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Characteristics of Liquid Co-Pyroliysis Products From Plastic Waste and Used Engine Oil

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Abstract

This study aims to utilize low-density polyethylene (LDPE) plastic waste and engine oil to produce alternative liquid fuel through the co-pyrolysis method. We carried out the co-pyrolysis process with various ratios of LDPE plastic waste and used engine oil, specifically 5:0, 5:1, 5:2, 5:3, and 5:4, within a temperature range of 165°C to 177°C for 1 hour. We tested the characteristics of the resulting liquid products to determine their calorific value, density, and viscosity. The results showed that the calorific value increased with the addition of used engine oil, reaching 11,061.67 cal/g at a 5:4 composition. The liquid products had an average density of 0.8686 g/mL, which was within the range of diesel fuel density. The viscosity of the liquid products also met gasoline standards, with an average value of <1 cSt. The highest yield efficiency reached 9.14 mL/kWh at a 5:4 composition with an efficiency of 1.93%, indicating significant potential for producing energy-efficient liquid fuel. This study sheds new light on the use of plastic waste and engine oil as environmentally friendly alternative liquid fuels.

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Introduction

The increase in plastic usage by 2015 has resulted in an estimated 300 million tons of plastic waste worldwide [1]. In 2019, Indonesia's total waste amounted to 68 million tons, with plastic waste accounting for 14%, or approximately 9.52 million, of this total [2]. The high amount of trash at the final disposal site (TPA) is one indication that garbage disposal is difficult and requires proper mechanisms [3]. Both landfill and incineration methods are used to tackle the problem of plastic waste, but both methods are ineffective because they can create new environmental problems [4]. The most developed plastic waste treatment nowadays is by converting it into liquid fuels through pyrolysis methods [5].

Pyrolysis is the process of decomposing an organic or inorganic material by heating it at high temperatures, either without oxygen or with little oxygen [6]. In addition to the issue of plastic waste, used lubricants from motor vehicles also pose a significant problem. Used lubricants are environmentally unfriendly waste because they contain hazardous and toxic substances (B3) [7]. The high amount of used lubricant is consistent with the increase in the number of vehicles in each city and region, so their use is increasing from year to year [8].

This study aims to utilize plastic waste and used lubricants, specifically through the co-pyrolysis method on low-density polyethylene (LDPE) waste plastic and waste lubricant types. This method can improve the quality and characteristics of the liquid products produced by pyrolysis We use LDPE plastic waste because it's easy to obtain, heats up faster, and produces more liquid products than other types of plastic waste [9]. When reviewing the use of both of these wastes, the primary raw material is petroleum [10]. Therefore, the method of co-pyrolysis can utilize the energy content of waste plastic and used lubricants to create alternative liquid fuels [11].

The purpose of this study is to convert plastic waste and waste lubricant into liquid fuel and determine the characteristics of the liquid product based on caloric value, density, and viscosity parameters.

Theory

Plastic is a macromolecular material formed by polymerization [12]. Polymerization is the combination of several molecules through a chemical process to become macromolecules with the main elements consisting of carbon (C) and hydrogen (H) [13]. Plastics generally fall into two categories: thermoplastic and thermosetting [14]. When heated to a specific temperature, thermoplastic undergoes a transformation into a liquid, allowing for further shaping [15]. Heat treatment cannot dilute thermosetting plastic [16]. Some thermal properties that should be known at the time of plastic recycling are melting point (Tm), transition temperature (Tg), and decomposition temperature [17].

One of the most widely used types of plastics is low-density polyethylene (LDPE), which has the characteristics of flexibility and strength [18]. High temperatures between 200 °C and 300 °C, along with a supercritical ethylene pressure of 130 MPa to 260 MPa, produce this type of plastic. LDPE plastics have long chains and branches with a type mass between 0.915 g/cm^3 and 0.925 g/cm^3 [19].

Pyrolysis is the method that deals with plastic garbage [20]. Pyrolysis is the process of decomposing organic or inorganic materials by heating them to high temperatures with little or no oxygen [21]. In the process of pyrolysis, the material undergoes a breakdown of the chemical structure into a gas phase [22]. The gas then passes through the iron medium and cools, changing its nature from gas to liquid [6]. To enhance the pyrolysis result, we implemented co-pyrolysis.

Co-pyrolysis, a method utilizing two or more raw materials, enhances the properties of a liquid product through increased yields, reduced water content, and increased calorie values [23]. The duration of the process, the reactor's heating temperature, the size of the raw material particle, and the mass or amount of raw material used are some of the factors that affect the ongoing pyrolysis process [6].

Method

The sample collection procedure involves comparing LDPE plastic waste samples with used engine oil. The mixture ratios of LDPE plastic waste and used engine oil are as follows:

TABLE 1. COMPOSITION RATIO OF LDPE PLASTIC AND USED ENGINE OIL

No.	Sample	Composition	
		LDPE Plastic (grams)	Used Engine Oil (grams)
1.	S1	200	0
2.	S2	200	40
3.	S3	200	80
4.	S4	200	120
5.	S5	200	160

The experiment proceeded by performing the pyrolysis process on the prepared samples using a simple pyrolysis apparatus, as shown in Figure 1. This process involved heating the raw materials in a reactor at high temperatures without oxygen, using tree waste or firewood as a heat source. A thermocouple monitored the temperature inside the repurposed can reactor, ensuring proper operational conditions.

We collected and tested the resulting liquid products after the pyrolysis process to measure their characteristics, including calorific value using a bomb calorimeter, density using a pycnometer, and viscosity using an Ostwald viscometer. We thoroughly evaluated the collected data to ensure their adequacy before conducting further analysis of the relationships and patterns.

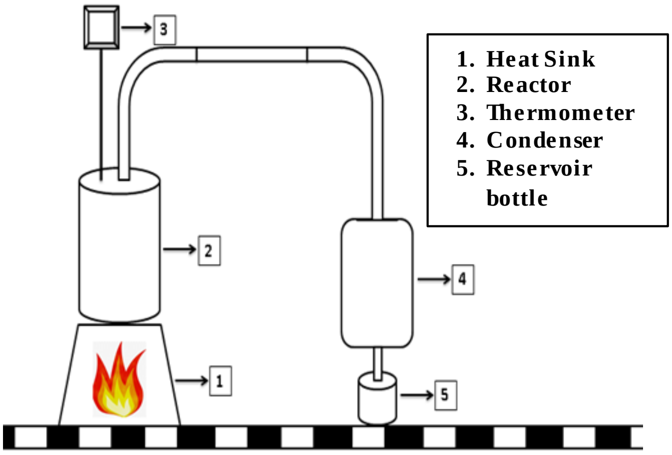

Figure 1: Pyrolysis Apparatus Diagram

Results and Discussion

We conducted the experiment using five different compositions, namely 5:0, 5:1, 5:2, 5:3, and 5:4, which refer to the ratios of LDPE plastic waste and used engine oil. We performed the co-pyrolysis process for one hour, maintaining a temperature range of 165°C to 177°C. It is important to note that the temperature inside the reactor varied due to the use of firewood as a heat source, leading to relative temperature differences in each trial. For each test, the plastic sizes ranged from 2 cm2 to 5 cm2, with a plastic mass of 200 grams .

TABLE 2. CO-PYROLYSIS PROCESS RESULTS

No.	Sample Code	Process Temperature (°C)	Time (hours)	Volume of Product (mL)
1.	S1	170,80	1	55
2.	S2	175,40		61
3.	S3	165,40		46,67
4.	S4	177		64
5.	S5	170,40		55

The experimental results shown in Table 2 indicate that adding used engine oil resulted in varying volumes of liquid product: 55 mL (S1), 61 mL (S2), 46.67 mL (S3), 64 mL (S4), and 55 mL (S5). Visual analysis indicated that the more engine oil added, the darker brown the liquid product became, as shown in Figure 2. The heavy fractions carried in the vapor and then condensed into oil in the condenser explain this phenomenon, leading to an increased viscosity of the product.

Figure 2: Co-pyrolysis Liquid Products

A. *Calorific Value*

Value The calorific value is the amount of heat generated by the combustion process between fuel and air [24]. Generally, the calorific value of liquid fuel ranges from 10,160 cal/g to 11,000 cal/g [25]. The Energy

Conversion Engineering Laboratory of the Jakarta State Polytechnic used a bomb calorimeter to test the calorific value in this study. We tested the calorific value three times, and the graph in Figure 3 presents the average results.

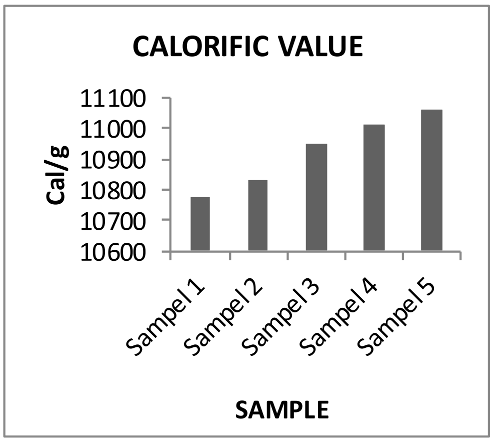

Figure 3: Results of the Calorific Value Test of Co-pyrolysis

The test results showed that the more used engine oil added, the higher the calorific value produced. The calorific values for the sample compositions 5:0, 5:1, 5:2, 5:3, and 5:4 were 10,780.67 cal/g, 10,834 cal/g, 10,952 cal/g, 11,015.33 cal/g, and 11,061.67 cal/g, respectively. The Department of Energy and Mineral Resources (ESDM) set a minimum standard of 10,000 cal/g for all these calorific values [26].

B. Density

DensityDensity measures mass per unit volume [27]. The higher an object's density, the higher its mass per volume [28]. The average density of each object is the total mass divided by the total volume [29]. We conducted the density test in this study using a 25-ml pycnometer and a digital scale. We conducted the test three times to determine the average density, as illustrated in Figure 4.

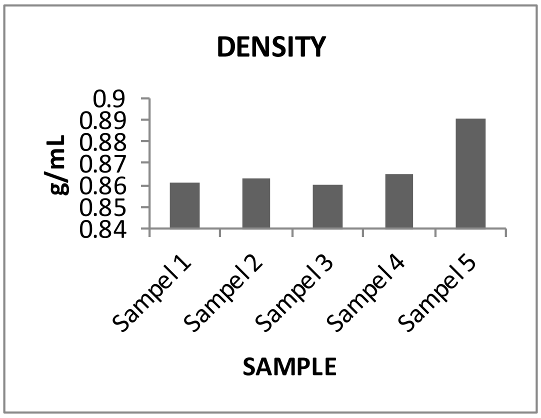

Figure 4: Results of the Co-pyrolysis Density Test

The test results showed densities of 0.8613 g/mL, 0.8631 g/mL, 0.8604 g/mL, 0.8646 g/mL, and 0.8906 g/mL. The average density was 0.8686 g/mL, within the diesel fuel density range of 0.815 g/mL to 0.870 g/m [30].

C. Viscosity

We determined the viscosity by comparing the fuel oil with a reference liquid, water, using an Ostwald viscometer and taking into account the density of both the produced fuel and the reference liquid [25]. Density affects the viscosity of liquid fuel; a higher density increases viscosity because more particles in the fuel hinder flow due to particle friction [31],[32]. The graph shown in Figure 6 below represents the average results of three viscosity tests.

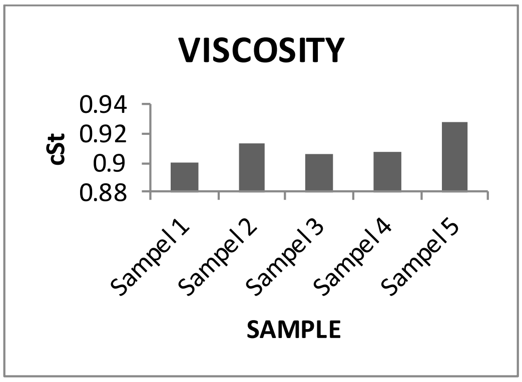

Figure 5: Viscosity Test Results of Co-pyrolysis

The average viscosity of the liquid products obtained from the co-pyrolysis of LDPE plastic waste and used engine oil was less than 1 cSt. Generally, the viscosity of liquid fuel ranges from 0.829 cSt to 2.248 cSt [33]. This study's measured viscosity satisfied Shell Petroleum Canada's 1999 gasoline standard [34].

D. Yield Efficiency

Yield efficiency was calculated by comparing the yield produced (in%) with the energy used to conduct the co-pyrolysis process. The calculation results showed that the highest yield efficiency was 9.14 mL/kWh in the sample with a 5:4 ratio (LDPE: used engine oil) and an efficiency of 1.93%.

Conclusions

This study successfully converted LDPE plastic waste and used engine oil as an alternative liquid fuel through the co-pyrolysis method. The results showed that adding used engine oil increased the calorific value of the liquid product up to 11,061.67 cal/g at the 5:4 composition, exceeding the minimum standard of 10,000 cal/g set by ESDM. The liquid product had an average density of 0.8686 g/mL, similar to diesel fuel, and its viscosity met gasoline standards, making it a potential candidate for a diesel fuel substitute.

The amount of liquid product made compared to the energy used in the process was used to figure out the efficiency. The highest efficiency was found at the 5:4 composition, with 9.14 mL/kWh. This shows that the co-pyrolysis method is very good at turning raw materials into liquid fuel, with a 1.93% energy conversion efficiency. These findings suggest that while co-pyrolysis can enhance the liquid product's characteristics, it is crucial to focus on energy efficiency to ensure the process's viability as a sustainable waste management solution.

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