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Characterization of Liquid Fuels from Pyrolysis of Low Density Polyethylene and Polystyrene Plastic Waste

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Abstract

Jember Regency, East Java faces the problem of increasing plastic waste, especially from packaging and household. Low density polyethylene (LDPE) and polystyrene (PS) plastics are difficult to decompose and have the potential to pollute the environment. One environmentally friendly management method is pyrolysis, a thermochemical process to convert plastic waste into liquid fuel. This study aims to analyze the effect of temperature and reaction time on the yield and characteristics of liquid fuel from LDPE and PS waste. The pyrolysis process was carried out in batches at temperatures of 150 °C and 250 °C for 30 and 90 min. The liquid products were analyzed based on density, viscosity, flash point, calorific value, and chemical composition using Fourier transform infrared spectroscopy and gas chromatography–mass spectrometry. The results show that the pyrolysis oil from LDPE and PS has similar physical and chemical properties to those of diesel fuel and kerosene. Temperature and reaction times significantly affect the characteristics of the fuel produced. Thus, plastics waste pyrolysis has the potential to be a solution for waste management and an alternative energy source in Jember Regency.

Keywords

LDPE, polystyrene, pyrolysis, GC-MS, FTIR

1 Introduction

Plastic waste has become a serious environmental issue worldwide, particularly in developing countries with rapid urbanization. In Indonesia, plastic waste generation continues to increase, especially in urban areas where disposable plastic consumption is high. In Jember Regency, East Java, plastic waste generation reaches approximately 2,873 m^3 per day, with low-density polyethylene (LDPE) and polystyrene (PS) dominating household plastic waste [1]. These plastics are difficult to manage using conventional recycling methods due to contamination and low economic value [2].

Pyrolysis has been widely reported as a promising thermochemical technology for converting plastic waste into liquid fuel with high calorific value. Numerous studies have demonstrated that LDPE and PS plastics can be transformed into fuel fractions comparable to gasoline, kerosene, and diesel [3]. However, most existing pyrolysis studies employ high operating temperatures (generally above 300 °C), catalytic systems, and electrical heating, which significantly increase energy consumption and operational costs. These limitations hinder the practical application of pyrolysis technology, particularly in small-scale and local waste management systems [4].

Plastic waste can be converted into pyrolysis oil as fuel through slow pyrolysis (with less than an hour heating times and temperatures between 300 °C and 900 °C). Previous studies have shown that pyrolysis can be influenced by the type of plastic waste, reactors, other supports, and catalysts used, affecting the amount of pyrolysis oil produced, ranging from 45% to 50% [5]. LDPE and PS plastics were chosen for this study because each degrades at moderate temperatures, with LDPE plastic degrading between 160 °C and 240 °C and PS plastic at temperatures above 100 °C [6]. To date, limited studies have focused on low-temperature pyrolysis without catalysts using alternative heat sources, especially for LDPE and PS plastic waste. Exploring pyrolysis at relatively low temperatures is important to improve energy efficiency, reduce operational costs, and simplify the process while maintaining acceptable fuel quality [3].

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Many previous studies have used catalytic pyrolysis to improve product yield and selectivity. However, catalysts increase process complexity, operational cost, and maintenance due to preparation, regeneration, and deactivation issues, especially when treating mixed plastic waste. These limitations reduce the feasibility of catalytic pyrolysis for small-scale and local applications. Therefore, this study applies a non-catalytic pyrolysis approach to simplify the process and reduce energy consumption and operational costs by using relatively low temperatures.

This study investigates the conversion of LDPE and PS plastic waste into pyrolysis oil using a non-catalytic batch reactor heated by liquefied petroleum gas (LPG). The effects of temperature and reaction time on oil yield and characteristics are evaluated. The resulting oil is analyzed for density, viscosity, flash point, calorific value, and chemical composition using gas chromatography–mass spectrometry (GC-MS) and Fourier transform infrared spectroscopy (FTIR). The findings are expected to support the development of an energy-efficient and cost-effective plastic waste-to-fuel technology for local-scale applications.

2 Experimental

2.1 Materials

Pyrolysis liquid fuel was produced using a simple small-batch pyrolysis reactor through thermal heating. The process is carried out without oxygen and catalysts. The reactor was made of stainless steel with a diameter of 28 cm, a height of 94 cm, a capacity of 12 L, and a heating system generated by burning LPG. The end of the reactor was connected to a water-cooled condenser tube 300 cm long. This heating system can reach temperatures of around 350 °C. The pyrolysis process was similar to the previous research by Suhartono et al. [7]. The schematic of the pyrolysis process is shown in Fig. 1.

The raw material of LDPE and PS plastic waste is cut into uniform sizes. 150 g plastic was then inserted into the pyrolysis reactor through the top door and ensured the reactor was closed during pyrolysis. This study aims to determine the physical and chemical characteristics of the pyrolysis oil. The characteristics analyzed include the physical properties and chemical properties of the pyrolysis oil, as well as spectrum analysis using FTIR and GC-MS. The physical properties examined include density and viscosity, while the chemical properties examined are flash point and calorific value. This study uses polyethylene (LDPE) and polystyrene (styrofoam) plastics pyrolyzed in reactors with temperature variations of 150 °C and 250 °C and time variations of 30 min and 90 min. The temperature range of 150–250 °C was selected to investigate low-temperature pyrolysis behavior and energy-efficient operation under practical small-scale conditions. Although thermogravimetric analysis (TGA) would provide more detailed decomposition profiles, it was not conducted in this study due to equipment

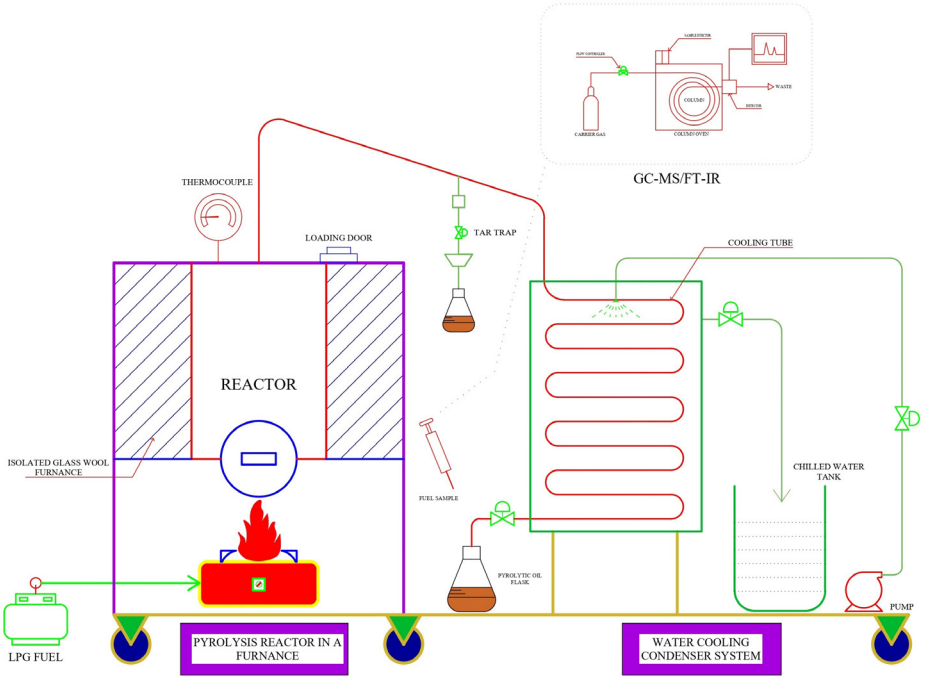


Fig. 1 Scheme of pyrolysis furnace

limitations and is suggested for future work. This research was conducted under adjusted conditions and equipment.

This experimental design focuses specifically on the effects of temperature and reaction time, as these parameters are considered the most dominant factors influencing thermal degradation behavior and oil yield. Other variables such as particle size, heating rate variation, and reactor pressure were not investigated in this study in order to maintain experimental simplicity and focus on practical operational conditions.

The heating rate was not strictly controlled and mainly depended on the LPG heating system and reactor thermal characteristics. Therefore, the heating rate was not quantitatively determined and is considered as a limitation of the present study.

The characteristics of the pyrolysis oil were studied to determine the quality of the oil products. Physical qualities such as density and viscosity were measured using formulas and an Ostwald viscometer according to applicable procedures. The density and viscosity values of the obtained pyrolysis oil were used to calculate the oil's calorific value. The flash point was tested using the ASTM D92 method, a standard test method for open-cup flash point testing [8]. The chemical composition of the pyrolysis oil was analyzed using Fourier Transform Infrared spectroscopy (FTIR) and gas chromatography–mass spectrometry (GC–MS). The FTIR spectra were recorded using an IRXross FTIR spectrometer (Shimadzu Corporation, Japan) with a resolution of 4 cm^{-1} in the spectral range of 400–4000 cm^{-1}. The chemical compounds were further analyzed using a GC–MS system [9]. The chemical compounds of the pyrolysis oil were analyzed with a Hewlett-Packard HP 7890 GC-MS. The functional groups and chemical compounds in the pyrolysis oil were studied and compared with the FTIR spectrum results, and compounds were analyzed from other fuel oils.

3 Results and discussion

3.1 Physical analysis

This research was conducted with pyrolysis temperature variations of 150 °C and 250 °C and durations of 30 min and 90 min. Each experimental condition was carried out in duplicate to enhance the reliability of the experimental data. The reported values of density, viscosity, flash point, and calorific value represent the average of two independent experimental runs. Although standard deviations were not statistically evaluated, duplicate experiments were considered sufficient to indicate reproducibility trends under the studied conditions. The resulting products had physical properties, including odor and the color of the pyrolysis oil, which was dark brown with a slight sediment and a strong odor.

The slight sediment observed in the pyrolysis oil is mainly attributed to fine char particles and unreacted solid residues generated during the thermal decomposition of plastic waste. This phenomenon is commonly found in non-catalytic pyrolysis processes, particularly in systems operated without inert gas. The presence of such solids may influence fuel appearance and stability; therefore, simple post-treatment methods such as filtration or sedimentation are required to remove these impurities and enhance fuel quality for practical applications. The pyrolysis oil from LDPE and PS plastic waste can be seen in Fig. 2.

(a)

(b)

Fig. 2 Pyrolysis oil from left to right (a) LDPE pyrolysis samples at varying temperatures and times: A1 (150 °C, 30 min), B1 (150 °C, 90 min), A2 (250 °C, 30 min), B2 (250 °C, 90 min). (b) PS pyrolysis samples at varying temperatures and times: X1 (150 °C, 30 min), Y1 (150 °C, 90 min), X2 (250 °C, 30 min), Y2 (250 °C, 90 min).

Fig. 2 shows the visual appearance of the pyrolysis oil obtained from LDPE (Fig. 2(a)) and PS plastic waste (Fig. 2(b)), indicating dark brown color with slight sediment formation. The PS waste produced a higher yield than LDPE plastic waste. The density of PS is about 980 kg/m^3 compared to LDPE's density of about 790 kg/m^3 because PS plastic contains more hydrocarbon chains [10]. Therefore, the greater the density of the plastic, the more pyrolysis oil it produces [11]. The melting point of the plastic type affects its ease of thermal degradation. The higher the melting point of the plastic type, the more difficult it is to break down the large carbon chain bonds with thermal pyrolysis [12]. LDPE plastic is more difficult to degrade thermally and requires longer pyrolysis times to achieve optimal results, as shown in Table 1. The first droplet for LDPE and PS was achieved in 25 and 10 min, respectively. This difference may be due to LDPE being more challenging to evaporate (degrade) than PS plastic.

Pyrolysis temperature is also one of the most critical factors related to the quantity and quality of pyrolysis oil. The higher the pyrolysis temperature, the faster the pyrolysis process occurs. Long-chain hydrocarbons from plastic waste will quickly degrade into shorter carbon chains to produce the desired pyrolysis oil [13]. As the pyrolysis time progresses, the temperature increases due to heating, resulting in a larger volume of pyrolysis oil and higher product yield for both LDPE and PS.

The oil yield was calculated using Eq. (1):

$$\text{Yield } (\%) = \frac{m_{\text{oil}}}{m_{\text{feedstock}}} \times 100, \quad (1)$$

where m_{oil} represents the mass of pyrolysis oil and $m_{\text{feedstock}}$ represents the mass of the plastic feedstock used in the experiment. In this study, the higher pyrolysis oil yield of 66% (v/w) was obtained from PS plastic.

Table 1 The results of LDPE and PS pyrolysis liquid oil

Type of plastic (150 g)	Temperature (°C)	Time (min)	Pyrolysis oil		
			Volume (mL)	Mass (g)	Yield (%)
LDPE	150	30	96	76	51
	150	90	108.5	86	57
	250	30	99	77	51
	250	90	119	94	63
PS	150	30	78	76	51
	150	90	86	84	56
	250	30	88	86	58
	250	90	100	98	66

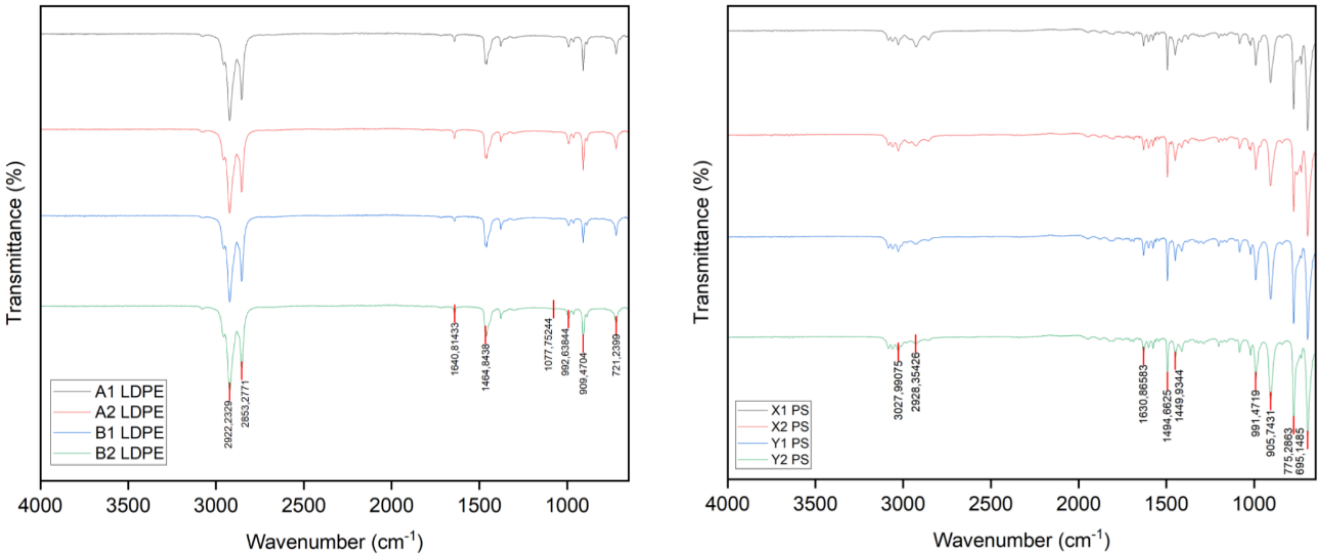
The pyrolysis oil yield from LDPE plastic was 63% (v/w). Suhartono et al. [7]. Reported that the pyrolysis of 300 g of LDPE plastic waste using a simple reactor produced approximately 151 mL pyrolysis oil (yield 50.3%). It had a lower yield than a study by Lumingkewas et al. [6]. With 100 g of PS plastic waste using a batch reactor, which obtained a pyrolysis oil yield of approximately 62%. These differences in pyrolysis oil can be attributed to the pyrolysis reactor and condenser capacity used, as well as the treatment of raw materials before the pyrolysis process, including washing, drying, and size reduction of the plastic waste to achieve optimal results [14].

This study analyzed pyrolysis oil using FTIR to determine the contents of the liquid fraction resulting from pyrolysis, represented by hydrocarbon functional groups. These results were compared with previous studies by Suhartono et al. [7] and Lumingkewas et al. [6]. Various chemical/functional groups present in the pyrolysis oil from LDPE and PS were characterized by identifying the results of the FTIR spectrum analysis. The FTIR spectra of the pyrolysis liquid oil (PLO) from LDPE and PS, representing the composition of functional groups, can be seen in Fig. 3.

The FTIR spectra of pyrolysis oil derived from LDPE and PS are presented in Fig. 3, which illustrates the main functional groups present in the liquid products. The FTIR spectrum results above show that the pyrolysis oil from LDPE (Fig. 3(a)) contains eight functional groups: a mixture of aliphatic hydrocarbon compounds (saturated and unsaturated) and hydrogen-bonded alcohol. The PS (Fig. 3(b)) pyrolysis oil spectrum contains nine similar functional groups: aliphatic hydrocarbon compounds (saturated and unsaturated), hydrogen-bonded alcohol, ammonia, and aromatic groups. The characteristic of the FTIR spectrum is the presence of dominant alkane and alkene groups [15].

Based on the wavelength, the identified functional groups with peaks at 2922 cm^{-1} and 2853 cm^{-1} indicate the presence of alkanes with strong intensity. Fig. 2(a) shows peaks between 3000 cm^{-1} and 2800 cm^{-1}, indicating the presence of $-CH_3$, $-CH_2$, and $-CH$ functional groups, characteristic of aliphatic alkane compounds and symmetric methyl groups. The determination of the FTIR spectra of PLO of LDPE are summarized in Table 2.

Alkene compounds with the C–H functional group were found in LDPE pyrolysis oil at a wavenumber peak of 721 cm^{-1}. These peaks indicate the highly aliphatic nature of the pyrolysis oil product [16]. The results of this study are similar to the research conducted



(a) (b)

Fig. 3 FTIR Spectrum of (a) LDPE PLO, (b) PS PLO

by Saputra et al. [17]. Where alkene compounds with C−H vibration types were found in LDPE pyrolysis oil at peaks of 992.63 cm^{-1} and 909.47 cm^{-1}. FTIR test results show that the liquid obtained from the pyrolysis process of LDPE plastic, with variations in temperature and time, mostly consists of alkane functional groups and has a carbon number range of C_9 to C_{24} [18].

The FTIR spectrum test results indicate that the LDPE pyrolysis fuel oil meets the characteristics of kerosene fuel with the chemical formula $C_{14}H_{28}$ and the chemical reaction

$$C_{14}H_{28} + 21O_2 \rightarrow 14CO_2 + 14H_2O \quad (2)$$

howing only carbon-carbon (CC) and carbon-hydrogen (CH) bonds, making LDPE pyrolysis a potential alternative fuel [19].

Based on the data in Table 2 can be explained as follows: functional groups identified at a wavenumber 3027 cm^{-1}, which is in the single bond stretch region, indicate the presence of aromatic ring functional groups with moderate intensity. Several identified spectrum peaks from wavelengths 695–991 cm^{-1} in the fingerprint region indicate the presence of aromatic ring functional groups with

Table 2 Characteristic peaks in FTIR spectra of the pyrolysis liquid oils

Type of plastic	Wavenumber (cm^{-1})	Functional group	Properties of functional group	Intensity
LDPE	2922	C−H	alkane	Strong
LDPE	2853	C−H	alkane	Strong
LDPE	1640	C=C	alkene	Variable
LDPE	1465	C−H	alkane	Strong
LDPE	1078	C−O	alcohol, carboxylic acid, ester	Strong
LDPE	993	C−H	alkene (−C=C−H)	Strong
LDPE	909	C−H	alkene (−C=C−H)	Strong
LDPE	721	C−H	alkene (−C=C−H)	Strong
PS	3028	C−H	alkene	Medium
PS	2928	C−H	alkane	Strong
PS	1631	C=C	alkene	Variable
PS	1495	C−H	alkane	Strong
PS	1450	C−H	alkane	Strong
PS	991	C−H	alkene (−C=C−H)	Strong
PS	906	C−H	alkene (−C=C−H)	Strong
PS	775	C−H	alkene (−C=C−H)	Strong
PS	695	C−H	alkene (−C=C−H)	Strong

strong intensity. The wavenumber 2928 cm^{-1} in the single bond stretch region indicates the presence of alkane functional groups with strong intensity. The functional group is supported by the wavenumber of 1449 cm^{-1}, which is in the fingerprint region, indicating the presence of alkane functional groups with strong intensity. The wavenumber 1630 cm^{-1} indicates the presence of alkene functional groups (−C=C−H) with strong intensity in the double bonds area. The remaining peaks correspond to nitrogen compounds. The FTIR results show that the four samples tested have the same functional groups.

These results are in line with the results of previous PS plastic pyrolysis research reported by Fang et al. [20]. The identified peaks are related to the presence of alkanes: C−H aromatic 3060.8 and 3026.0 cm^{-1}, aromatic alkenes 1600.8, 1492 and 1452.2 cm^{-1}, aromatic rings 756 and 698 cm^{-1}, −C−H-methylene 2921.9 and 2848.6 with strong absorption intensity and monosubstituted aromatic compounds 1942.8 and 1669.73 cm^{-1} with moderate absorption intensity. The results of the FTIR spectrum in the study were similar to diesel fuel. Diesel fuel functional groups are dominant aliphatic functional groups. Styrene compounds are almost the same as benzene compounds with the chemical formula $C_6H_5CH=CH_2$ (C_8H_8), showing only carbon-carbon (CC) and carbon-hydrogen (CH) bonds [21].

The description shows that diesel oil (diesel fuel) contains highly functional groups of aliphatic hydrocarbons (saturated and unsaturated) and aromatic compounds. PS can be converted into hydrocarbons within the range of diesel oil. Due to the high similarity of aliphatic hydrocarbons, PS plastic pyrolysis oil can be used as an alternative fuel to diesel oil. This PS plastic pyrolysis oil is produced through low-temperature polystyrene plastic pyrolysis to address waste utilization and fuel oil replacement. The discussion of the research results above is by the results of previous research [20].

The liquid smoke or oil from the pyrolysis of LDPE and PS plastics was then analyzed using GC. The results of GC-MS analysis of pyrolysis oil display various compounds, each represented by a number of peaks in the GC spectrum; chemical compounds contained in LDPE and PS pyrolysis oil can be seen in Fig. 4.

The chemical composition of the pyrolysis oil was further analyzed using GC-MS, and the corresponding chromatograms for LDPE and PS are shown in Fig. 4. The chromatogram results in Fig. 4(a) describe 12 chemical compounds found in LDPE pyrolysis oil. The chemical compounds include 1-octene, 1-decene, 1-undecene, cyclododecane, 1-tetradecene, n-pentadecanol, 1-tridecene, 1-nonadecene, nonadecane, heneicosane, and tricosane. The results of the GC-MS analysis of LDPE pyrolysis oil can be seen in Table 3.

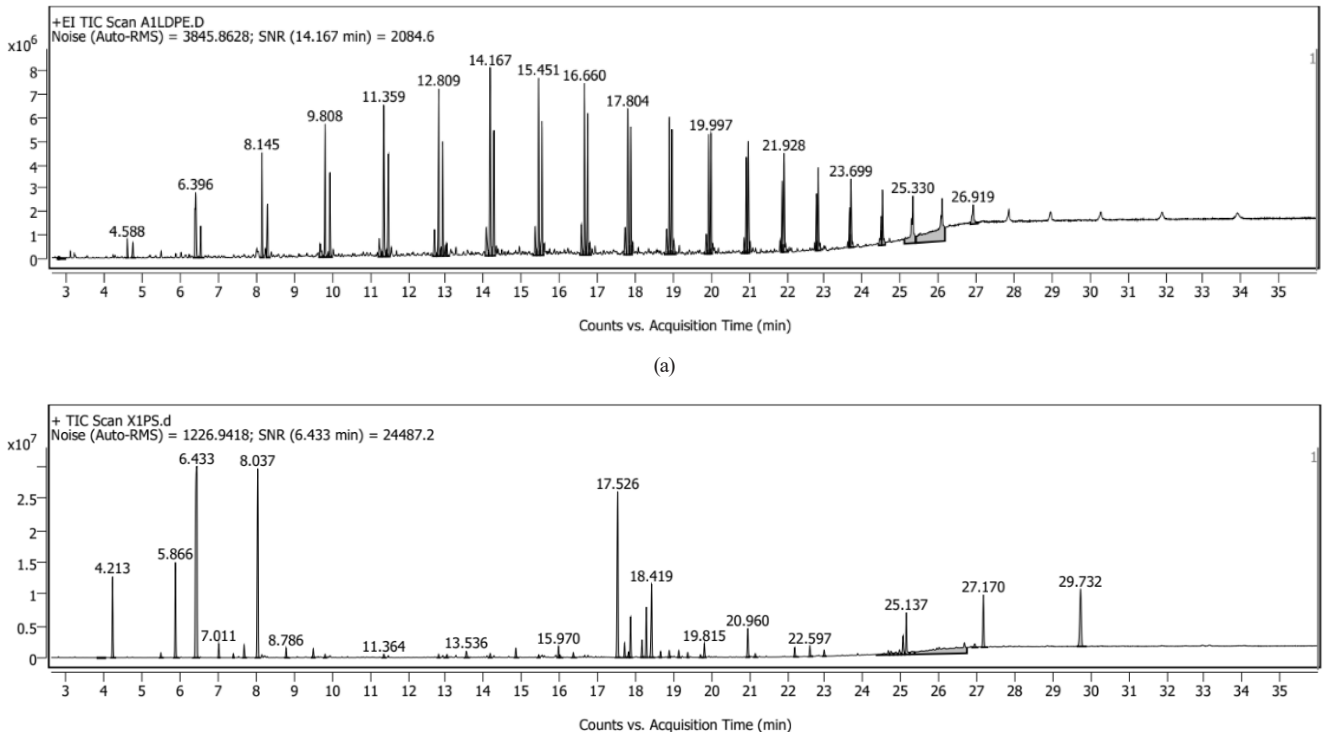


Fig. 4 GC-MS spectrum from (a) LDPE PLO, (b) PS PLO

Table 3 GC-MS results of LDPE pyrolysis liquid oil

Peak	Retention time (min)	Area (100%)	Chemical formula	Name of the chemical compound
1	4.6	4.84	C_8H_{16}	1-Octene
5	8.1	27.79	$C_{10}H_{20}$	1-Decene
8	9.8	36.65	$C_{11}H_{22}$	1-Undecene
11	11.4	41.50	$C_{12}H_{24}$	Cyclododecane
14	12.8	46.73	$C_{13}H_{26}$	1-Tridecene
18	14.2	54.48	$C_{14}H_{28}$	1-Tetradecene
21	15.5	52.93	$C_{15}H_{32}$	n-Pentadecanol
24	16.7	49.25	$C_{16}H_{34}$	1-Hexadecanol
28	17.8	44.55	$C_{19}H_{38}$	1-Nonadecene
36	20	35.10	$C_{19}H_{40}$	Nonadecane
41	21.9	31.65	$C_{21}H_{44}$	Heneicosane
45	23.7	21.57	$C_{23}H_{48}$	Tricosane

The analysis showed that the twelve-compound-composition was dominated by the 1-tetradecene ($C_{14}H_{28}$) as much as 54.48%. LDPE pyrolysis oil from GC-MS testing results is characterized by kerosene with the chemical formula C_{11}–C_{14}. These results agree with Abbas and Mohammed [16], who reported that the pyrolysis products of LDPE are dominated by 1-tetradecanol ($C_{14}H_{30}$), a compound with properties similar to those of household kerosene.

Fig. 4(b) shows the GC-MS analysis results of the entire PS pyrolysis oil chromatogram, showing the peak areas of the identified substances. This shows that the primary substance detected is determined based on the highest peak area. The analysis results of the chemical compounds found in the PS pyrolysis oil showed 16 peaks, indicating 16 chemical compounds in the pyrolysis oil. The 16 main compounds contained in the PS pyrolysis oil, specifically the peak areas detected at more than 2%, are listed in Table 4.

The GC chromatogram shows that the PS pyrolysis oil fraction comprises 16 compound peaks with many compounds. From the MS spectra data and area data on the GC chromatogram, it turns out that the PS pyrolysis oil consists of a mixture of hydrocarbon compounds, namely toluene (18.68%), benzene (49.92%), cyclohexane (12.11%), ethylbenzene (23.69%), alpha-methyl styrene (57.05%), 1,3-diphenyl propane (49.92%) and the compound with the highest composition is styrene (100%). Styrene peak at 100% in Table 4 represents normalized peak area, not absolute composition.

According to the above GC-MS data, as shown by previous studies, the pyrolysis oil produced from processing consists of a mixture of various hydrocarbon compounds:

Table 4 GC-MS results of PS pyrolysis liquid oil

Peak	Retention time (min)	Area (100%)	Chemical formula	Name of the chemical compound
1	4.2	18.68	C_7H_8	Toluene
3	5.9	23.69	C_8H_{10}	Ethylbenzene
4	6.4	100	C_8H_8	Styrene
5	7.0	3.19	C_9H12	Benzene, (1-methylethyl)
8	8.0	57.05	C_9H_{10}	alpha-Methyl styrene
9	8.8	2.28	C_9H_{10}	Benzene, cyclopropyl
15	13.5	2.24	$C_{10}H_{11}N$	Benzene, butane nitrile
19	16.0	2.91	$C_{14}H_{14}$	Bibenzyl
22	17.5	49.92	$C_{15}H_{16}$	Benzene, (1,3-propanediyl)
28	18.4	21.10	$C_{15}H_{14}$	1,2-Phenylcyclopropane
34	19.8	3.52	$C_{16}H_{12}$	Anthracene, (9-ethenyl)
35	21.0	7.83	$C_{16}H_{12}$	Naphthalene, (2-phenyl)
38	22.6	2.73	$C_{18}H_{14}$	m-Terphenyl
45	25.1	12.11	$C_{24}H_{24}$	Cyclohexane, (1,3,5-triphenyl)
49	27.2	16.57	$C_{24}H_{18}$	Terphenyl, (4-phenyl)
50	29.7	27.61	$C_{24}H_{18}$	Terphenyl, (5-phenyl)

alkane derivatives, alkene derivatives, cycloalkane derivatives, ketone derivatives, alcohol derivatives, styrene derivatives, and substituted benzene [6]. Research from Adnan et al. [17]. Also proved that PS pyrolysis oil contains benzene, toluene, ethylbenzene, styrene, isopropyl benzene, alpha-methyl styrene, and 1,3 diphenyl propane compounds. GC-MS results from the above data show that PS pyrolysis oil has the same compounds as diesel oil, where the $C_{15}H_{16}$ (benzene) compound is close to the diesel oil formula ($C_{16}H_{32}$). The carbon range composition of the fuel is presented in Table 5 [7].

Based on the data discussed above, LDPE pyrolysis oil tends to resemble hydrocarbons produced by kerosene fuel. While PS pyrolysis oil tends to be similar to hydrocarbons produced by diesel fuel oil. Therefore, a comparison of the measured physical properties of the fuels that can be used as a comparison to meet this hydrocarbon range was conducted. Some of the measured physical properties of the fuel and pyrolysis oil are presented in Table 6.

Table 5 Fuel carbon ranges

Fuel	Range of carbon composition
Gasoline	C_5–C_{10}
Kerosene	C_{11}–C_{14}
Diesel	C_{15}–C_{27}
Lubricant oil	C_{18}–C_{20}

Table 6 Comparison of physical properties of pyrolysis liquid oil and fuels

Parameter	Pyrolysis oil		Kerosene [3]	Solar [4]
	LDPE	PS		
Density (kg/m^3)	79	98	0.7909	0.807
Viscosity (mm^3/s)	3.35	2.14	0.744	1.9–4.1
Flash point (°C)	61.25	9.75	52	52
Calorific value (cal/g)	11,125	9,984	9,440.72	10,277.2

Based on the results in Table 6, the density of LDPE pyrolysis oil is very similar to kerosene, while the viscosity, flash point, and heating value are similar to diesel oil. The slightly lower density of LDPE pyrolysis oil may be due to the content of small amounts of paraffin fractions (lower molecular weight hydrocarbons) [4]. PS pyrolysis oil has density, viscosity, and heating values close to diesel oil. The flash point of PS pyrolysis oil is relatively low compared to kerosene and diesel oil. The flash point is the lowest temperature at which the fuel begins to vaporize [4]. The low flash point of PS oil requires careful storage in sealed containers away from ignition sources.

The flash point of fuel oil tends to decrease as its viscosity decreases. Fuel auto-ignition temperature is the lowest temperature at which the fuel ignites spontaneously without a fire source. Low fuel viscosity will reduce the flash point and auto-ignition of the fuel. Therefore, low viscosity, flash point, and initial ignition values are necessary for good fuel combustion quality [22]. The physical properties of fuel from LDPE pyrolysis oil from the above results are not much different from kerosene, while PS pyrolysis oil is not much different from diesel oil (Table 6). It can be concluded that the pyrolysis oil from LDPE and PS plastic waste is easily vaporized and ignited like kerosene and diesel oil. The resulting LDPE and PS pyrolysis oil can be an alternative fuel substitute.

4 Conclusion

Based on the results and discussion above, the characterization and physical properties of LDPE and PS pyrolysis oil at 150 °C and 250 °C can produce pyrolysis oil that is close to the kerosene fuel formula and diesel oil hydrocarbon range with high oil yield.

This study did not investigate key combustion and environmental parameters such as cetane number, sulfur content, and long-term fuel stability. Although the obtained pyrolysis oils exhibit physical and chemical properties comparable to commercial fuels, these unmeasured parameters represent important limitations for real-world fuel applications.

Future studies should include detailed engine performance and emission tests to assess real combustion behavior of the produced fuels. Moreover, blending experiments with commercial diesel or kerosene are necessary to evaluate fuel compatibility and long-term stability. Finally, life cycle assessment (LCA) is required to quantify the environmental impacts and energy efficiency of the plastic waste-to-fuel conversion pathway.

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