CHARACTERISTICS STUDY OF LIQUID FUEL FROM PYROLYSIS OF POLYETHYLENE PLASTIC WASTE

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Graphical abstract
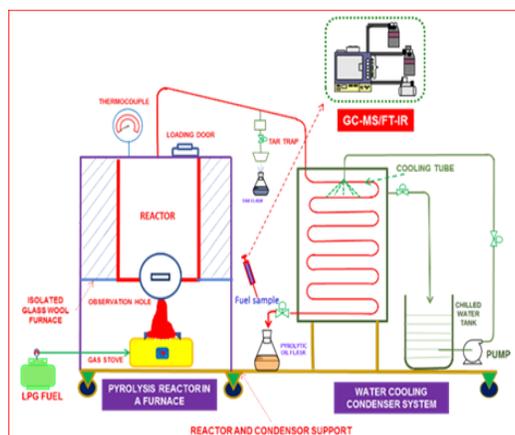
Abstract

Polyethylene plastic waste was selected as pyrolysis feedstock. This plastic waste is not recycled mechanically and is abundantly available at the landfill. The plastic-type of low and high-density polyethylene (LDPE and HDPE) was converted into pyrolysis liquid fuel (PLF). This study aims to characterize the physicochemical properties of the PLF to attest to its potential use as a kerosene fuel for household purposes. The PLF was generated from the collecting of household plastic waste through pyrolysis. A design of the simple non-catalytic semi-batch reactor was applied to pyrolyze this plastics waste into PLF at about 360 °C and isothermal residence time up to about 1 hour. The high enough PLF yield of 50.3% (v/w) and 77.0% (v/w) was obtained from LDPE and HDPE plastics waste, respectively. The dominance of alkane (CH) and alkenes (C=C) functional groups of PLF and commercial kerosene fuel was analyzed by the Fourier transform infrared spectroscopy (FT-IR) spectra. Gas Chromatography-Mass Spectrometer (GC-MS) analysis indicates that most PLF substances in the form of tetradecane ($C_{14}H_{30}$), pentadecane ($C_{15}H_{32}$), hexadecane ($C_{16}H_{34}$), octadecene ($C_{18}H_{36}$), eicosane ($C_{20}H_{42}$) are similar to commercial kerosene substances. The combustion properties of this PLF are so similar to the standard values of the kerosene fuel. The combination of thermal efficiency, η_T using wick stove and PLF from LDPE and HDPE of 45.66% and 32.37%, respectively was obtained in this work. The results of this study provide an innovative scientific contribution in the term of PLF characterization. The PLF is in the kerosene hydrocarbons range, so that it is suitable to be used as fuel for household needs in rural communities.

Keywords: Hydrocarbon range, kerosene, liquid fuel, polyethylene, pyrolysis

1.0 INTRODUCTION

In developing nations like Indonesia, plastic trash plays a significant role in the composition of household waste in municipal solid waste (MSW). The volume of plastic waste produced by the whole community throughout Indonesia reaches 30.000 m^3/day. While in West Java, especially in the City of Cimahi, the volume of plastic waste produced is 91.4-117.3 m^3/day [1]. Polyethylene (PE) plastic type of low and high-density polyethylene (LDPE and HDPE) is the major component of municipal plastic waste (MPW) from household waste in this city [2]. Polyethylene plastic is the most abundant type of plastic with a composition of more than 90% of MPW [3, 4]. Plastic bag and commercial products packaging plastic are an example of LDPE type plastic. Detergent bottles, waste bags, plastic shopping, toys, milk bottles, oil containers are HDPE type. This polyethylene solid waste (PSW) from MPW is not all recyclable via conventional mechanical or thermal means recycling techniques to recover the medium value range products. By the reason of their contamination with dirt, paper labels, and several other reasons. Comparable to conventional fuels, plastic solid waste (PSW) has a higher calorific value of around 40-50 MJ/kg[3]. Therefore, thermochemical conversion technologies, specifically pyrolysis is one promising technique for the management of PSW due to significant advantages over the others, such as incineration and gasification [5, 6].

PSW can be converted into a wide range of hydrocarbons product. The liquid fraction obtained through PSW pyrolysis into the form of gasoline range hydrocarbons (C_4-C_{12}), kerosene (C_{10}-C_{18}), diesel (C_{12}-C_{23}), motor oil (C_{23}-C_{40}), etc [5, 7]. The high calorific value of pyrolysis liquid fuel (PLF) from the PSW pyrolysis process is comparable to commercial fuels. As a result, the usage of PSW for energy recovery has become a superior option for resolving skewed environmental issues as well as a replacement for domestic energy demands. This was the reason why LDPE and HDPE wastes were selected as pyrolysis feedstock. Converting PSW into pyrolysis oil as fuel can be performed in slow pyrolysis (i.e., residence time longer than 1 h and low range temperature of 300-900 °C) will attain the oil yields of 45–50% [8]. Some researchers reported that the amount of pyrolytic oil yield could be increased through the pyrolysis of individual plastic waste, types of reactors and their support units, and the catalysts utilized [5, 9]. Previous researchers have also studied and conducted experiments to convert plastic waste into liquid fuel [7, 10], but only a few authors have studied the pyrolysis oil as fuel on its application using domestic cooking wick stoves as a substitute for conventional kerosene fuel [11, 12]. In addition, most of the pyrolysis processes were carried out using electricity as a heat source which makes it uneconomical.

In this study, a good condensation unit also has been experimentally proved in enhancing the amount of oil fraction from individual plastic pyrolysis [1, 2]. Converting PSW into pyrolysis oil as fuel, assessed and characterized the yield and quality of this fuel in its utilization to replaced kerosene for domestic purposes is the scope of the research. The characterization of the hydrocarbon range of kerosene fuels and the combustion performance of the fuel-stove combination will contribute to scientific innovations. In further research, organic municipal solid waste (MSW) other than plastic will be utilized as a thermal source of the pyrolysis process. The use of various catalysts derived from widely natural resources in pyrolysis is also one of the new things in further research.

2.0 METHODOLOGY

In this work, the pyrolysis liquid fuel (PLF) was produced by the thermal pyrolysis using a small simple pilot-scale batch pyrolysis reactor in the absence of air and without any catalyst. The reactor was constructed of stainless steel and insulated using glass wool and with a heating system obtained from the combustion of liquid petroleum gas (LPG) that enable it to achieve a high temperature of about 360 °C. The inner diameter of the reactor was 255 mm and height of 328 and capacity 15 L. A thank containing flowing water chiller as a tube-type condenser with 150 cm length was coupled to the end of the reactor, as sketched in Figure 1.
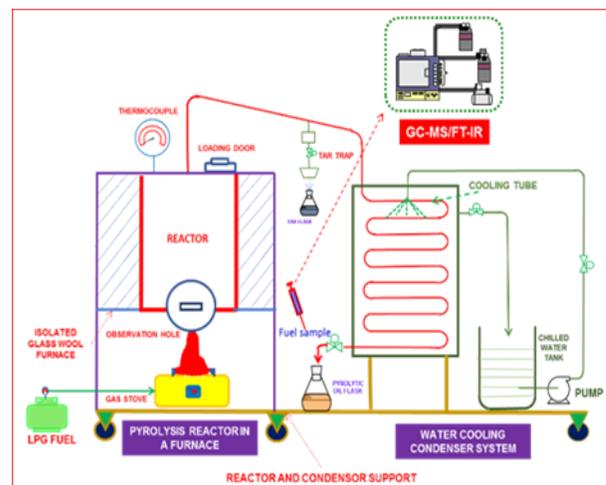
Figure 1 The pilot-scale batch pyrolysis reactor

The polyethylene plastics type was chosen as feedstock for the pyrolysis process due to moderate temperatures degradation (200 °C-600 °C) and major contains MPW in Cimahi City. The other types of plastic such as polypropylene (PP) and polyvinyl chloride are harder to degrade under pyrolysis conditions and produce harmful gases [1, 7]. The collected plastic waste samples of grocery bags, drinking or juice cups, etc. were mainly made of

polyethylene (PE). These waste plastics were cut into small pieces of about 2 cm² and used individually as pyrolysis feedstock. An amount of 300 g of polyethylene plastics waste was fed into a closed batch pyrolysis reactor through a loading door at the top of the reactor.

The physical and combustion properties of PLF were investigated in order to determine the qualities and quality of PLF fuel products. PLF's physical qualities included density and viscosity. These physical properties were measured using volumetric glassware and hydrometer, respectively according to appropriate procedures. The obtained value of PLF density and viscosity was used to determine the oil energy content (heating value) of the oil according to a widely used and high accuracy correlation equation [13, 14]. ASTM D92-2005 of Cleveland open cup standard test method was adopted to evaluate the combustion properties of smoke point, flash point, auto-ignition point [15].

The chemical composition of the PLF collected from the whole pyrolysis of plastic waste was analyzed using a Bruker Fourier Transform Infrared Spectroscopy (FT-IR) and Gas Chromatography-Mass Spectroscopy (GC–MS). The spectrum measurements as the peak identification of the various characteristic functional group composition of PLF were identified using FT-IR resolution of 4 cm⁻¹ and the range of 400-4000 cm⁻¹. GC-MS of Hawlett-Packard HP 7890 with a 5975-quadrupole detector was used to analyse the chemical compounds of PLF. The functional group and chemical compounds present in the PLF were studied and compared to the FTIR spectrum results and compounds analysed of conventional kerosene fuel. PLF was utilized directly as fuel using a wick stove to evaluate the combustion performances. The water-boiling test (WBT) method was adopted to calculate thermal efficiency (energy recovery for cooking) of the fuel-stove-pot combination [16]. The flame temperature of the PLF combustion was measured according to the probe thermometry method.

3.0 RESULTS AND DISCUSSION

The product yield of PLF is one of the most important parameters in pyrolysis energy recovery. Pyrolysis of 300 grams of HDPE waste plastic type yielded 231 mL of PLF after total degradation duration of 94 minutes. With a total operation period of 35 minutes, 151 mL of PLF was produced from pyrolysis of 300 grams LDPE waste plastic-type (Figure 2).

1. PLF from HDPE
2. PLF from LDPE

Figure 2 The collected PLF from waste plastic pyrolysis

HDPE waste plastic produced a higher yield than LDPE plastic waste. The greater HDPE density of about 0.941-0.965 kg/m³ rather than the LDPE density of about 0.91-0.94 kg/m³ due to the contain greater hydrocarbon chains [17]. Hence, it was possible that the greater the density of the plastic, the more the quantity of PLF produced. The density, hardness, and solidity of HDPE plastic types are greater than the type of HDPE plastic which causes HDPE melting point of 132 ˚C is greater than the melting point of LDPE of 111 ˚C [18]. The melting point of the type of plastic affects the ease of thermally degrading. The higher the melting point of plastic types can also lead to the bonding of large molecules of carbon chains, C and hydrogen, H is more difficult to separate by thermal pyrolysis [17]. The HDPE plastic is more difficult to be degraded thermally and it takes a longer time for pyrolysis to achieve yield completely as presented in Table 1. The first droplet of PLF for HDPE and LDPE plastics was achieved in 30 and 10 minutes, respectively. The distinction might be probably caused by HDPE type plastics was more difficult to vaporized (degrade) than LDPE plastic-type.

Table 1 Pyrolysis products yield

Plastic-type			Product yield				Residue	
	t_f (min.)	T_f (˚C)	PLO		Wax			
(300 g)			mL	% (v/w)	mL	% (v/w)	g	% (w/w)
HDPE	94	360	231	77	23	7.7	16.7	5.6
LDPE	35	350	151	50.3	42	14	41.3	13.8

Process temperature is also one of the most important factors related to influencing the quantity and quality of PLF. The higher the operating temperature, the faster the pyrolysis process takes place. Long chain hydrocarbons from plastic waste will quickly degrade into shorter carbon chains to become the desired PLF [4]. As operation time goes by, the pyrolysis temperature increases due to heating and induces the greater PLF volume and product yield for both types of HDPE or HDPE. In this work, the pyrolysis oil products were separated into two phases, namely as PLF and as wax by decantation treatment, while the undegradable plastic wastes were collected as a residue.

The maximum PLF yields of plastic waste pyrolyzing were achieved at the final of fully complete pyrolysis time, t_f, and average constant of pyrolysis temperature, T_f. The higher PLF yield of 77% (v/w) was obtained from HDPE waste plastic degradation. While LDPE pyrolysis only produces a PLF yield of 50.3% (v/w) (Table. 1). Kusrini *et al*. report their work on the pyrolysis of 500 g of HDPE plastic waste using a simple reactor equipped with an electric coil heater that produces pyrolysis oil of around 300 mL or about 60% yield [19]. The Better results from this work may be due to the quite large capacity of the condenser used and the treatments

including washing, size reducing, and first drying of plastic waste that would be used for the pyrolysis process so that the results get more leverage.

To be compared with the results of previous studies conducted by Suhartono *et al.* [1, 2], in this study only PLF of HDPE was analyzed using FT-IR to find out the pyrolysis liquid fractions contain that represented by the hydrocarbon functional group. Various chemical/functional groups present in PLF of HDPE were characterized by identifying the results of FT-IR spectra analysis. Figure 3 shows the FT-IR spectra of the PLF of HDPE that represent the functional group's composition. The differences in the determination of the FTIR spectra of PLF of HDPE are summarized in Table 2.
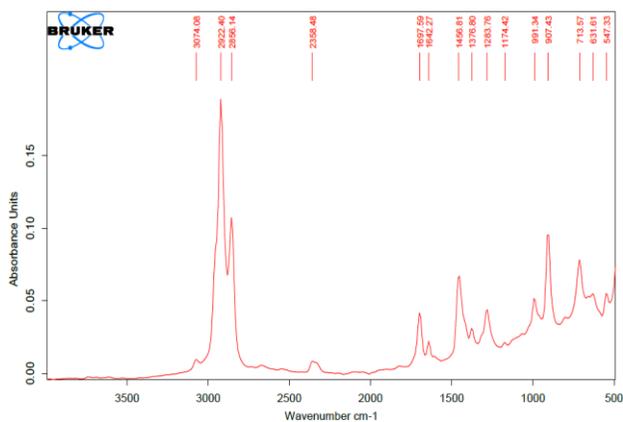
Figure 3 FT-IR spectra of the PLF of HDPE

The acquired results provided in Table 2 revealed 17 functional groups which are a mixture of aliphatic (saturated and unsaturated) and small aromatic groups of hydrocarbon compounds. The distinct signature of the FTIR spectrum of PLF is the presence of the predominant alkane and alkene groups. Table 2 can be explained as follows; the functional groups with peaks identified at wavelength from 1350-1470 cm^{-1} and 2850-2960 cm^{-1} signify the presence of stretching alkanes. The peaks identified at wavelength from 675-870 cm^{-1} and 3020-3080 cm^{-1}, 675-870 cm^{-1} and indicate the presence of stretching alkynes and C=C stretching alkynes, respectively. A few of aromatic ring was designated by the peak at wavelength 1283,64 cm^{-1} and 1697,62 cm^{-1}. The remain peaks correspond to stretching aldehydes, tertiary alcohols, stretching esters, and amine wagging. These results are exactly similar to the results of previous studies reported by Suhartono *et al.* [1, 2]. Similar results to this work have also been reported by many previous researchers [7, 20]

Similar FTIR spectra results between commercial kerosene and HDPE are provided from previous results as reported by Suhartono *et al.* [1]. The functional groups of kerosene are aliphatic groups of substances. The identified peaks associated with the presence of alkanes: C–H stretching-1402.25 cm^{-1} and 2856.58 cm^{-1}; alkene: C=C stretching-1642.54 cm^{-1}; aromatic compounds (aromatic: C–C stretching in ring; 1093.64 cm^{-1}; amines: N–H waging- 908.96 cm^{-1}, 3390.86 cm^{-1}, 3417.86 cm^{-1}, and 3444.87 cm^{-1}; carboxylic acids; O-H stretching- 3251.98 cm^{-1}, 3390.86 cm^{-1}, 3417.86 cm^{-1}, 3444.87 cm^{-1}; and an additional peak of tertiary alcohols: O-H stretching- 2856.58 cm^{-1} [1]. Dollah *et al.* also revealed that kerosene consists mainly of C_6H_{14} which implies only carbon-carbon (C-C) and carbon-hydrogen (C-H) bonds [21].

Table 2 FTIR signature of PLF from HDPE pyrolysis

Nature of functional group	Wavelength (cm-1)	Vibration band assignment
	2922,41	C-H stretching Asymmetric
Alkanes	2856,09	C-H stretching
	1456,64	C-H stretching
	1376,68	C-H stretching
Alkenes	3073,91	C-H stretching Asymmetric
	801,83	C-H bending
	713,67	C-H bending
Alkenes	1697,62	C=H stretching
	1642,28	C=H stretching
Aldehyde ketone	1697,62	C=O stretching
Alcohols	3073,91	O-H stretching
Phenol (hydrogen stretch)	2922,41	O-H stretching
	2856,09	O-H stretching
Carboxylates Acid	3073,91	C=O stretching
Amine	1283,64	C-N wagging
Aromatic	1283,64	C-C stretching in the ring
	1697,62	C-C stretching in the ring

The above description shows that commercial kerosene contains highly aliphatic and carboxylic acids hydrocarbon functional groups with negligible aromatic hydrocarbons. PLF of HDPE on the other hand, contains a significant fraction of aliphatic hydrocarbons functional groups with only the peak O-H carboxylic acid stretching-3073.91 cm^{-1}. Since there were no functional groups of aromatic rings in the kerosene, the presence of aromatics functional groups of C-H stretching-ring-1283,64 cm^{-1} and 1697,62 cm^{-1} is enriched for PLF of HDPE as kerosene fuel hydrocarbon range. It can conclude that polyethylene polymers can be converted into hydrocarbons in the kerosene range.

Because of its high aliphatic hydrocarbon similarity, HDPE PLF has potential to be used as an alternative fuel to kerosene. This PLF is produced under low-temperature pyrolysis from polyethylene plastic to address plastic waste utilization and kerosene fuel substitution. The above discussion of the research results is following the results of the previous research [1] and a quite good congruence with recent studies [3, 7].

The findings of PLF's GC-MS analysis reveal a variety of compounds, each of which is represented by a

number of peaks in the GC-spectra, each of which describes a chemical substance found in PLF. The mass spectra GC-MS was created utilising the National Institute of Standards and Technology (NIST) library's mass spectra database. The chromatograms of HDPE and LDPE pyrolysis fuel (PLF) revealed 114 and 92 peaks, respectively, in this study. Figure 4 shows the results of the PLF of HDPE analyzed with the GC-MS. This appearance spectra have a similar band shape with kerosene from the previous study [1], which is indicated by the majority of carbon-carbon (C-C) and carbon-hydrogen (C-H) bonds.
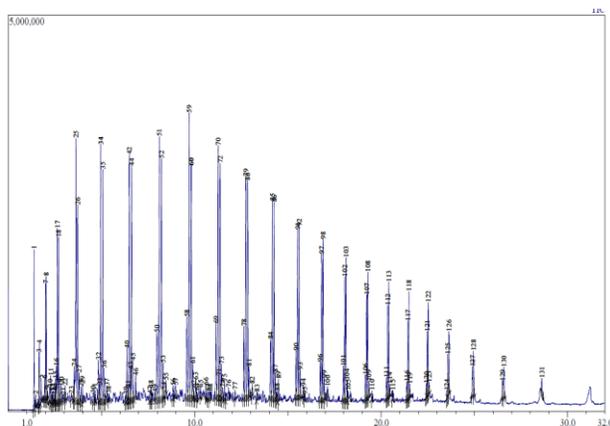
Figure 4 GC-MS spectra of PLO from HDPE pyrolysis

Figure 4 denote the GC-MS analysis results of the whole chromatograms of PLF of HDPE which indicate all identified substance's peak areas. It exhibits that the main substances detected are assigned by the highest peak area. Aliphatic hydrocarbons (alkanes and alkenes) in the $C_{11}H_{20}$ range are mostly present in PLF of HDPE. The 14 major substances confirmed for PLF of HDPE, particularly peak areas detected of more than 2% are listed in Table 3.

Table 3 GC-MS results for PLF from pyrolysis of HDPE

Retention time (min.)	Area (%)	Name of substance	Molecular formula
3.724	2.01	n-Dodecane	$C_{12}H_{26}$
4.958	2.90	n-Undecanol	$C_{11}H_{24}O$
5.070	2.55	n-Undecane	$C_{11}H_{24}$
6.489	2.95	n-Dodecanol	$C_{12}H_{26}O$
6.612	2.71	n-Tetradecane	$C_{14}H_{30}$
8.098	3.31	n-Tridecanol	$C_{13}H_{28}O$
8.220	3.08	n-Tetradecane	$C_{14}H_{30}$
9.703	3.68	1-Tetradecanol	$C_{14}H_{30}O$
9.818	3.08	n-Tetradecane	$C_{14}H_{30}$
11.257	3.40	1-Octadecene	$C_{18}H_{36}$
11.365	2.97	n-Hexadecane	$C_{16}H_{34}$
12.746	3.00	1-Octadecene	$C_{18}H_{36}$
12.846	2.79	n-Hexadecane	$C_{16}H_{34}$
14.258	2.46	n-Eicosane	$C_{20}H_{42}$

It is confirmed that 14 of the major's substances out of all 114 substances identified, presence mostly aliphatic and aromatic substances as revealed by the results of FT-IR and GC-MS analysis. Table 3 indicates main substances detected reveal the presence of hydrocarbons substances in the C_{11}-C_{20} range. The latest similar work has been carried out by Ajibola *et al.* [22]. The cracking of LDPE and HDPE plastic wastes into liquid fuel was executed using a non-catalytic stainless-steel batch reactor at a temperature of 230 °C. No major substance differences were detected in the liquid fuel oil produced from the two types of plastic and most of the alkene and aromatics in the C_{13}-C_{20} hydrocarbon range. The 7 major substances detected at the peak areas of more than 3% were 2-Tetradecene ($C_{14}H_{28}$), 1-Tridecene (C13H26), 3-Heptadecene ($C_{17}H_{34}$), 1,13-Tetradecadiene ($C_{14}H_{26}$), Dibutyl Phthalate ($C_{16}H_{22}O_4$), 1,19-Eicosadiene ($C_{20}H_{38}$) [22]. The other similar result as fuel oil produced from the pyrolysis of HDPE plastic waste at 450 °C was revealed by Patil *et al.* [23]. The FT-IR spectra in Figure 3 also contain the major functional groups of aliphatic (saturated and unsaturated) hydrocarbon substances. This PLF was also consisting predominantly of the $C_{12}H_{20}$ hydrocarbons range.

The results of GC-MS analysis of PLF from LDPE plastic waste pyrolysis revealed complex hydrocarbons with a high proportion of aliphatic and slightly aromatic hydrocarbons. The 15 primary identified chemicals are given in Table 4 as the highest peak area.

Table 4 GC-MS results for PLF from pyrolysis of LDPE

Retention time (min.)	Area (%)	Name of substance	Molecular formula
9.697	3.51	1-Tetradecanol	$C_{14}H_{30}O$
11.251	3.41	1-Octadecene	$C_{18}H_{36}$
12.739	3.26	1-Octadecene	$C_{18}H_{36}$
11.358	3.04	Pentadecane	$C_{15}H_{32}$
14.159	3.03	1-Octadecene	$C_{18}H_{36}$
12.839	2.96	Eicosane	$C_{20}H_{42}$
14.250	2.9	Eicosane	$C_{20}H_{42}$
8.093	2.86	1-Tridecene	$C_{13}H_{26}$
4.950	2.84	1-Undecanol	$C_{11}H_{24}O$
15.513	2.72	1-Octadecene	$C_{18}H_{36}$
9.810	2.7	Tetradecane	$C_{14}H_{30}$
15.595	2.7	Eicosane	$C_{20}H_{42}$
3.626	2.62	1-Decene	$C_{10}H_{20}$
6.482	2.58	1-Dodecanol	$C_{12}H_{26}O$
16.880	2.57	Hexacosane	$C_{26}H_{54}$

1-Tetradecanol ($C_{14}H_{30}O$) was recorded as the most substance according to the largest percentage area in PLF of LDPE. As a comparison 1, 13-Tetradecadiene ($C_{14}H_{26}$) and 1-Dodecene ($C_{12}H_{24}$), respectively was the most substance in pyrolysis oil of LDPE reported by Ajibola *et al.* and Patil *et al.* [22, 23]. These substances have similarities in the range of C_{11}-C_{14} fuel hydrocarbons and are close to the quality of household kerosene fuels. In general, the quality of the fuel will be affected by the hydrocarbon composition content in the range of $\geq C_{20}$ as a saturated hydrocarbon. In this study, the

substance which has the composition of the range was n-icosane ($C_{20}H_{42}$). Meanwhile, 1.19-Eicosadiene ($C_{20}H_{38}$) and Eicosane ($C_{20}H_{42}$) are the hydrocarbon composition contents of C_{20} in pyrolysis oil reported by previous researchers [22, 23]. The content of saturated hydrocarbon substances in pyrolytic fuel is influenced by the high-temperature pyrolysis process. The higher temperature pyrolysis facilitates the degradation of carbon chains and accelerates the reaction rate. Thus, high temperatures are needed to facilitate the decomposition of HDPE long linear chain, low branching with a high degree of crystallinity and strength to produce shorter carbon chains [7, 24]. This work has less saturated substance content compared to the Ajibola study, but a little more than the Patil study due to the operating conditions of pyrolysis temperatures [22, 23]. Pyrolysis oil in the kerosene hydrocarbons range resulting from the pyrolysis process of polyethylene plastic waste has also been widely reported by researchers [3, 23]. The GC-MS PLF results of LDPE plastic waste pyrolysis in Table 4 are also confirmed by the results of a study by Ajibola et al. [22]. The nine major substances in liquid fuel produced from LDPE plastic at 260 °C containing; 1-Tridecene ($C_{13}H_{26}$), 7-Dodecen-1-ol acetate ($C_{14}H_{26}O_2$), 2-Tetradecene ($C_{14}H_{28}$), 14-methyl-(Z)-8-hexadecen-1-ol, ($C_{17}H_{34}O$), 1-Pentadecene ($C_{15}H_{30}$), Dibutyl Phthalate ($C_{16}H_{22}O_4$), cis-3-Heptadecene ($C_{17}H_{34}$), 1-Octadecyne ($C_{18}H_{34}$) [22]. The paraffin substances according to the formula C_nH_{2n+2} are present as pentadecane $C_{15}H_{32}$ and Tetradecane $C_{14}H_{30}$. Naphthenic substances molecules also exist as 1-Octadecene $C_{18}H_{36}$, 1-Tridecene $C_{13}H_{26}$, and 1-Decene $C_{10}H_{20}$ following the C_nH_{2n} formula. Several alcohol substances of 1-Tetradecanol, 1-Undecanol, 1-Dodecanol also include. The results of this study were also confirmed by Sarker et al. stated the results of GC-MS analysis of fuel oil pyrolysis indicated alkane group long-chain hydrocarbons and alkene group substances in the range C_5 to C_{28} [25]. The fuel oil produced from LDPE plastic pyrolysis at a temperature of 340-365 °C contains 6 main substances of tetradecane ($C_{14}H_{30}$), tridecane $C_{13}H_{26}$, eicosane $C_{20}H_{42}$, hexadecane ($C_{16}H_{34}$), pentadecane ($C_{15}H_{32}$), decane ($C_{10}H_{22}$) [25]. Eicosane ($C_{20}H_{42}$) and Hexacosane ($C_{26}H_{54}$) are hydrocarbons in the $\geq C_{20}$ range of saturated substances which will affect fuel quality. These substances induce the acidity of PLF, while oxygen bonds cause an increase in the boiling point of PLF as fuel [22].

Table 5 presented the group of the hydrocarbon range related to the number of all peaks in the GC-spectra (chromatograms of 114 peaks for HDPE and 92 peaks for LDPE) and compared to the various fuels. In general, heavy fuel contains hydrocarbons composition of $>C_{20}$ as additives and impurities [20]. In this study, PLF of LDPE had the highest percentage of hydrocarbon composition $>C_{20}$ was 34.28% compared to PLF of HDPE of 16.5%. It can also be seen from Table 5 that PLF of HDPE has the closest hydrocarbon composition to kerosene with a

percentage of 40.11% because of a small difference compared to the PLF of LDPE of 37.2%. PLF from HDPE pyrolysis has similar functional groups (substances) with kerosene. PLF of HDPE is very suitable for stove fuel utilization due to relatively small impurities (heavy hydrocarbon) compared to PLF of LDPE.

Table 5 The carbon range of various fuel

Fuels	Carbon range	Composition (%)
Kerosene	C_{11}-C_{14}	100
Gasoline	C_5-C_9	100
Diesel	C_{15}-C_{19}	100
	C_{11}-C_{14}	40.11
	C_5-C_9	6.15
HDPE PLO	C_{15}-C_{19}	30.48
	$>C_{20}$	16.37
	C_{11}-C_{14}	37.11
	C_5-C_9	8.98
LDPE PLO	C_{15}-C_{19}	19.855
	$>C_{20}$	34.28

As discussed above, the PLF pyrolysis of polyethylene plastic waste tends to be similar to the kerosene fuel hydrocarbons range. To meet this hydrocarbon range, only the measured physical properties of the kerosene are used as a comparison. Some physical properties measured of PLF and kerosene fuel are summarized in Table 6.

Table 6 Physical properties of PLF and kerosene

Parameters	PLF		Kerosene
	HDPE	LDPE	
Density (g/l)	0.7902	0.7889	0.7909
Viscosity (cSt)	1.338	1.099	0.744
Flash point (°C)	48	29-32	52
Fire point (°C)	45	35	40
Autoignition (°C)	240	230	220

The density of HDPE PLF and LDPE PLF is quite similar to that of kerosene likewise, and their viscosity is comparable to that of kerosene. Slightly lower density and viscosity of PLF of LDPE may be due to the content of a small amount paraffin fraction (lower molecular weight hydrocarbon). The lowest viscosity of kerosene is since it contains a lot of aromatic fractions [5]. The viscosity of the PLF is related to the flash point of the PLF, which is the lowest temperature at which the fuel starts to vaporize. The flash point of fuel oil tends to decrease as its viscosity decreases. The fuel auto ignition temperature is the lowest temperature where fuel (vapor fuel) ignites spontaneously without a source of fire [2, 9]. Decreasing the fuel viscosity will reduce the flash point and autoignition of fuel. Thus, a low value of viscosity, flash point, and initial ignition is needed to attain the good combustion quality of fuel [26]. The physical fuel properties of the two PLF from the experiment resulted are not much different from that of kerosene (Table 6). This revealed that PLF from

plastic waste is easily vaporized and ignited as though kerosene. The produced PLF can be utilized to substitute kerosene for household heating applications using a wick stove or pressurized stove.

In order to test use of PLF as fuel, a wick stove based on energy recovery was used to boil water. The thermal efficiency of 45.66% and 32.37 % were obtained for the utilized as the fuel of PLF of LDPE and HDPE, respectively. The fuel consumption rate (FCR) of 0.29 L/h for LDPE PLF and 0.19 L/h for PLF of HDPE. The maximum flame temperature that can be achieved for each fuel was 920 °C. In comparison, the efficiency of 20%-32% was obtained from the combination of stove and cooking oil fuel with an FCR of ±1.50 L/h [27]. Thermal efficiency varied in the range of 36.2- 28.6% for conventional cookstove was reported by Kaushik and Muthukumar [28].

4.0 CONCLUSION

The description above reveals that the pyrolysis process temperature of below 360 °C could produce a PLF that corresponds to the kerosene fuel hydrocarbons range with a high oil yield. The characterization and physical properties of the PLF perfectly meet kerosene fuel and be able to replace it as fuel for the domestic wick stove.

Acknowledgement

References

[1] Suhartono. 2019. Kerosene-like Fuel Characteristics from Municipal Solid Plastics Waste Pyrolytic Oil for Domestic Purposes. *IOP Conf. Series: Materials Sci. and Eng*. 620: 1-12. DOI:10.1088/1757-899X/620/1/012102.

[2] Suhartono, Kusumo, P., Romli, A., Aulia, M. I. and. Yanuar, E. M. 2018. Fuel Oil from Municipal Plastic Waste through Pyrolysis with and without Natural Zeolite as Catalysts. *E3S*. 73: 1-6. DOI: https://doi.org/10.1051/e3sconf/20187301021.

[3] Al-Salem, S. 2019. Thermal Pyrolysis of High Density Polyethylene (HDPE) in a Novel Fixed Bed Reactor System for the Production of High Value Gasoline Range Hydrocarbons (HC). *Process Safety and Environmental Protection*. 127: 171-179. DOI: https://doi.org/10.1016/j.psep.2019.05.008.

[4] Maryudi, Setyawan, M., Noni and Yahayor, S. 2015. Essential Characteristics of Plastics Waste for Pyrolysis Process: Comparison of Selected Packaging Plastic and PVC. *Jurnal Teknologi*. 77(23): 41-45. DOI: https://doi.org/10.11113/jt.v77.6685.

[5] Dwivedi, P., Mishra, P., Mondal, MK., and Srivastava, N. 2019. Non-biodegradable Polymeric Waste Pyrolysis for Energy Recovery. *Heliyon*. 5: 1-15: DOI: https://doi.org/10.1016/j.heliyon.2019.e02198.

[6] Wu, S. L., Kuo, J. H., and. Wey M. Y. 2019. Thermal Degradation of Waste Plastics in a Two-stage Pyrolysis-catalysis Reactor Over Core-shell Type Catalyst. *Journal of Analytical and Applied Pyrolysis*. 142: 1-6. DOI: https://doi.org/10.1016/j.jaap.2019.104641.

[7] Miandad, R., Barakat, M., Aburiazaiza, AS, Rehan, M., Ismail, I., and Nizami, A. 2017. Effect of Plastic Waste Types on Pyrolysis Liquid Oil. *International Biodeterioration & Biodegradation*. 119: 239-252. DOI: http://dx.doi.org/10.1016/j.ibiod.2016.09.017.

[8] Bezergianni, S., Dimitriadis, A. and Faussone, G. C. 2017. Alternative Diesel from Waste Plastics. *Energies*. 10(1750): 1-12. DOI: 10.3390/en10111750.

[9] Sharuddin, S., Abnisa, F., Daud, W. and Aroua, K. 2017. Pyrolysis of Plastic Waste for Liquid Fuel Production as Prospective Energy Resource. *IOP Conf. Series: Materials Science and Engineering*. 334: 1-8. DOI: 10.1088/1757-899X/334/1/012001.

[10] Thahir, R., Altway, A., Juliastuti, S. R., and Susianto. 2019. Production of Liquid Fuel from Plastic Waste using Integrated Pyrolysis Method with refinery Distillation Bubble Cap Plate Column. *Energy Reports*. 5: 70-77. DOI: https://doi.org/10.1016/j.egyr.2018.11.004.

[11] Brown, L. J., Collard, F. X., and Görgens, J. 2019. Fast Pyrolysis of Fibre Waste Contaminated with Plastic for Use as Fuel. *Journal of Analytical and Applied Pyrolysis*. 138: 261-269. DOI: https://doi.org/10.1016/j.jaap.2019.01.007.

[12] Budsaereechai, S., Hunt, AJ., and Ngernyen, Y. 2019. Catalytic Pyrolysis of Plastic Waste for the Production of Liquid Fuels for Engines. *RSC Advances*. 9: 5844-5857. DOI: 10.1039/c8ra10058f.

[13] Suhartono, Suharto and Ahyati, A. E. 2017. The Properties of Vegetable Cooking Oil as a Fuel and Its Utilization in a Modified Pressurized Cooking Stove. *IOP Conf. Series: Earth and Environmental Science*. 105: 1-10. DOI: 10.1088/1755-1315/105/1/012047.

[14] Demirbas, A. 2000. A Direct Route to the Calculation of Heating Values of Liquid Fuels by Using Their Density and Viscosity Measurements. *Energy Conversion & Management*. 41: 1609-1614. DOI: 10.1016/S0196-8904(00)00012-1.

[15] ASTM, D. 2005. Standard Test Method for Flash and Fire Points by Cleveland Open Cup Test. *ASTM Int*. Barr Harbor Drive. Laurentian University Pursuant. 1-10.

[16] Honkalaskar, V. H., Bhandarkar, U. V., and Sohoni, M. 2013. Development of a Fuel Efficient Cookstove through a Participatory Bottom-up Approach. *Energy, Sustainability and Society*. 3(16): 1-21. DOI: 10.1186/2192-0567-3-16.

[17] Anene, A. F., Fredriksen, S. B., Sœtre, K. A., and Tokheim, L. A. 2018. Experimental Study of Thermal and Catalytic Pyrolysis of Plastic Waste Components. *Sustainability*. 10(3979): 1-11. DOI: 10.3390/su10113979.

[18] Das, P., and Tiwari. 2018. Valorization of Packaging Plastic Waste by Slow Pyrolysis. *Resources, Conserv & Recy*. 128: 69-77.
DOI: http://dx.doi.org/10.1016/j.resconrec.2017.09.025.

[19] Kusrini, E., Supramono, D., Degirmenci, V., Pranata, S., Bawono, A. A., and Ani, F. N. 2018. Improving the Quality of Pyrolysis Oil from Cofiring High Den. Plastic Waste and Palm Empty Fruit Bunches. *International Journal of Technology*. 7: 1498-1508. DOI: https://doi.org/10.14716/ijtech.v9i7.2531.

[20] Tulashie, S. K., Boadu, E. K., and Dapaah, S. 2019. Plastic Waste to Fuel Via Pyrolysis: A Key Way to Solving the Severe Plastic Waste Problem in Ghana. *Thermal Science and Engineering Progress*. 11: 417-424. DOI: https://doi.org/ 10.1016/j.tsep.2019.05.002.

[21] Dollah, A., Rashid, Z., Othman, N. H., Nurliyan, S., Hussein, C. M., Yusuf, S. M., Japperi, N. S. 2018. Effects of Ultrasonic Waves during Water Flooding for Enhanced Oil Recovery.

International Journal of Engineering & Technology. 7(3.11): 232-236. DOI: 10.14419/ijet.v7i3.11.16015.

[22] Ajibola, A. A., Omoleye, J. A., and Efeovbokhan, V. E. 2018. Comparative Study of the Chemical Compositions of Liquid Fuel from Thermal Cracking of Low and High-density Polyethylene Plastic Waste. *IOP Conf. Series: Materials Science and Engineering*. 413: 1-9: DOI: 10.1088/1757-899X/413/1/012014.

[23] Patil, L., Varma, A. K., Singh, G., and Mondal, P. 2018. Thermocatalytic Degradation of High Density Polyethylene into Liquid Product. *J Polym Environ*. 26: 1920-1929. DOI: 10.1007/s10924-017-1088-0.

[24] Istoto, E. H., Widayat and Saptadi, S. 2019. Production of Fuels from High Density Polyethylene and Low Density Polyethylene Plastic Wastes via Pyrolysis Methods. *Iranian (Iranica) Journal of Energy & Environment*. 10(3): 185-189. DOI: 10.5829/ijee.2019.10.03.04.

[25] Sarker, M., Rashid, M. M., and Rahman, M. S. 2012. Low Density Polyethylene (LDPE) Waste Plastic Transformation into Renewable Heavy Fuel using Thermal Cracking. *World Environment*. 2(6): 140-147. DOI: 10.5923/j.env.20120206.06.

[26] Mokhtar, M. O. M., Ja'afar, M. N. M. Yusoff, M., Said, M., Rahim, M. R., and Malik, M. S. A. 2018. Combustion Performnce of Syngas from Biomass Waste in Gas Burner System. *Jurnal Teknologi*. 80(5): 189-195. DOI: https://doi.org/10.11113/ jt.v80.12431.

[27] Suhartono, Putri, T. A., and Fauziah, L. 2017. Performance Evaluation of a Pressurized Cooking Stove Using Vegetable Cooking Oils as Fuel. *International Journal on Advanced Science, Engineering and Information Technology*. 7(4): 1255-1261. DOI: http://dx.doi.org/10.18517/ijaseit.7.4.2430.

[28] Kaushik, L. K., and Muthukumar, P. 2020. Thermal and Economic Performance Assessments of Waste Cooking Oil/Kerosene Blend Operated Pressure Cook-stove with Porous Radiant. *Energy*. 206: 1-15. DOI: https://doi.org/ 10.1016/j.energy.2020. 118102.