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Viscosity Characteristics of Renewable Energy Fuels from PP and HDPE Plastic Waste Conversion

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ABSTRACT

This study investigates the viscosity characteristics of Renewable Energy Fuel derived from plastic waste, specifically Polypropylene (PP) and High-Density Polyethylene (HDPE). The plastics were subjected to pyrolysis using a plastic waste conversion technology machine at temperatures of 250°C to 400°C. Compared to diesel, the average viscosity of pyrolyzed PP oil is approximately 4.25 cSt, while for pyrolyzed HDPE oil, it is about 3.3725 cSt. Compared to gasoline, the average viscosity values for the oils are 0.603 cSt for PP and 0.5965 cSt for HDPE. These results indicate that both oils have viscosities similar to petrol, suggesting that PP and HDPE plastics can produce fuels with comparable fluid properties. However, further evaluation of other factors like yield, chemical composition, and combustion performance is necessary to determine which plastic provides the overall best characteristics for renewable energy fuel.
Keywords: HDPE Plastic, PP Plastic, Pyrolysis, Viscosity

ABSTRAK

Penelitian ini menyelidiki karakteristik viskositas dari Bahan Bakar Energi Terbarukan yang berasal dari limbah plastik, khususnya Polypropylene (PP) dan High-Density Polyethylene (HDPE). Plastik-plastik ini mengalami proses pirolisis menggunakan mesin konversi limbah plastik pada suhu 250°C hingga 400°C. Jika dibandingkan dengan diesel, viskositas rata-rata minyak pirolisis PP sekitar 4,25 cSt, sedangkan untuk minyak pirolisis HDPE sekitar 3,3725 cSt. Jika dibandingkan dengan bensin, nilai viskositas rata-rata untuk minyak PP adalah 0,603 cSt dan untuk minyak HDPE adalah 0,5965 cSt. Hasil ini menunjukkan bahwa kedua minyak tersebut memiliki viskositas yang mirip dengan bensin, yang mengindikasikan bahwa plastik PP dan HDPE dapat menghasilkan bahan bakar dengan sifat fluida yang sebanding. Namun, evaluasi lebih lanjut terhadap faktor-faktor lain seperti hasil, komposisi kimia, dan performa pembakaran diperlukan untuk menentukan plastik mana yang memberikan karakteristik terbaik secara keseluruhan untuk bahan bakar energi terbarukan

Kata kunci: Pirolisis, Plastik HDPE, Plastik PP, Viskositas

1. Introduction

Waste is a widely discussed problem and is difficult to overcome because people's habits tend to be wrong in responding to it [1]. Plastic waste remains an unresolved environmental issue. Plastic waste is increasing with Indonesia's population growth and economic expansion, notably in the industrial sector. The versatility, lightweight, flexibility, strength, resistance to inertia, low cost, and abundance in various locations continue to drive plastic waste usage. Plastic use has precipitated adverse effects on the local environment, including decreased sanitation levels, air pollution, and compromised public health. Plastic waste is an obstinate inorganic substance that is challenging to decompose naturally due to its robust chemical composition. Hence, innovative solutions are needed to manage plastic waste and mitigate its production. One such approach to diminishing the amount of plastic waste is transforming it into fuel. Plastic can be converted into fuel due to its derivation from the petroleum distillation process [2]. There are two main types of plastic: thermoplastic and thermosetting. Thermoplastic is a plastic that does not change its chemical composition when heated, allowing it to be easily molded into various forms.

On the other hand, thermosetting is a polymer that solidifies and cannot be remelted, making it difficult to reshape. Due to its characteristics, thermoplastic can be reprocessed into various other forms [3]. One method for converting plastic waste into fuel is pyrolysis, which decomposes plastic waste by heating it in an oxygen-free environment. This distillation process produces gas, liquid smoke, and carbon residue [4], and the temperature plays a substantial role in the yield, with higher temperatures leading to more significant amounts of product [5]. Polypropylene (PP) plastic is a thermoplastic polymer made from the monomer propylene, with a boiling point of approximately 168°C. PP plastic is commonly used in consumer products, including bottle caps, cups, and containers [6]. The pyrolysis of PP plastic produces a fuel with a light-yellow hue comparable to gasoline, caused by an uneven proportion of carbon and hydrogen in the fuel [7]. During the pyrolysis process of polypropylene (PP) plastic, the highest quantity of pyrolysis oil was found between 350°C and 400°C [8], [9]. The pyrolysis of PP plastic to produce fuel is visually comparable to premium gasoline, has similar density and viscosity, and has a similar calorific value. Therefore, PP plastic can be used as an alternative fuel source resembling petrol [10]. High-density polyethylene (HDPE) is a plastic with cross-linked molecular bonds that lend it high resistance. When subjected to optimal temperatures during pyrolysis, HDPE waste produces a substantial volume of oil [11]. HDPE plastic can be found in various types of equipment, including dirty detergent, medicine, shampoo, and liquid soap bottles [12]. During the processing of HDPE plastic, the oil produced must undergo additional refinement to reduce its water content, allowing it to be suitable for fuel for cars and motorcycles [13].

Viscosity is a measure of a fluid's resistance to flow. In the context of fuel, low viscosity can lead to leaks in the fuel injection pump, while high viscosity can impair the performance of the fuel injection system and complicate the atomization process during combustion. One standard method for measuring the viscosity of a liquid is using an Ostwald viscometer. This technique involves comparing the flow times of two liquids typically the aquadest and the test fluid through a capillary tube of the exact dimensions. The viscosity of the unknown fluid is determined relative to the reference fluid based on its flow times and densities.

Based on the above explanation, this study highlights the potential of pyrolyzed plastic waste, particularly PP and HDPE, as a renewable energy fuel source. The findings demonstrate that higher reactor wall temperatures enhance the yield and viscosity of the resulting pyrolysis oil. PP-derived fuel showed slightly higher viscosity and better performance in stove efficiency tests, indicating its suitability as an alternative energy source.

2. Materials and Methods

2.1. Materials

The process of converting plastic into fuel is illustrated in Figure 1. This study uses PP and HDPE plastics sourced from Waste Management Sites (TPS) at the University of North Sumatra (USU). The plastic is weighed using a scale, and the duration of the pyrolysis process is measured with a stopwatch. Temperature changes in the pyrolysis tube are monitored using a thermocouple, with readings obtained via a thermocouple reader.

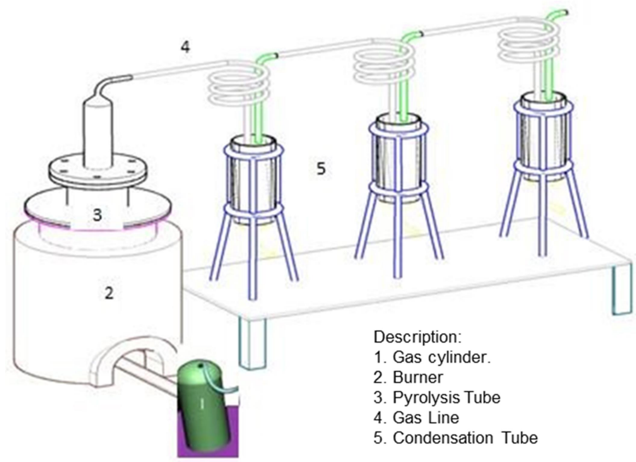

Figure 1. Pyrolysis device for plastic waste.

2.2. Methods

The plastic waste processing procedure begins with collecting plastic waste, which is then sun-dried. After drying, the waste is cleaned to remove soil and dirt before being cut into smaller pieces. These pieces are fed into a plastic waste converter machine, where pyrolysis occurs. The machine's furnace heats the plastic waste, converting the solid plastic into vapor. The vapor travels through a tube to the first condenser, which is cooled and separated into liquid and gas phases. The liquid phase is collected in the first tank, while the gas phase moves to a second condenser for further cooling and separation. The process continues in a third condenser, ensuring that any remaining vapor is condensed into liquid fuel and stored in a final tank. This multi-stage condensation process maximizes the conversion of vapor into liquid fuel.

The procedure begins with setting up the connecting pipe between the pyrolysis gas discharge hole and the condenser tube, then installing and activating the thermocouple in the reactor. PP and HDPE plastic waste is then loaded into the conversion apparatus, and the pyrolysis process is initiated using LPG gas until the temperature reaches 250°C (PP) and 300°C to 400°C (HDPE). After collecting the pyrolyzed oil from the collection tube, the LPG heater is turned off, and the amount of LPG gas used is measured. Once all pyrolysis oil samples are gathered, their properties are analyzed to determine their suitability as renewable energy fuels.

3. Results and Discussion

3.1. Product Yield from Plastic Pyrolisis Process

The test data is based on the oil produced from the pyrolysis of 2.5 kg of plastic waste. The quantitative results, detailing the amount of oil obtained from the conversion of plastic waste, are shown in Figure 2.

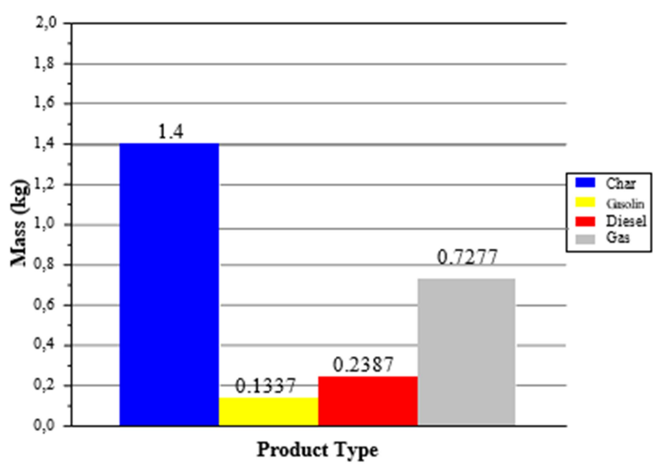

Figure 2. Graph of product yield from pyrolysis of HDPE plastic.

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The results of the HDPE plastic pyrolysis process yielded 2.5 kg of products. 1.4 kg of the products were solids, while the gasoline output was the least at 0.1337 kg. The remaining products were diesel and gas.

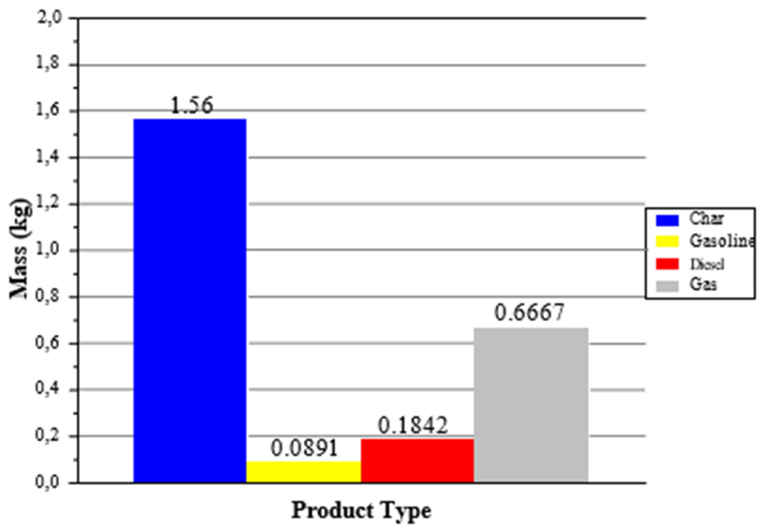

Figure 3. Graph of product yield from pyrolysis of PP plastic.

Figure 3 shows the results of the pyrolysis process of 2.5 kg of PP plastic. Producing most products in the form of solids, as much as 1.56 kg, and the least product is gasoline, which is 0.0891 kg; the rest is diesel and gas.

3.2. Viscosity Test Results

The viscosity of pyrolyzed plastic oil is an observable parameter. The test method employed is ASTM D 445-97; a viscometer is the preferred testing equipment. The technique involves measuring the time it takes for the sample to flow at 40°C within a pre-determined boundary. A viscometer factor that conforms to the viscometer's specifications will be utilized to ascertain the viscosity value used in the experiment. It's pertinent to note that the viscometer factor may vary based on the viscometer number used.

Table 1. Viscosity data of diesel equivalent oil.

Sample	Experiment Number	Viscometer Number	Multiplier Factor	t_1 (s)	t_2 (s)	$t_{Average}$(s)	Viskosity (cSt)
Pyrolyzed PP oil	1	S 163	0.03740	115.4	115.7	115.5	4.332
	2	U 189	0.03587	116.1	116.3	116.2	4.168
Pyrolyzed HDPE Oil	1	U 225	0.03812	87.5	87.6	87.55	3.337
	2	S 251	0.04160	83.6	83.7	83.65	3.480

* viscosity limit of Gasoline: 0.628-0.652 cSt

Table 1 displays that the mean viscosity value of pyrolyzed PP oil, comparable to gasoline, registers at 0.603 cSt, whereas the viscosity of pyrolyzed HDPE oil equivalent to gasoline is measured at 0.5965 cSt.

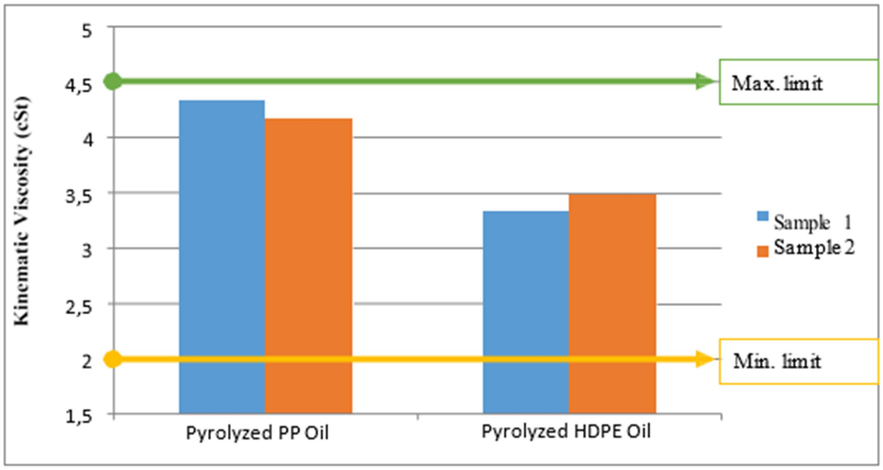

Figure 4. Viscosity graph of diesel-equivalent oil.

Experiments on pyrolyzed PP and HDPE oil twice produced viscosity values equivalent to diesel, ranging between 3.337 and 4.332 cSt (Figure 4). The viscosity value exceeds the minimum limit of diesel viscosity (2 cSt) but has not yet attained the maximum value (5 cSt).

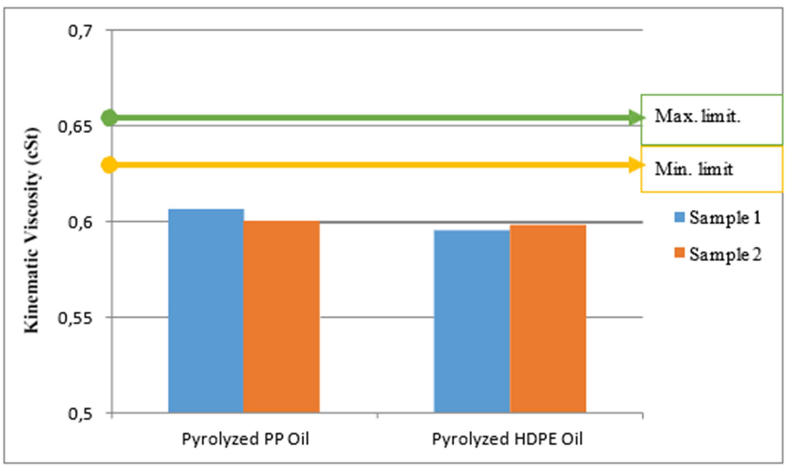

Figure 5. Viscosity graph of gasoline-equivalent oil.

Experiments were conducted twice on pyrolyzed PP and HDPE oil, resulting in diesel-equivalent viscosity values of 0.595-0.606 cSt (Figure 5). It should be noted that this viscosity value falls below the minimum and maximum values of gasoline viscosity, which are 0.628-0.652 cSt.

4. Conclusion

Based on the data analysis results from the conducted experiments, we can conclude that polypropylene (PP) and high-density polyethylene (HDPE) plastic waste can be transformed into alternative fuels through an airless pyrolysis process (without oxygen). The viscosity test results indicate that the viscosity of diesel equivalent from plastic fuel is higher than that of gasoline-equivalent. The viscosity of fuel produced from PP plastic is higher than that of HDPE plastic. The average diesel equivalent viscosity value obtained from pyrolyzed PP oil is approximately 4.25 cSt; for pyrolyzed HDPE oil, it is around 3.3725 cSt. The average gasoline equivalent viscosity values obtained from PP plastic pyrolysis oil and HDPE pyrolysis oil were 0.603 cSt and 0.5965 cSt, respectively.

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