Kerosene Like Fuel Characteristics from Municipal Solid Plastics Waste Pyrolytic Oil for Domestic Purposes

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Abstract. The aims of the research are to characterized pyrolytic oil as fuel and utilize it for heating purpose. The pyrolytic oil was characterized to decide whether this oil can be used as fuel for the desired application or not. The highest pyrolytic fuel yield of about 67.48% w/w was obtained from converting of 3000 g of plastic waste at pyrolysis time, t_{opt}, of 240 minutes and a pyrolysis temperature of 360 °C in a small pilot-scale batch reactor. The characteristic of pyrolytic fuel had an average value of density and viscosity were 771 kg/m³, 1.031 cSt, respectively. The combustion quality as other characteristics of the fuel was obtained as heating value, flash point and auto-ignition point of 37.996 MJ/kg, 48 °C and 240 °C, respectively. The similar functional groups of pyrolytic oil and commercial kerosene fuel were found in Fourier-transform infrared spectroscopy (FTIR) spectrum. This pyrolytic oil provided a higher flame temperature of 1300 °C and a higher thermal efficiency of 33% upon utilized as fuel using a modified pressurized cook stove. These pyrolytic oil’s parameters are close to the standard values of the kerosene fuel.

1. Introduction

The increased amount of municipal solid waste (MSW) resulting in increasing environmental, health and economic problems in Indonesia. Plastic waste is a type of non-biodegradable MSW that is difficult to decompose naturally. About 30,000 m³/day of plastic waste generated throughout Indonesia. The average Indonesian people produce 0.5 kg/day of waste and 13% of which is a plastic waste. In Cimahi City, West Java, 117.3 m³/day (70.60%) recyclable plastic, and 91.4 m³/day (6.0%) nonrecyclable plastic were produced from MSW [1]. Due to increased MSW and lack of integrated solid waste management, most of the plastic waste is not collected properly or disposed of in the proper way. Disposal of plastic waste in the landfill is no longer the proper manner. However, this plastic waste can be collected and recycled in the most environmentally friendly way by converting it into a resource. Grocery bags, bottle packing liquid milk and juice, shampoo, liquid soap and ice cream container are the example of the nonrecyclable plastic waste type of high-density polyethylene (HDPE). This plastic waste is very potential to be converted into pyrolytic oil and utilized for domestic purposes. This pyrolytic oil can be used directly as fuel for domestic purposes. This plastic waste can be converted into pyrolytic oil via thermal processes. Pyrolysis is seen as one of the promising techniques in converting solid waste (SWP) into liquid fuels.

Pyrolysis is an effective solution for treating plastic waste due to several advantages over combustion process. The direct combustion of plastic waste is considered less suitable due to toxic gases produced and high production costs. Thermal pyrolysis has a high potential for recycling,
breaking down carbon solids into flammable gases and reducing pollution. Pyrolysis can be performed at temperatures as long as it is low within the range of 300-900°C by heating in an inert atmosphere [2-5]. The plastic waste materials were degraded into volatile condensable hydrocarbon oil, solid residue (char) and gases. Depending on the pyrolysis technology, the pyrolysis of plastics waste can attain yields on average 45–50% of oil, 35–40% of gases, and 10–20% of tar [6,7]. Some researcher reported that a high amount of pyrolytic oil yield could be produced in the pyrolysis of individual plastic waste [8,9]. Gaurav et al (2014), Arumkubar and Nataraj (2017) carried out 600 g of plastic waste by low temperature at 325 °C into pyrolytic oil yield of 40% [2,5]. Syamsiro also reported the maximum oil production for HDPE at the pyrolysis temperature of 450 °C was 70.0 w/w% [10]. However, up to the present time, there has been no report on the use of pyrolytic oils that are widely used for household fuel needs. Similarly, there is no simple, inexpensive and easy to operate of the pyrolysis reactor that can be applied definitely in urban and rural communities [5,7,11].

One of the works developed to day is converting plastic waste into fuel on a par of kerosene. The processing system is through pyrolysis where plastic waste is heated at a relatively low temperature of about 300 °C to be condensed gases and cooled by cold water to obtain pyrolytic oil. The aims of the research are to characterized pyrolytic oil as fuel and utilize it for heating purpose. The high-density polyethylene (HDPE) which is available in our day to day life was non-catalytic converted into pyrolytic oil that could be used as fuel to fulfilled the daily household’s energy needs. The optimization of the fabricated pyrolytic reactor to provide the required temperature for the reaction was also found out. A modified pressurized cooking stove for vegetable cooking oil was used to utilize the pyrolytic oil product as fuel in the first trial. Suhartono et al (2017) developed this pressurized stove and provided the highest thermal efficiency of 31.57% by utilizing used cooking oil (UCO) as fuel [12]. It was reported that a small amount of ethanol is needed for start-up using this decreased the viscosity and ignition temperature of UCO to produce a flame temperature of about 900°C [13]. This pyrolytic oil was utilized as fuel using this pressurized stove substitute liquid petroleum gas (LPG) or kerosene for domestic purposes.

2. Experimental details

2.1. Non-catalytic thermal pyrolysis

The non-catalytic or thermal pyrolysis experiments were carried out using an inexpensive simple stainless steel semi-batch pyrolysis reactor with an inner diameter, thickness, and height of 25.5 cm, 0.5 cm and 32.8 cm, respectively and covered with glass wool insulator. This reactor was fabricated to provide the required reaction system temperature of about 500°C in the absence of air and did not employ any catalyst (Fig.1). The reactor was equipped with a temperature and pressure monitoring system. The process temperature was observed by laying down a thermocouple exactly on the degradation zone of a plastic waste of the reactor. Loading vantage at the top of the reactor was used to feed plastic waste. During the thermal cracking process plastic portions, the liquid pyrolytic yield increased as temperature increases and finally, when optimum temperature was achieved, the yield is fully completed. The heat source is obtained from LPG combustion using a gas burner system. Spiral copper pipe in a cylindrical tube of the water-cooled condenser was connected to the pyrolysis gas output pipe of the pyrolysis reactor where condensable gases were cooled into the pyrolytic oil.

Converting waste plastic into pyrolytic oil was carried out by a thermal cracking process without the catalyst in the reactor. Only one type of HDPE-plastic waste was used individually as feedstock in this distinctive experiment. HDPE-plastic waste was used as feedstocks in a batch process system due to moderate temperatures degradation. These HDPE plastics as oil container, toys, detergent bottles, milk bottles, trash bags and plastic bags were collected easily from local municipal waste. HDPE has the simplest structure with the crystallinity rate (70-95%) and high molecular weight (941-965 kg/m³). These plastics are easy to degrade under thermal pyrolysis and non-harmful gases product compared to other types of plastics, i.e. polypropylene (PP) and polyvinyl chloride (PVC) [14]. The properties of conventional fuel as such as gasoline, kerosene, and diesel are matched to pyrolytic oil from HDPE.
[15]. Collected solid waste plastic was cleaned using soap and water and cut into about 2 cm to fit it as feedstock on the existing reactor. Three different amounts of 1000 g, 2000g, and 3000g of HDPE-plastics waste were loaded individually into a close pyrolysis reactor at atmospheric pressure reaction system without vacuum process. The plastic waste was heated from 25 °C to a maximum of 360 °C for around 4 h. The plastic waste started to melt at 100 °C and turned into liquid slurry along with the gradual temperature rise of about 1.5 °C/min increment. The liquid slurry turned into condensable (vapourable) gaseous at about 300 °C. The vapourable gases were passed through a water-cooled unit and condensed to about 30°C. The condensable gaseous as pyrolytic oil was collected in a conical flask at each operating time interval of 30 min. The optimum operating conditions of the HDPE plastic waste pyrolysis process were achieved at 210 minutes and the temperature of the reactor was 360 °C, the yield was fully completed. The pyrolytic oil was then separated from as the black viscous organic liquid produced in the product (tar) by settling and filtering method. The volume of pyrolytic oil was measured, recorded and calculated as the product yield using Eq. 1 [8,11].

\[
\text{Yield} \left(\frac{\text{weight}}{\text{weight}}\right) = \frac{\text{Desired product (g)}}{\text{Total feed (g)}} \times 100\%
\]

(1)

**Figure 1.** Pyrolysis of plastic waste technique

**Figure 2.** HDPE plastics waste

**Figure 3.** HDPE plastics waste as feedstock of pyrolysis.
2.2. Physical and chemical properties of HDPE pyrolytic oil
The pyrolysis oil cannot be used directly as fuel and sometimes require further treatment in order to have suitable physical properties as fuel utilized. The quality of any pyrolytic oil depends on its physical properties. The suitability and the quality of any pyrolytic oil for a specific purpose can be identified from its properties. Some of the physical properties such as density and viscosity are used to evaluate the quality of the pyrolytic oil.

The density of a pyrolytic oil is defined as the mass per unit volume. The density of the pyrolytic oil was measured using pycnometer and a hydrometer at 25 °C according to the density test method ASTM D 1298. The density of the pyrolysis oil was calculated based on Eq. (2) [8,16].

\[ \rho \left( \frac{\text{kg}}{\text{m}^3} \right) = \frac{m(\text{g})}{V(\text{m}^3)} \]  

where \( \rho \) expressed in kilograms per cubic meter, \( m \) is the mass of liquid and \( V \) represents the volume of the pycnometer. The greater the pyrolytic oil density, the greater the mass of pyrolytic oil that can be stored in each reactor. The increasing density of pyrolytic oil will increase the energy content of this fuel. The energy value of fuel oil is affected by its density. Variations density of fuels will influence the energy quantity of fuels that have the same heating value. Bardalai and Mahanta (2015) reported that the normal range of density of pyrolysis oil is found as 1,000-1,240 kg/m\(^3\) measured between the temperature of 15° C and 40° C [16].

The other important property of pyrolytic oil is viscosity. Operating conditions with different parameters and different types of plastic waste will result in varying viscosity of the pyrolytic oil. The viscosity of pyrolytic oil decreases as the temperature increases. Lower viscosity of the pyrolytic oil is easier to atomize into fine droplets, vice versa as the viscosity of a liquid increases will create some disturbances atomization. The kinematic viscosity of pyrolytic oil was measured from the time for a fixed volume of liquid to flow by gravity through a capillary. Cannon Fenske capillary was used the kinematic viscosity of pyrolytic oil corresponds to test method D445-3. The petroleum industry The kinematic viscosity of this pyrolytic oil is expressed in centistokes, cSt and calculated using the below formula:

\[ \nu \text{ (cSt)} = \frac{Ct}{\nu} \]  

\( \nu \) kinematic viscosity in centistokes, cSt (mm\(^2\)/s), \( t \) the flow time (seconds) and \( C \) the calibration constant of the viscometer, cSt/s.

The chemical properties of various characteristic functional groups present in the oil were studied and identified FTIR spectrometer (Spectrum 400). The samples scanned were performed at an average signal in the range of 400–4,000 cm\(^{-1}\) with a resolution of 4 cm\(^{-1}\).

2.3. Combustion characteristics of HDPE pyrolytic oil
One of the most important properties of pyrolytic oils as fuel for a particular application is its energy content and it can be characterized by its heating value (HV). The amount of energy present in any fuel oil is indicated by this HV, as the HV of fuel increases, the more efficient of this fuel. HV of fuel is essential for the selection of fuel for any purpose. So, HV of fuel become an important parameter in fuel selection for its particular application. The HV can be divided into two types: higher heating value (HHV) and lower heating value (LHV). The HV is one of the most important parameters for estimating the combustion performance parameter, such as specific fuel consumption and thermal efficiency. The bomb calorimeter was usually used to determine the HV. Dulong formula also can be used to calculate the based on ultimate analysis of fuel. While in this work, the HV is predicted on the basis of correlation with the density or the viscosity of its pyrolytic oil. The energy content of HDPE pyrolytic oil as HHV (in MJ/kg) related to its the density was calculated according to Eq. (4) [17,18].

\[ \text{HHV} = -0.0382\rho + 74.468 \]  

(4)
HHV heating of pyrolytic oil, \((MJ/kg)\) and \(\rho\) density, \((kg/m^3)\). The HHV prediction models that correlate the heating value with fuel oil viscosity was also used to predict the pyrolytic oil employing the below equation [17]:

\[
HHV = 0.6154v + 38.998
\]

These predicting equations provide values which very closely match with the measured ones [17,18]. Applying these empirical equations were also no cost, easier, faster and effective.

The other combustion characteristics of the HDPE pyrolytic oil measured at this work are the smoke point, flash point, ignition point, and flame temperature. The smoke point is the temperature of a combustion process at which pyrolytic oil starts to break down at a flame height to generate bluish smoke. The lowest temperature of a pyrolytic oil at which an oil generates combustible vapors momentarily takes to fire is defined as the flash point. While the ignition temperature of the pyrolytic oil was determined as the lowest temperature at which the oil ignite and achieve sustained flame without a fire source and defined as auto-ignition. These combustion properties were conducted according to the current standard procedure standard test method of Cleveland open cup tester described in American Society for Testing and Materials (ASTM D92-2005). The HDPE pyrolytic oil was experimentally by heating an open cup containing the tested oil under specified environmental conditions [13]. A small amount of oil in an open cup was heated at the rate of 1 °C per minute. The smoke point was taken as the temperature read on the digital thermocouple Krisbow-KW06-283 at the time of volatile compounds start to smoke. The flash point was read when a bluish smoke becomes clearly visible that causes a bright flash in the interior of the cup. The auto-ignition temperature and ignition time were taken when the lowest temperature at which the combustible vapors of the pyrolytic oil start to burn without fire source [12,13]. To determine flame temperature, the HDPE pyrolytic oil was used directly as fuel using the modified pressurized cooking stove. This stove was developed by Suhartono et al (2017) to combust used vegetable cooking oil (UCO) as fuel [12]. In this work, the flame temperature measurement that produced from pyrolytic oil combustion was performed with a probe thermometry method. The method is the most easily available and frequently used. The flame temperature was measured by introducing of a probe into surface flame. This thermocouple measurement technique was employed due to certain advantages, i.e. high precision (very low measurement error measurements), high temperatures resistant and allows data recording. The functional group composition of HDPE pyrolytic oil obtained at the optimum pyrolysis condition was performed with Fourier Transform Infrared spectroscopy (FTIR). FTIR specification of resolution of 4 cm\(^{-1}\) and the range of 400-4000 cm\(^{-1}\) was used.

3. Results and discussions

3.1. Characteristic of HDPE plastic waste

The high-density polyethylene (HDPE) plastic waste was used as feedstock in these experiments. This individual plastic waste was selected as a feedstock due to abundant availability and collected easily from the local area. Preliminary tests of HDPE plastic waste pyrolysis higher liquid oil yield than gas. Pyrolysis of individual HDPE plastic produces higher fuel oil production yield compared to other types of plastics, as reported by previous researchers. A high yield of oil product (83.15 %) was obtained from HDPE through two-stage pyrolysis-catalysis reported by Ratnasari et al (2017) [19]. According to Sarker and Rashid (2012), an oil production yield of 89.36 % was obtained by simple thermal degradation of individual HDPE waste plastic at a temperature ranging from 120 to 400 °C in 5-6 hours [20]. Many other researchers have also reported similar results. Therefore, the HDPE type plastic is more potential as a material to be converted into the pyrolytic oil as kerosene-like fuel.

The high-density polyethylene (HDPE) of plastic waste in the form of cosmetics bottles (white colour) was utilized for this experiment to pyrolytic oil, Fig. 2 And Fig. 3. The HDPE plastic was chosen because it has the simplest structure among other types of plastic. This plastic waste is
composed of the long linear polymer chain in a regular arrangement, low branching, and low density. This HDPE plastic waste test provides a lower density of 761 kg/m$^3$-781 kg/m$^3$ and the volatile matter is 100% in the proximate analysis. Kumar and Singh reported the similar results of some HDPE properties [21]. These characteristics of the regular arrangement linear polymer chain with lower branching, lower density, and highest volatile matter are very important parameters because it reveals information which leads to easy degradation and the minimal residual formation in pyrolysis products.

3.2. Pyrolytic Oil Yield

As a comparison, pyrolysis of individual of polyethylene terephthalate (PET) and HDPE plastics waste was carried out to observe potential products from them in a preliminary study. The degradation products of plastic pyrolysis are varying with the type of plastic waste. Each individual plastic waste was pyrolyzed using stainless steel semi-batch reactor at a pyrolysis temperature range of 200 °C – 400 °C in about 240 minutes to oil fuel production. The experimental results showed that HDPE plastic could produce the higher pyrolytic oil volume than PET plastic’s, as shown in Table 1 and Fig. 4. The PET type plastic produced very less pyrolytic oil and dominated by gases due to the lower amount of volatiles compound, high ash content in PET and the natural property to sublime.

| Plastic waste types | Plastic weight (g) | Pyrolytic oil volume (mL) |
|---------------------|-------------------|--------------------------|
| HDPE                | 2,000             | 1500                     |
| PET                 | 2,000             | 300                      |

Sharuddin et al (2017) also reported that PET was inefficient in terms of time and cost due to the yellowish substance product as a benzoic acid that could clog piping from reactor to condenser which caused problems in product collection [8]. From the above description, it is clear that the HDPE plastic waste type is great potential to be used as a feedstock material in the pyrolysis process to produce high liquid oil yield. The liquid oil which is with the similar physical characteristics as kerosene fuels depends on the setup parameters and operating parameters. Since the yield of liquid oil was very less, PET was not preferable for pyrolysis.

In this work, only individual of HDPE plastic waste was used as a raw material. Different amounts of HDPE plastic waste were placed into a closed at atmospheric pressure reactor system. Temperature
is one of the most vital parameters because it controls the cracking reaction of HDPE polymer chains. The pyrolysis was carried out from 30 °C to 400 °C for around 4 hours. The melting of plastics waste starts to begin at about 100 °C and turn into liquid slurry and vapors when temperature increased.

It was observed that longer pyrolysis time at temperatures from about 280 °C, the vapours start exhausted from the reactor and dripped out from a condenser unit. As the increased temperature, the liquid oil yield increased gradually. Pyrolytic oil was collected along with the pyrolysis temperature. The whole pyrolysis time in the reactor great influence on the final pyrolytic yield. It is evident that temperature has the greatest influence on plastic degradation which may affect the yields of pyrolytic liquid oil, gaseous and solid residue (char). As shown in Fig. 5, starting at 200 minutes the resulting pyrolytic oil product was close to constant, the increasing temperature was no longer significantly affected to the cracking reaction of the polymer chain of HDPE plastic waste. The fully complete plastic waste degradation at the highest liquid yield was obtained at the optimum pyrolysis time, \( t_{opt} \) of 240 minutes and a pyrolysis temperature of 360 °C. The input energy for every individual experiment about 112 MJ for 1-liter liquid oil production. The incondensable gaseous will dominate in product fraction at a higher temperature of 360 °C. It was observed that the highest liquid yield, 67.48 %w/w and gaseous product, 27.24 %w/w obtained at this conditioning process. The highest liquid yield than gaseous might be due to difficult to degrade the long hydrocarbon chains into lighter hydrocarbons of HDPE polymer structure. As a comparison of these experimental results, the thermal pyrolysis of HDPE plastic waste at a temperature range of 400°C to 550°C produced the highest liquid yield 79.08 %w/w and gaseous product, 24.75 % w/w was conducted by Kumar and Singh (2011) [21]. Ahmad et al (2015) reported the pyrolysis high HDPE into fuel like products was investigated over a temperature range of 250– 400°C. Total liquid yield, 80.88 %w/w, gaseous,17.24% w/w, and residue, 1.88 % w/w was achieved at 350°C [22]. According to Syamsiro et al (2014), HDPE waste produced the highest liquid fraction and a lowest gaseous fraction. The catalyst presences reduced the liquid oil yield and increased the gaseous yield, while the presence of catalysts only slightly effects to the product yields. The thermal pyrolysis with and without catalyst produced highest liquid fraction about 56% w/w and 56% w/w, respectively [23]. Figure 5 also shows that the amount of feedstock used in this pyrolysis process is directly proportional to the amount of product of fuel oil and the solid residue. Some solid black residue was collected from the reactor the yield is full. In the pyrolysis process, the unmeasured of the non-condensable gaseous product gas was calculated as the weight difference between the plastic and the solid residue. The product yields different amounts of HDPE plastic waste pyrolysis process are presented in Table 2.

### Table 2. Pyrolysis products yields

| Amount of HDPE (g) | Yield (w/w) | Pyrolytic oil | Solid residue | Incondensable Gaseous |
|-------------------|-------------|---------------|---------------|----------------------|
| 1,000             | 54.67       | 18.09         | 27.24         |
| 2,000             | 57.83       | 12.20         | 29.95         |
| 3,000             | 67.48       | 8.26          | 24.26         |

From these experimental results can be inferred that the lower temperature in the range of 280 °C-360 °C is recommended to produce pyrolytic oil as the main desirable product. The increasing temperature of pyrolysis over 460 °C will only produce more gaseous and solid residue. The increase in the amount of HDP feedstock will also enhance the liquid pyrolytic oil yield.

3.3. **Characteristic of HDPE pyrolytic oil**

It is necessary to test the physical and combustion characteristics of HDPE pyrolytic oil as the main product of the pyrolysis process. These characteristics are important to find out whether liquid pyrolytic produced eligible to utilized as a conventional fuel substituted. Table 3 summarizes several related parameters of HDPE pyrolytic oil and other commercial fuels.
Heating value is one important parameter in a fuel selection. This value determines the energy content of the fuel that affects the combustion efficiency. The calculated heating value for pyrolytic oil produce from HDPE plastic waste pyrolysis was about 40 MJ/kg. As a comparison, Yuliansyah et al (2015) conducted an experiment of pyrolysis of plastic waste to produce pyrolytic oil as an alternative fuel. The heating value of pyritic oil from plastic waste pyrolysis without catalyst was 46 MJ/kg [11]. According to Ahmad et al, the pyrolytic oil heating value from HDPE of above 45 MJ/kg [22]. The heating value of 42.8 MJ/kg was also obtained from HDPE pyrolysis by Syamsiro et al (2014) [23]. The lower heating of pyrolytic oil produces from this work probably due to the difference in the chemical structure of HDPE plastics used and the operating conditions. However, the heating value of this pyrolytic oil is very close to the fuel grade criteria of the common commercial kerosene fuel, as shown in Table 3. This is due to both plastic and commercial fuel derived from the same origin that is petroleum. In addition, the heating value of pyrolytic oil obtained from the calculation using Eq. (5) is sufficient and no significant difference between the results of the analysis using bomb calorimeter.

In this work, the pyrolytic oil produced was found to remain the same within normal range i.e. 1,000 kg/m³ but lower than other commercial oils density. It was observed that the density of HDPE pyrolytic produced decreases with increases in the pyrolytic temperature process. Obviously, that decreases the density of HDPE pyrolytic oil close to kerosene fuel. The pyrolytic oil produced is closely related to its density, the oil density affects the heating value of the pyrolytic oil product. The variation of pyrolytic oil densities of 772 kg/m³ - 882 kg/m³ have different heating value (energy content) of 39 MJ/kg - 42 MJ/kg. As the density increases, the heating value also increases. Table 3 shows that kerosene has the same density as HDPE pyrolytic oil compared to diesel fuel.

The density of the pyrolytic oil is one of the important parameters in the straight use of this oil as fuel for domestic purpose. It is an accepted fact that fuel density has a great influence on combustion performance. The atomization/spray combustion process of directly used this oil as fuel using a pressurized stove is affected by this property. Thus, knowledge of these parameters is a very important part of the research process to ensure the combustion quality of this fuel. The viscosity of the pyrolytic oil is a crucial parameter when used as fuel in direct combustion for domestic purpose. Fuel viscosity will determine the ability of the fluid to flow, atomization, spray characteristics and volatility of the fuel. When high fuel viscosity is utilized as fuel using a pressurized stove will affect incomplete combustion due to bad spray characteristics [13]. The reduction in viscosity will enhance the spray characteristic of the fuel. Based on Table 3, it depicted the value of kinematic viscosities of HDPE pyrolytic oil is very close with the viscosity of kerosene. The lower viscosity of HDPE pyrolytic oil is directly related to degradation the long hydrocarbon chains into lighter hydrocarbons of HDPE polymer structure during pyrolysis process. The negligible ash content of HDPE, free from any metal contamination and the lower fraction of hydrocarbons (C>20) contributed to the lower kinematic viscosity. Although Syamsiro et al (2014) classifies oil from HDPE waste into low-quality oils as heavy oils (> C20) rather than gasoline fractions (C5-C12), diesel fuel fractions (C13-C20) [23], however, from this result (Table 3), it is observed that the fuel properties of the thermal pyrolytic oil from HDPE match the properties of kerosene fuel. These results in agreement with the resulting liquid fuels that have a long range of carbon chains for HDPE plastics to fuel C5 to C28 reported by Olufemi and Olagboye (2017) [24].

### Table 3. Comparation of oil properties as fuel

| Parameter                     | Diesel oil | Kerosene | HDPE pyrolytic oil |
|-------------------------------|------------|----------|--------------------|
| Heating value (MJ/kg)         | 45.6°C     | 43°C     | 39-42              |
| Density (kg/m³)               | 815-860    | 780-810  | 772-882            |
| Viscosity (cSt), 30 °C        | 2.0-4.5    | 1.285    | 0.899-1.159        |
| Flash point (°C)              | 52         | 40       | 48                 |
| Auto ignition point (°C)      | 256        | 220      | 240                |

*Common commercial data*
The other important property of pyrolytic oil is a flash point. Flash point of the liquid is defined as the lowest temperature at which the pyrolytic oil starts to vaporize. This physical property used to prevent fire and explosion hazards. The flash point of pyrolytic oil is related to its viscosity, while the viscosity is related to and the length of the hydrocarbon chain of HDPE plastic. The higher pyrolysis temperature will reduce the viscosity of pyrolytic oil due to the more degradation of the hydrocarbon chain length. The lower viscosity will reduce the flash point as well as the ignition point of oil which can improve the combustion quality. The flash point of HDPE pyrolytic oil was comparable to both petroleum fuel in this work. The flash point of HDPE pyrolytic oil was so close to the commercial kerosene, it means that pyrolysis oil easier vaporized and easy to ignite just like kerosene.

The auto ignition temperature of fuels was tested using open cup devices, the fuel sample is contained in an open cup which is heated and at which the vapor ignites spontaneously without an ignition source (without fire source). Table 3 summarizes the auto-ignition temperature of fuels. The auto-ignition temperature of HDPE pyrolytic oil, 240 °C is relatively similar to kerosene. It is probably due to increasing the hydrocarbons chain of light oil (C5-C12) during the HDPE pyrolysis process [23].

The produced HDPE pyrolytic oil was analysed by FTIR to find a functional group of hydrocarbons as the liquid fractions contain. The results of the FTIR spectrum measurement of HDPE pyrolytic oil is presented in Fig. 6. The figure shows the FTIR spectrum results of oil sample obtained by thermal pyrolysis of HDPE plastic waste. The FTIR spectrum results of commercial kerosene are summarized in Table 4. Both fuels are dominated by mostly alkanes and alkenes group. The functional group's distribution of alkanes (CH), alkenes (C=C), aromatic (C=C), aldehydes, ketones, carboxylic acids and esters (C=O), alcohols, phenols hydrogen bonds (OH), carboxylic acid (OH) groups and amine (NH). The similar functional groups were also found in FTIR spectrum of HDPE pyrolytic oil. The HDPE pyrolytic oil is enriched by two additional functional groups of alkenes (H=C=C) and aromatics (C-H) in wave lengths of 675-870 cm\(^{-1}\), 3000-3,100 cm\(^{-1}\) and 3020-3080 cm\(^{-1}\). The obtained results were in agreement with the results reported by many researchers [8,23,24]. It can be said that both fuels have similar chemical properties, which indicates that pyrolytic fuel oil has good qualities as kerosene-like fuel.
Table 4. FTIR bands assignment of waste HDPE and kerosene

| Wave length (cm$^{-1}$) | Group name | Nature of functional group | The absorption area (cm$^{-1}$) |
|------------------------|------------|----------------------------|-------------------------------|
|                        |            | HDPE pyrolytic oil         | Kerosene                      |
| 2850-2960              |            | 1376.68                    | 1402.25                       |
| 1350-1470              | C-H        | 1456.64                    | 2856.58                       |
|                        |            | 2856.09                    |                               |
|                        |            | 2922.41                    |                               |
| 3020-3080              | C-H        | 713.67                     |                               |
| 675-870                | Alkenes    | 801.83                     |                               |
|                        |            | 3073.91                    |                               |
| 3000-3100              | C-H        | 713.67                     |                               |
| 675-870                | Aromatics  | 801.83                     |                               |
|                        |            | 3073.91                    |                               |
| 1640-1680              | C=C        | 1642.28                    | 1641.42                       |
|                        | Alkenes    | 1697.62                    |                               |
| 1080-1300              | C=C        | 1175.63                    | 1093.64                       |
|                        | Aromatics (ring) | 1283.64                  |                               |
| 1690-1760              | C=O        | 1697.62                    |                               |
|                        | Aldehydes  |                           |                               |
|                        | Ketone     |                           |                               |
|                        | Carboxylates acid |                  |                               |
|                        | Ester      |                           |                               |
| 2000-3600              | O-H        | 2856.09                    | 2856.58                       |
|                        | Alcohols   |                           |                               |
|                        | Phenol (hydrogen stretch) | 2922.41                  |                               |
|                        |            | 3073.91                    |                               |
| 3000-3600              | O-H        | 3073.91                    | 3251.98                       |
|                        | Carboxylates Acid |                  | 3390.86                       |
|                        |            |                           | 3417.86                       |
|                        |            |                           | 3444.87                       |
| 3310-3500              | N-H        | 3390.86                    | 3417.86                       |
|                        | Amine      |                           | 3444.87                       |
| 1180-1360              | C-N        | 1283.64                    |                               |

3.4. The potential application of HDPE pyrolytic oil

HDPE pyrolytic oil has the potential to be used as an alternative source of household energy needs. The produced pyrolytic oil from pyrolysis of plastic waste can play a significant role to replace the LPG as daily conventional fuels. As a preliminary test, the pyrolytic oil was utilized as fuel using a modified pressurized cooking stove. The modified pressurized cooking stove with spiral pipeline mechanism was developed by Suhartono et al (2017) [12]. Used vegetable cooking oil (UCO) and vegetable cooking oil were utilized as fuel, in this case. This work describes the comparison of utilizing HDPE pyrolytic oil and kerosene using this stove. HDPE pyrolytic oil produced a maximum flame temperature of about 1300 °C in a red-bluish flame, as depicted in Fig. 7. The lower flame temperature of 1100 °C was achieved when utilizing kerosene fuel.

The combination of fuel/stove/pot performance was evaluated according to water boiling test method (WTB) by measuring the fuel consumed to heat an amount of water to boiling point as thermal efficiency, $\eta_1$. The utilized of HDPE pyrolytic oil as fuel using this pressurized cooking stove provided the average thermal efficiency of 33%. While the average thermal efficiency of kerosene utilized was about 30%. The higher thermal efficiency of pyrolytic oil might be due to lower density,
high enough heating value and light hydrocarbon content (aromatic group) of this fuel to produce good combustion quality. From these results, it is obvious that the quality pyrolytic oil is equal to those of commercial kerosene fuels according to the oil properties and the utilized performance. The quality pyrolytic oil is suitable to be used directly as kerosene-like fuel.

4. Conclusion
The lower temperature in the range of 280 °C - 360 °C and pyrolysis time of 240 minutes is recommended to produce HDPE pyrolytic oil as the main desirable product. The produced pyrolytic oil that has characteristic and consisting functional groups similar to commercial kerosene fuel. The highest pyrolytic fuel yield of about 67.48% w/w was obtained from converting of 3000 g of plastic waste. This fuel had an average value of density and viscosity were 771 kg/m³, 1.031 cSt, respectively. The combustion properties of heating value, flash point and auto-ignition point of 40 MJ/kg, 48 °C and 240 °C, respectively were obtained in this work. Likewise, this pyrolytic oil plastic contains plenty of alkanes and alkenes group. Two additional functional groups of alkenes (H₂C=⁻C) and aromatics (C-H) were found in this HDPE pyrolytic oil. The utilized of the pyrolytic oil using modified pressurized cook stove provided better combustion performance than kerosene fuel. From the findings description above, it can be concluded that; (a) The lower thermal operation at such this condition is an effective way to convert HDPE plastics waste into kerosene-like fuel and to reduce municipal plastic waste, (b). replacing the LPG as daily conventional fuels that yield economic benefits, (c). environmentally friendly due to reducing municipal waste and since the product form contains negligible toxic compounds.

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