

## Pyrolysis of Plastic Waste as an Alternative Fuels in Spark Ignition Engine

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### ABSTRACT

Plastic waste is a potential alternative energy source in terms of its heating value. In general, plastic is processed by pyrolysis to produce oil, so that internal combustion engines can utilize it in producing power. The purpose of this study is to analyze the characteristics of plastic pyrolysis oil (PPO) and evaluate engine performance and exhaust emissions on the use of fuels resulting from the pyrolysis of plastic waste. In this research, plastic pyrolysis oil was produced through a slow pyrolysis process using raw materials from the type of plastic Low-density Polyethylene (LDPE) and Polyethylene Terephthalate (PET). Experiments were carried out by testing the characteristics of plastic pyrolysis oil (PPO), which included tests of heating value, octane number, density, kinematic viscosity, and flashpoint. The testing of engine performance and exhaust emissions was carried out on a single-cylinder gasoline motor. Testing the use of gasoline fuels was also done as a comparison of the characteristics of the PPO produced. The results showed that the characteristics of PPO have similar physical properties when compared to gasoline fuels. Performance testing of gasoline motors showed that the maximum power PPO of PET plastic types is lower by 3.3% (5.9 HP at 7167 rpm), and the LDPE type is lower by 14.8% (5.2 HP at 7030 rpm) when compared to gasoline fuel at 6.1 HP at 6619 rpm. Maximum torque is 6.77 Nm at 4314 rpm for the use of PPO of PET plastic-type, and LDPE plastic-type is 5.77 Nm at 5434 rpm, where this value is 19% and 31% lower than gasoline (8.36 Nm at 4428 rpm). PPO produces exhaust gas emissions in the form of lower HC and CO and more efficient fuel consumption compared to gasoline. These results indicate that the pyrolysis oil of plastic waste is a promising alternative fuel to be applied to spark ignition engine.

**Key words:** Engine performance, Exhaust Gas Emissions, LDPE, PET and Pyrolysis Plastic Oil Emissions.

### 1. INTRODUCTION

Global plastic production has increased over the years due to a large number of plastic applications in many sectors. Plastic is

also an important material for modern existence. Plastic has become a part of daily life in both the household and industrial sectors. Plastic material is a type of polymer compound formed from a series of carbon, hydrogen, and other elements such as chlorine, nitrogen [1] which is lightweight and strong, good durability, corrosion-resistant, fast production processes, and has a design flexibility that is easy to shape.

The continuous demand for plastic causes much accumulation of plastic waste and requires much space for landfills (TPS), which contribute to environmental problems [2]. Global plastic production is estimated at 300 million metric tons annually and growing at a rate of 4% annually. Over the past three decades, plastic production in large countries has faced explosive growth and reached an average of 129 million tons per year [3]. The World Bank noted that projects using plastics in the world reached 1.3 billion metric tons (Municipal Solid Waste/MSW) produced each year, and are estimated to grow 2.2 billion metric tons per year (MTPY) in 2025. 10% of the total MSW produced, or 130 MTPY, is plastic. Plastic waste will harm the environment because it is non-biodegradable, does not decompose naturally by micro-organisms, and harms the environment and living things because of the chemical elements contained therein. In addition, a massive buildup of plastic waste can cause pollution in both soil, air, and water.

A large percentage of plastic waste in landfills not only requires a large space but also causes pollution. The accumulation of plastic waste as solid waste will lead to fears of environmental degradation and pollution in most soils [4]. The landfills will not be the right solution for this plastic because it will cause increasingly severe environmental problems. To overcome this problem, the best solution is to find a method to reduce plastic waste by mechanical processes (sorting, grinding, washing), sweltering, or thermal/catalytic cracking [4] or by turning it into useful fuel [1]. Through the right process, plastic waste is a type of waste that is abundantly available and can be used effectively as new energy [3].

Efforts to handle plastic waste must be appropriately made [5], including the 3R method, namely reuse, reduce, recycle [6]. Conventional ways such as landfilling and incineration only cause air pollution, are less effective, and risky because combustion arises pollutants from exhaust gas emissions (CO<sub>2</sub>, CO, NO<sub>x</sub>, and SO<sub>x</sub>) and several other polluting particulates that are harmful to human health [7]. The concept of plastic recycling (recycling of plastic wastes) is then the preferred method because plastic waste is considered a cheap and abundant raw material. Processing into oil, as a liquid fuel, is an attractive alternative way to produce energy sources while improving the quality of handling the plastic waste. A popular recycle technique for processing plastics into liquid fuels is pyrolysis. Pyrolysis is a chemical decomposition and thermal decomposition of molecules under conditions without oxygen [8].

The community's need for fuel oil (BBM) derived from fossils is increasingly growing, causing increasingly depletion of oil and gas reserves. Efforts to find and process alternative fuels must continue. In recent decades, the ethanol-gasoline mixture has been widely investigated and considered a potential alternative fuel for gasoline engines. Investigations related to performance and emissions from fuel use are with various gasoline-ethanol mixture ratios [9]–[11]. Research on the application of pyrolysis oil from plastics shows the thermal efficiency of plastic oil, which is lower than gasoline and diesel fuels and various mixtures thereof [12]. Specific fuel consumption (brake-specific fuel consumption/BSFC) in the use of oil from plastics also looks more efficient. Likewise, with the level of exhaust gas emissions, plastic pyrolysis oil has lower CO, HC, and NO<sub>x</sub> levels [13] [14], and contains a little sulfur [15].

Efforts to find and process alternative fuels must continue. It is also motivated by the demand for energy on both national and international scale. Very high dependence on BBM must be reduced immediately, and a solution needs to be sought. Plastic is a material made from the element of petroleum so that it can be converted into its original form. The process of pyrolysis of plastic waste can produce plastic oil, charcoal/ash, condensed gas, and non-condensable gas. The operation temperature of plastic pyrolysis is around 450°C for 75 minutes, showing the most optimal production results, with 80.8% oil, 13% gas, and 6.2% charcoal [16].

The product quality of pyrolysis depends on the type of plastic waste that is put on the pyrolysis reactor and the process parameters (such as temperature, pyrolysis time, and catalyst). The use of plastic pyrolysis to date has been prioritized in the use of liquid fuel products for further processing into several types of fuel oil (BBM). Plastic pyrolysis oil (PPO) has properties similar to petroleum products; therefore, it has the potential to be used in internal

combustion engines [17]. Pyrolysis oil from HDPE, LDPE, PP, and PS plastic has a higher heating value than wood and coal [18].

Optimization of engine performance on combustion engines can be done in several ways, including using alternative energy [19], where the testing parameters use engine performance parameters and exhaust emissions [20]. The purpose of this study is to investigate the characteristics of plastic pyrolysis oil properties from PET and LDPE types to determine their eligibility as a fuel. The parameters studied in the engine performance test were the amount of power, and engine torque at the maximum changes achieved. While the parameters studied in the exhaust gas emission test were the amount of HC and CO at stationary rotation. So far, the existing research and publications have been more dominant in testing PPO on diesel engines. For this reason, this test can determine the effect of the use of PPO when applied as fuel on a gasoline motor.

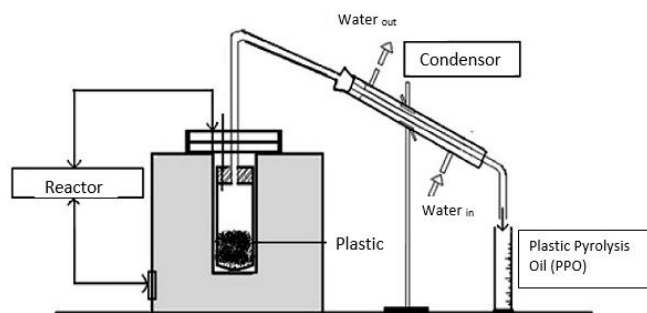


Figure 1: Plastic pyrolysis process.

## 2. MATERIALS AND RESEARCH METHOD

This research was carried out in four stages, namely the research preparation stage, the testing phase of plastic pyrolysis oil characteristics, the fuel testing stage of the engine, and the data analysis stage. The materials used were plastic waste from mineral water bottles for PET plastic types and plastic bags for LDPE plastic types. Testing of engine performance and exhaust gas emissions was carried out on a one-stroke four-cylinder motorized vehicle with a capacity of 100 ccs using plastic pyrolysis oil from PET, LDPE, and Pertamina type gasoline. The equipment used was in the form of Dynamometer Sportdyno V3.3 and Engine gas analyzer 4-Gas gasoline/ Model 10174175.

The process of utilizing plastic waste into fuel (Figure 1) with this pyrolysis method involved preparing plastic waste from PET and LDPE types, chopping, washing, and drying. The plastic material was put into a pyrolysis reactor at 350°C in a room without oxygen. The gas that came out of the reactor was then put into the condenser to obtain plastic pyrolysis oil (PPO). Testing the characteristics of oil properties included the heating value test, octane number, density test, kinematic viscosity test, and flash point test.

The spark-ignition engine performance test and exhaust gas emissions (Figure 2) were carried out to find out how much influence the use of PPO on motor power, torque, and emissions. The motorcycle was placed and turned on the Dynamometer, then spontaneously accelerated from 4000 rpm to the maximum rotation of the motor for ten seconds. On the measuring panel, a graph showing the amount of power, torque of the motor would be seen. The testing of exhaust gas emissions was then carried out using a gas analyzer. The motorcycle was turned on with a measuring probe inserted at the exhaust tip. Raised and held the engine speed to 4000 rpm for at least five seconds and returned it to the stationary engine speed. Performed measurements of exhaust gas emissions with a duration of 20 seconds, then recorded the appointment of numbers on display or printed to find out the levels of HC, CO, CO<sub>2</sub>, and O<sub>2</sub>

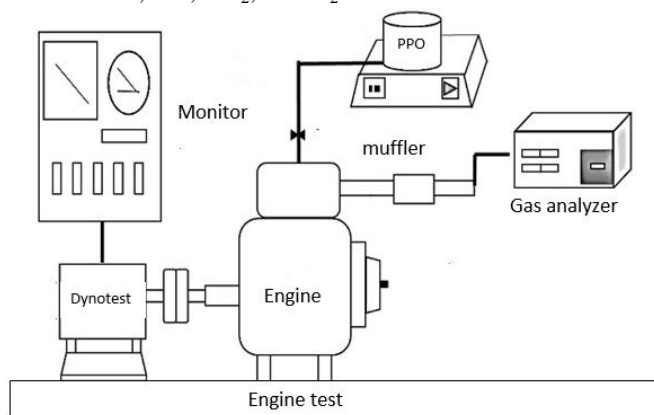


Figure 2: Testing tool layout.

### 3. RESULTS AND DISCUSSION

This section presents and discusses the experimental results of using pyrolysis plastic oil (PPO) from LDPE and PET plastic types from the spark-ignition engines. The testing was compared to gasoline fuel. The investigation focused on PPO property characteristics, engine performance, and exhaust gas emission analysis.

#### 3.1 Characteristics of Plastic Pyrolysis Oil (PPO)

Testing the characteristics of PPO included RON, MON, heating value, kinematic viscosity, density, flash, and fire point. Based on Table 1 it shows that the characteristics of plastic pyrolysis oil are in the range of characteristics of gasoline fuels that are marketed in the community.

Table 1: Testing the PPO characteristic values

Characteristics	PET	LDPE	Gasoline
Heat Value (MJ/kg)	46.54	45.77	45.63
Density in the 15 °C (gr/ml)	0.7562	0,7611	0.7492
Viscosity kinematic in the 40 °C (mm <sup>2</sup> /s)	0.851	0.967	0.509

Flash point & Fire point PMCC (°C)	< 21	< 24	22 - 23 [21]
Octane Number	92.6	87.9	88 - 95 [22]

Testing of the octane value of fuel (RON number) of liquid fuel from PET and LDPE plastic waste was carried out using a portable octane analyzer using the Zeltex method ASTM D 613. The magnitude of the RON value can be shown in table 1. The octane value of liquid fuel from waste PET plastic is equivalent to Pertamina's Pertamax type materials. It indicates that PPO, which is also a type of ethanol, can be used effectively for gasoline motors [23]. PPO ethanol has a high calorific value, octane number, flash, and fire point, and is similar to petrol, so it is very suitable to be used as a substitute for motor fuel.

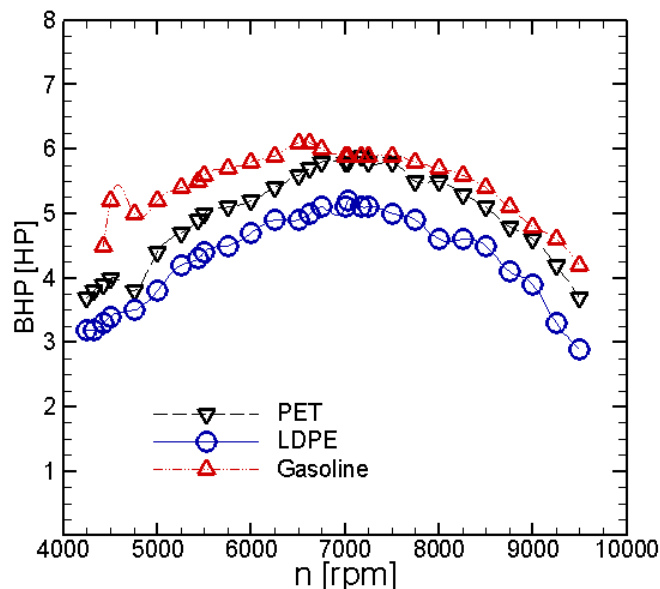


Figure 3: Relationship between engine speed and power.

#### 3.2 The Performance of The Motor Fuel

Motor performance testing which included torque, power, and speed of increase of motor rotation. A comparison of the magnitude of motor power and motor torque was from each use of LDPE PPO fuel, PET PPO, and Pertamina gasoline. The relationship between motor speed and power can be shown in Figure 3. The test results show that the motor power for the use of PPO from PET type is 3.3% lower, and PPO from LDPE type is 14.8% compared to Pertamina gasoline. Motor power from the use of PPO PET type is also higher than the LDPE type by 13.5%. Where the maximum motor power for PPO PET type is 5.9 HP at 7167 rpm, PPO LDPE type is 5.2 HP at 7030 rpm, and Pertamina gasoline is 6.1 Hp at 6619 rpm engine speed.

Testing of motor torque, as shown in Figure 4, shows that the maximum motor torque with fuel from PPO PET plastic is 6.77 Nm at 4317 rpm, PPO LDPE plastic is 5.77 Nm at 5434 rpm, and Pertamina is 8.36 Nm at 4428 rpm. The maximum

motor torque of PPO PET types and LDPE type is 19.02% and 30.98% lower compared to Pertamina gasoline. PET PPO is better than LDPE PPO with maximum torque greater than 18.77%. The motor torque for PPO is smaller compared to Pertamina gasoline, due to the lower heating value of PPO from Pertamina gasoline. Torque is strongly influenced by the amount of energy produced by combustion, which is influenced by the amount of heat in the fuel.

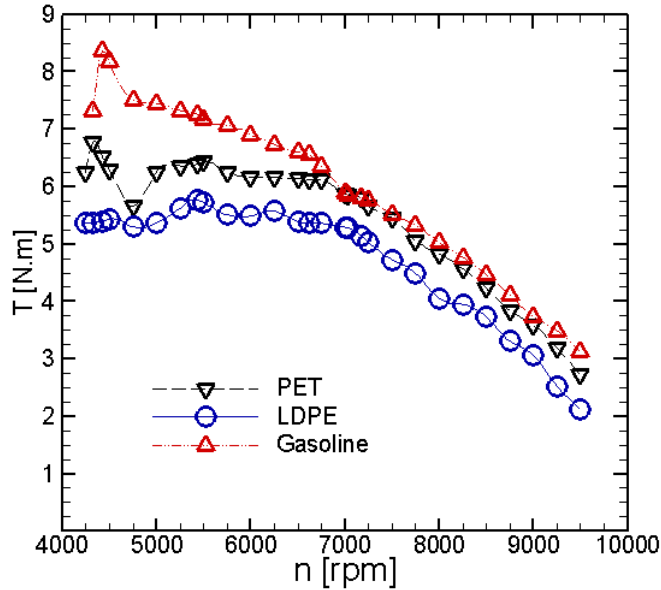


Figure 4: Relationship between engine speed and power

### 3.3 Specific Fuel Consumption (SFC)

Measurement of specific fuel consumption (SFC) is the ratio between the mass of fuel consumed by the engine and the power generated during a specific time. SFC value is very dependent on the power generated by the engine. Figure 5 presents the specific fuel consumption levels of various types of PPO use to Pertamina gasoline.

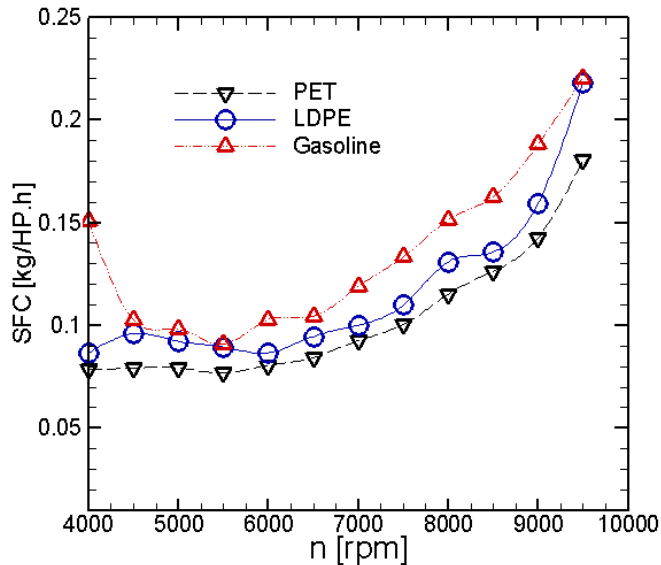


Figure 5: Relationship of engine rotation and specific fuel consumption

The use of plastic pyrolysis fuels can reduce fuel consumption or more efficiently. The specific fuel consumption for the type of gasoline Pertamina is an average of 0.1350 kg/HP.Hours, so the percentage of SFC reduction in each PPO type is PET by 32.5% and LDPE by 17.8%. With the magnitude of the level of consumption of the smallest specific fuel is at 4000 - 5500 rpm (medium speed). PPO from PET plastic type has proven to be more efficient compared to PPO of LDPE type.

### 3.4 Exhaust Gas Emissions

Exhaust gas emission testing is to measure the effect of the use of liquid plastic fuels on levels of exhaust gas emissions of a motor vehicle. Measurements were made at stationary rotation, which was 1500 rpm that included levels of hydrocarbons (HC), carbon monoxide (CO), and lamda. A comparison of levels of exhaust gas emissions is shown in Figure 6.

Figure 6 is a comparison of exhaust gas emissions from each use of Pertamina fuel, PPO LDPE types, and PET types. HC levels for PPO LDPE types have the lowest emissions of 991 ppm, lower than PPO PET types of 1341 ppm, and Pertamina of 2504 ppm. Reducing HC emissions is by using PET PPO by 46% and LDPE PPO by 60%. The average use of ethanol in gasoline engines is proven to be able to reduce emissions by 60% compared to gasoline fuels. Likewise, with CO levels, PPO LDPE plastics produce emissions of 3.70%, PET PPO types of 5.25% better than Pertamina of 5.6%. For non-hazardous gas content in PPO, it shows a higher concentration of carbon monoxide (CO<sub>2</sub>). Vehicles powered by ethanol or ethanol-gasoline mixtures show a decrease in the concentration of CO and UHC (unburnt hydrocarbons), compared to gasoline [24].

The combustion process also occurs with a ratio of a mixture of fuel and air, which is relatively thin, with a value of lamda higher than one. The process of combustion of PPO fuel is more perfect in terms of higher CO<sub>2</sub> levels and lower O<sub>2</sub> levels. Regarding the value of the air-fuel ratio (lamda) in the combustion conditions of the motor, it can be concluded that the PPO fuel can be said to be more efficient.

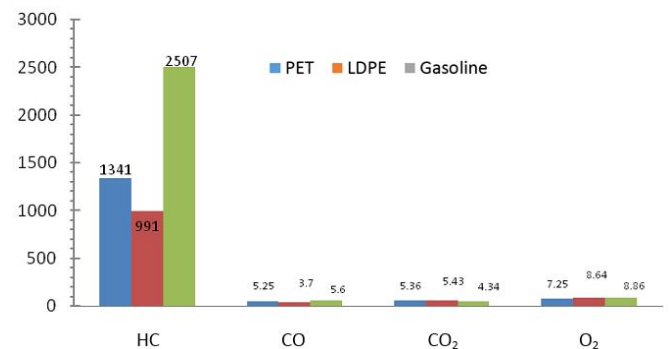


Figure 6: Comparison of exhaust gas emissions levels

#### 4. CONCLUSION

An experimental investigation was carried out to analyze and understand the characteristics of property, performance, and emissions from a spark ignition (SI) engine fueled by pyrolysis plastic oil (PPO). Tests carried out on a 100 cc one-cylinder four-stroke gasoline engine. The characteristics of PPO properties are similar to petrol/gasoline in terms of the heating value, and octane number, but the viscosity is higher. The performance of SI engines for PPO PET fuels is higher than PPO LDPE but lower than gasoline fuels. PPO also shows the consumption of specific fuels that are more efficient and levels of exhaust gas emissions that are lower. Therefore, PPO is very suitable to be used as an alternative fuel for SI engines.

#### 5. ACKNOWLEDGEMENT

Both the first and the second authors would like to acknowledge the financial from Indonesian Government in supporting the research through Universitas Muhammadiyah Surakarta under magister research project No. 199.10/A.3-III/LPPM/2019.

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