable at 420 ° C-430 ° C until the 130th minute. The sample E1 has reached a peak temperature of 400 C and takes about 60 minutes. The peak temperature and the heating rate of the pyrolysis process for samples A, B, C, D, and E respectively are 450 °C; 5,3125 °C / min, 425 °C; 4,25 °C / min, 425 °C; 3 °C / min, 450 °C; 22.5 °C / min, and 450 °C; 13,333 °C / min. The following table shows the relationship of peak temperature, time and rate of heating namely:

Sample	Peak Temperature (°C)	Time (minutes)	Holding time (menit)	Fuel consumption rate (g / min)	Heating rate (° C / min)	formed oil in the minutes of-
Sample A1*	425	80	50	4,77	5,31	10
Sample B1*	425	100	30	3,77	4,25	10

Sample C1*	390	130	0	2,46	3,00	30
Sample D1**	450	20	110	3,77	22,50	20
Sample E1**	400	40	90	2,46	13,33	30

* = Sample particle size A1, B1, C1 is $\pm 50 \times 50$ mm

** = Particle size D1 and E1 is $> 100 \times 100$ mm

Table 2. Profile of peak temperature, time and rate of heating

When compared to the same particle size between A1, B1, and C1 it appears that A1 has the highest heating rate. And if D1 and E1 are compared, it would appear D1 has a higher heating rate. This is because the treatment of heat energy in sample A1 is greater than B1 and C1, and D1 is larger than E1.

Based on the overall result the D1 sample has the highest heating rate and the C1 sample has the lowest heating rate. When compared on the basis of particle size, samples with smaller particle sizes tend to be relatively lower heating rates than larger particle sizes. In graph 4.1 the sample D1 and E1 rapidly reach the peak temperature but then decrease until the temperature is stable.

The size of the particles D1 and E1, which are larger than the other affects the gas temperature and cracking process in the pyrolysis reactor, resulting in a drastic increase in temperature but in the same minute, no oil has yet formed. This is obtained after duplicating the process on a smaller sample. In the D1 sample, in the 0th minute until the 20th minute, there is only dense white gas in larger quantities when compared to the A1 sample process that has produced the first oil droplets. Based on observations, oil formation in samples having the same particle size and having different heating rates indicates faster oil formation ie in samples with higher heating rates. The formation of oils on samples with smaller particle sizes produced faster activity than larger particle size samples.

3.2.2 Volume and Yield measurement results

The yield and volume of oil obtained in this research have shown different results in each treatment (sample). The following is the volume of v / wo (ml / g) and yield (wt %) of pyrolysis oils on Al-PE plastics as shown in Table 3.

No		Sample A	Sample B	Sample C	Sample D	Sample E
Volume v (ml)						
1	P1	279	235	96	209	90
2	P2	303	225	117	229	83
	Average	291	230	106	219	86
v/w₀ (ml/g)						
1	P1	0,279	0,235	0,096	0,209	0,090
2	P2	0,303	0,225	0,117	0,229	0,083
	Average	0,291	0,230	0,106	0,219	0,086
Massa wt (g)						
1	P1	215	181	75	167	72
2	P2	233	173	91	183	66
	Average	224	177	83	175	69
Yield (wt%)						
1	P1	21,5	18,1	7,5	16,7	7,2
2	P2	23,3	17,3	9,1	18,3	6,6
	Average	22,4	17,7	8,3	17,5	6,9

$$\text{yield} = \frac{w_t}{w_0}; w_0 = 1000\text{g}$$

Table 3. volume and yield of pyrolysis oils on Al-PE plastic waste

Based on the data obtained in Table 2, the comparison between samples A, B, and C with the same particle size but having different heating rates; shows that sample A with higher heating rate produced a larger oil volume of 291 ml, when compared to samples production on samples B and C with 230 ml and 106 ml. Similarly, samples with 100 × 100 mm particle size on sample D1 with higher heating rates than E1, resulted in the higher volume of oil. If the observations were conducted by the same heat but with different particle sizes between samples A and D, then the average oil yield on sample A was higher than sample D. Overall conclusion, the pyrolysis process in sample A yielded the greatest amount of oil.

The oil yield ratio produced by each sample is relatively the same as the volume. The yields of sample A, B, C, D, and E were 22.4%, 17.7%, 8.3%, 17.5% and 6.9%, respectively. The highest yield is produced in the sample A pyrolysis process with the smaller particle size and the higher rate of heating than others.

3.2.3 Physical Characteristics

Physical differences in viscosity and color are also seen in each process. Oil in samples A, B, C with particle sizes of materials of 50x50mm tends to be clearer and yellower than oils of a material particle size of 100 × 100mm. The odor generated is also relatively similar, but the oils in samples

A, B, C are more flammable than samples D and E. In addition, the oils in the D and E samples leave more soot after burning.



Figure 5. Oil pyrolysis results from left to right (samples A, B, C, D, E)

Other physical differences are seen in the residual solids of pyrolysis. The residual solids in the pyrolysis reactor of each process have shown differences. The difference can be observed physically from the level of purity of aluminum foil. The pyrolysis residual solid product is presented in Figure 6.

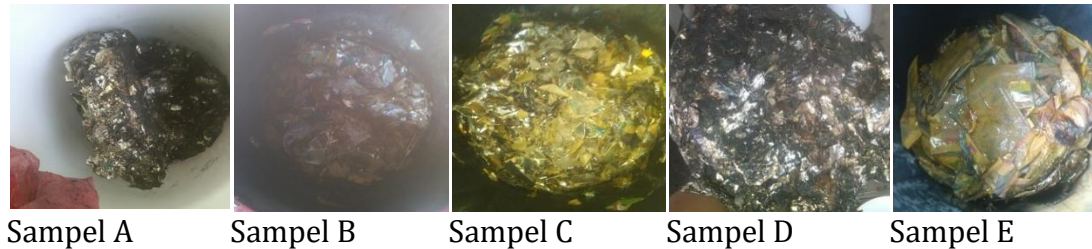


Figure 6. Rendement of the remaining plastic pyrolysis of Al-PE

Based on the pyrolysis results, the process of sample A has produced a cleaner residual solid than any other process. The C and E processes where the maximum temperature and the lowest heating rate produced the residual solids that still contain wax and plastic. This indicates that there are still many ingredients that have not yet undergone in a pyrolysis process. When compared to processes A and D, the solids from process D are much dirtier because they still leave much more carbon in the aluminum foil. Analyzed from the residual pyrolysis solids, the pyrolysis process over sample A has resulted in a cleaner residual solid, making it easier in the aluminum purification process.

The results of pyrolysis oil are analyzed qualitatively on the basis of their physical characteristics. Table 4. shows the physical characteristics of the oil products of each process.

No	Type of Examination	Unit	Results of Plastic Pyrolysis Examination					Examination methods
			Sample A	Sample B	Sample C	Sample D	Sample E	
1	Specific Gravity at 60/60 °F	-	0,7651	0,7705	0,7724	0,7948	0,7987	ASTM D 1298
2	Viscosity Kinematic at 40 °C	mm ² /s	0.667	0,692	0,700	0,861	1,064	IKU/5.4/T K-02
3	Gross Heating Value	BTU/lb	20107	20075	20064	19932	19908	Calculated
4	API Gravity	-	53.4	52.1	51.7	48.8	45.6	Calculated
5	Pour Point	°C	< -30	< -30	< -30	< -30	< -30	ASTM D 97
6	Flash Point COC	°C	15,0	16,0	18,0	18,0	19,0	ASTM D 92

Explanation = The result of Laboratorium examination at TMBGM (Chemical Engineering) UGM

Table 4. The Physical Characteristics of Al-PE Pyrolysis Oil

Based on the result of the physical characteristic test from sample A shows the highest gross heating value that is 20.107 BTU / lb, compared with other samples. The higher the heating value, it means the greater energy generated from the combustion process of these fuels. The calorific value of oil generally ranges from 18,300 - 19,800 BTU / lb. In general, the pyrolysis oil, as conducted in this research has the same range of heating value as the general oil, so it can be used for substitution alternatives. The lowest specific gravity value is indicated by the oil in sample A. Fuel oil generally has a specific gravity between 0.74-0.96. Therefore, it can be said that the all sample is still within that range. The kinematic viscosity means the amount of liquid fuel resistance to flow (the size of the shear resistance), so based on the data in Table 4, sample A has the lowest kinematic viscosity value. The flash point value for all samples is <73 ° C so that it is classified as A class (Effendi, 2012), (Pranata, 2008),

The comparison of pyrolysis oils in this study between Al-PE plastics and other oils is shown in Table 5.

No	Oil Type	Parameter					
		Specific gravity	Viscosity kinematic	Gross heating value	API Gravity	Pour point	Flash point
1	Sample A	0,7651	0.667	20107	53.4	< -30	15,0
2	Sample B	0,7705	0,692	20075	52.1	< -30	16,0
3	Sample C	0,7724	0,700	20064	51.7	< -30	18,0
4	Sample D	0,7948	0,861	19932	48.8	< -30	18,0

5	Sample E	0,7987	1,064	19908	45,6	< -30	19,0
6	Kerosene	0,835 (Maks)	1,2 (30 C)	18642,61	37,96	< -47	
7	Solar	0,82- 0,83	1,3-1,4	18470,79	41,06- 38,98	< -35 s/d < - 15	
8	Gasoline	0,724	0,88	18900,34	65,03	< - 3	
9	HFO	0,978	-----	17654	13,18	< - 10	
10	LFO	0,89	30 (30 C)	17998,28	27,49		

Table 5. Comparison of pyrolysis oil of Al-PE plastic waste with kerosene, gasoline, diesel, HFO and LFO

Based on comparison with gasoline, kerosene, diesel, HFO, and LFO it can be seen that oils in samples A, B, C tend to have specific gravity near gasoline, while oils in samples D and E tend to approach kerosene and diesel. The pour point value of all samples tends to approach the value of the pour point of the solar.

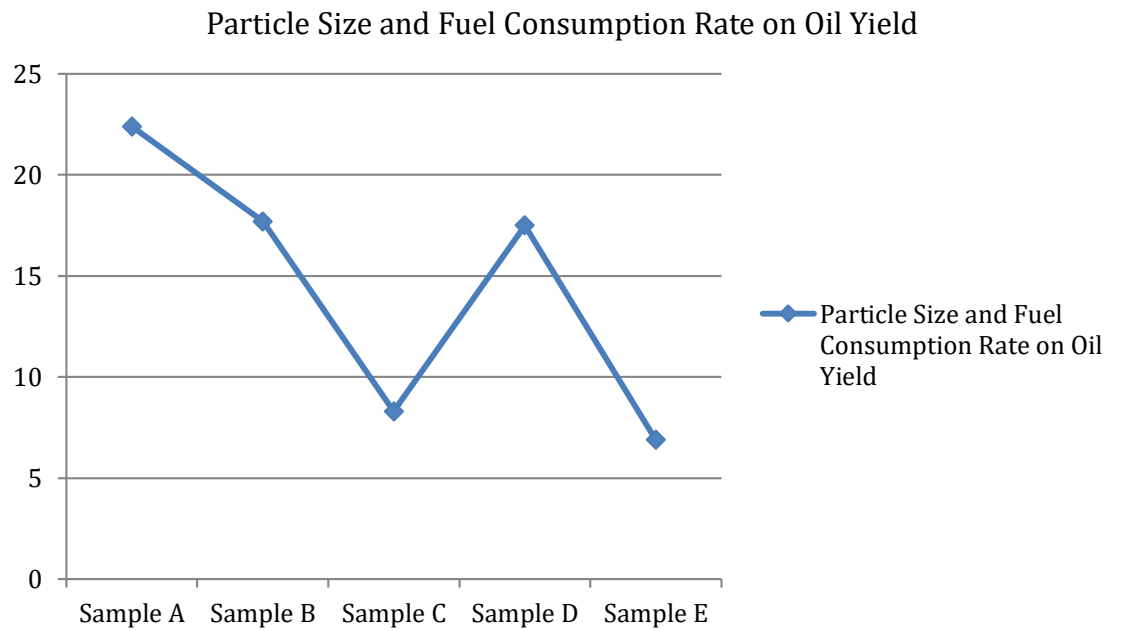


Figure 7. relationship between particle size and fuel consumption rate on oil yield and heating value

Based on the graph, sample A produces the highest Oil Yield. Sample A has smaller particle size variables and higher fuel consumption rates than others. Based on the physical characteristic test, it can be obtained that the

smaller particle size with higher fuel consumption rate produces the oil with the highest heating value.

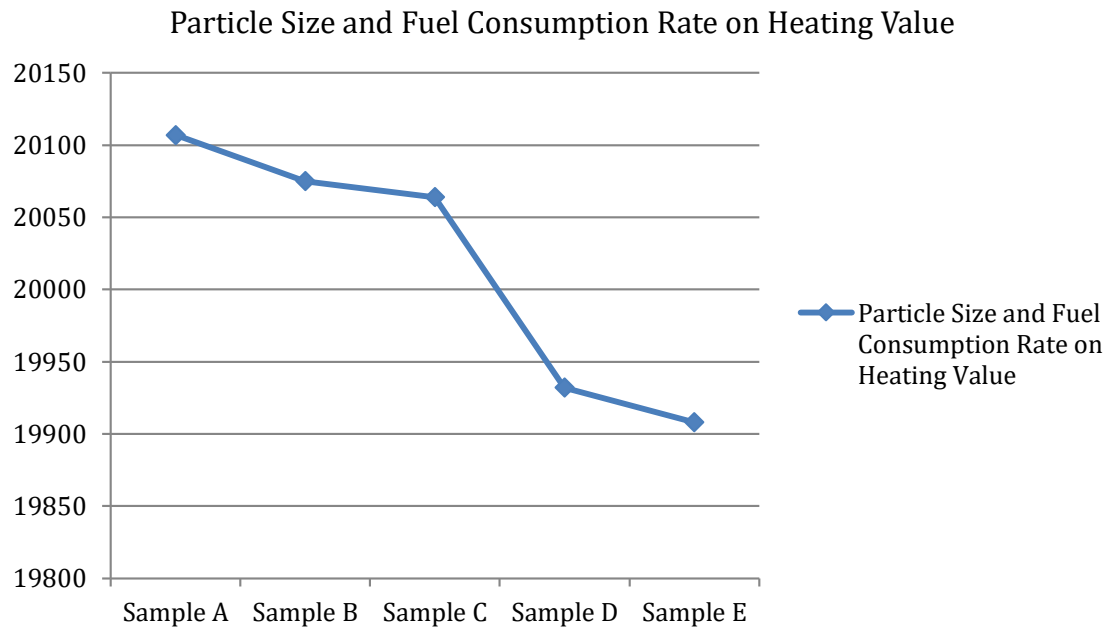


Figure 8. relationship between particle size and fuel consumption rate on heating value

Based on the graph, sample A has the highest heating value with smaller particle size variables and higher fuel consumption rate. Based on the physical characteristic test, it can be obtained that the smaller particle size with higher fuel consumption rate produces the oil with the highest heating value. This shows that the relationship between smaller particle size and higher fuel consumption rate will yield the highest yield of oil and calorific value in Al-PE plastic pyrolysis process.

4. Conclusion

Based on what has been done in this research, it can be drawn some conclusions as follows:

1. a. In general, Al-PE pyrolysis oil in this research has a characteristic of clear yellow color to brownish color, distinctive odor, and flammability. The physical characteristics of Al-PE pyrolysis oils are very specific, in terms of gross heating value, kinematic viscosity and specific gravity, these pyrolysis oils are close to the characteristics of diesel to gasoline.

- b. The oil yield of pyrolysis of Al-PE plastic waste is between 6.9% wt to 22.4% wt.
2. The highest oil yield and the highest heating value obtained from sample A with the particle size of 50 × 50 mm and fuel consumption rate of 4.99 g / min (0.29 kg / h) per kg of Al-PE, for 130 min with material density in reactor of 27 kg / m³.

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