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by I Gede Bawa Susana

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Conversion of LDPE and PP plastic waste into fuel by pyrolysis method

Ida Bagus Alit, I Gede Bawa Susana * and I Made Mara

Department of Mechanical Engineering, Faculty of Engineering, University of Mataram, Jl. Majapahit No. 62 Mataram-Nusa Tenggara Barat 83125, Indonesia.

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Abstract

This study aims to produce fuel from plastic waste and determine the physical properties of the fuel. Plastic waste used is mineral water bottles (polypropylene/PP) and plastic bags (low-density polyethylene/LDPE). The method used is an experimental method using pyrolysis. 1 kg of raw material is chopped before being put into the pyrolysis container. The container is then heated and turns the plastic into a liquid and then evaporates. The hot plastic vapor flows into a heat exchanger to be condensed. The cooling process uses water with a counter flow direction of the steam flow. The results of the steam condensation process are then analyzed for their physical properties. The fuel obtained from 1 kg of raw materials is 0.863-0.908 kg, with a density of 742 – 761 kg/m^3. The kinematic viscosity of the fuel is between 1.75-1.93 cSt. Flash points 1-2 ^oC and fire points 8-9 ^oC with HHV of 44.6-46 MJ/kg. The volume of fuel from plastic bottles of mineral water is more and has a higher calorific value when compared to the fuel from plastic bags waste.

Keywords: Plastic Waste; Fuel; Pyrolysis; Physical Properties

1. Introduction

Plastic is a polymer that has unique and extraordinary properties. A polymer is a material consisting of molecular units called monomers [1]. The use of plastic is often found in the community because it has several advantages such as: easy to shape according to needs, easy to carry, and low price. However, plastic has the disadvantage of being difficult to decompose by the soil so that it can pollute the environment. Plastics can be divided into two types, namely thermoset plastics and thermoplastic plastics. Thermoset plastic cannot be recycled because the polymer composition is in the form of three-dimensional bonds. such as PU (Poly Urethane), UF (Urea Formaldehyde), MF (Melamine Formaldehyde), polyester, epoxy, and so on. While thermoplastic plastic is plastic that can be molded repeatedly in the presence of heat. Thermoplastic plastics include PP, PE, PS, ABS, SAN, nylon, PET, BPT, Polyacetal (POM), PC, and so on [2].

Indonesia is in the 2nd position as a producer of plastic waste after China [3], so it has the potential to cause considerable environmental damage. The Indonesian government has begun to commit to reducing plastic waste through the 3R (Reduce, Reuse, Recycle) program, and the Government is targeting a reduction of up to 70% by 2025 [4]. Various studies have been conducted to contribute to the processing of plastic waste. The Integrated Sustainable Waste Management (ISWM) model states the need to collaborate between stakeholders, final disposal, and waste processing units [5]. Reducing plastic waste can also be done by restricting the use of plastic bags, such as those carried out by several countries in Denmark, China, Bangladesh, South Africa, and Belgium, through prohibitions and or the application of taxes [6].

* Corresponding author: I Gede Bawa Susana
Department of Mechanical Engineering, Faculty of Engineering, University of Mataram, Jl. Majapahit No. 62 Mataram-Nusa Tenggara Barat 83125, Indonesia.

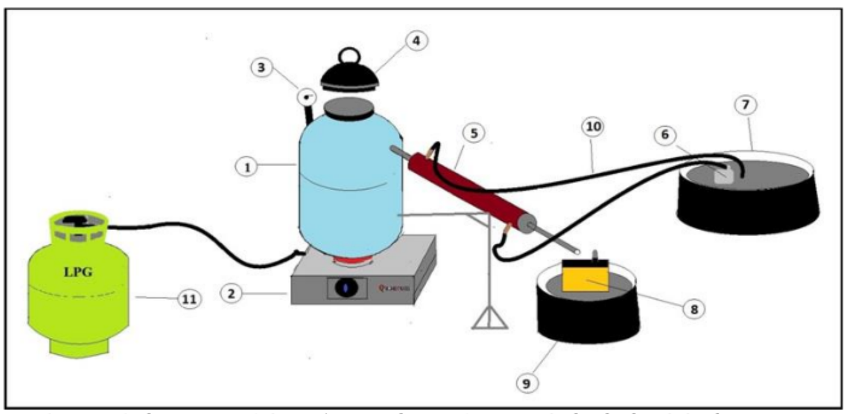
Converting plastic waste into fuel includes tertiary recycling. Converting plastic waste into fuel can be done by a cracking process. Cracking is the process of breaking polymer chains into lower molecular weight compounds. The results of this plastic cracking process can be used as chemicals or fuel. There are three types of cracking processes, namely [7]: 1. Hydro Cracking. Hydrocracking is a cracking process by reacting plastic with hydrogen in a closed container equipped with a stirrer at a temperature between 423 K – 673 K and a hydrogen pressure of 3–10 MPa. The hydro-cracking process is assisted by a catalyst. To assist the mixing and reaction, 1-methyl naphthalene, tetralin, and decalin are usually used as solvents. Some of the catalysts that have been studied include alumina, amorphous silica-alumina, zeolite, and sulfate zirconia. 2. Catalytic Cracking. This catalytic cracking process uses a catalyst to carry out the cracking reaction. In the presence of a catalyst, it can reduce the temperature and reaction time. 3. Thermal Cracking. Thermal cracking is a pyrolysis process, namely by heating the polymer material without oxygen. This process produces charcoal, oil from the condensation of gases such as paraffin, isoparaffinic, olefin, naphthene, and aromatics, as well as gases that cannot be condensed. In plastic thermal cracking, the macro-molecular polymer structure is broken down into smaller molecules. Thermal cracking reactions can be carried out with or without a catalyst. Several pyrolysis reactors have been developed and tested, such as batch/semi-batch reactors [8], fixed bed reactors, fluidized beds, and spouted beds [9].

The utilization of plastic waste as fuel has also been developed such as the process of making fuel from plastic using a catalyst [10]. The catalyst used in this research is ZSM-5 using a batch reactor. making fuel from LDPE type plastic waste by pyrolysis method with temperature variation [11]. This study did not use a catalyst in the manufacturing process. The operating temperature is 150 ^{o}C and 420 ^{o}C. The result is that plastic oil is equivalent to kerosene, which is approximately 30% of the pyrolysis product and contains a high element of sulfur. The manufacture of fuel from LDPE-type plastic material uses a pyrolysis technique without a catalyst [11]. The experiment was carried out at atmospheric pressure with a temperature range of 150-420 ^{o}C. The result is that the fuel obtained is a type of kerosene. Composition of sulfur content and calorific value using ASTM method and analyzed using gas chromatography.

In this study, fuel will be made from waste plastic bottles of mineral water (PP) and plastic bags (LDPE), the results will be tested for physical properties such as; density, viscosity, and calorific value. This test is carried out to compare the properties of the fuel to other fuels.

2. Material and methods

The research method used is experimental, namely making fuel from plastic waste with the pyrolysis method and then testing the physical properties of the resulting fuel. The raw materials for making fuel from plastic waste are mineral water bottles (polypropylene/PP) and plastic bags (low-density polyethylene/LDPE).



1. Pyrolysis reactor; 2. Heater; 3. Thermometer; 4. Cover; 5. Heat exchanger; 6. Pump; 7. Cooling bucket; 8. Condensate container; 9. Condensate cooling bucket; 10. Hose; 11. LPG cylinder;

Figure 1 Pyrolysis apparatus

First, the plastic waste is cleaned, then cut into pieces, dried in the sun, then weighed (1 kg of plastic waste for each fuel production). The raw materials are then fed into the pyrolysis reactor to be heated. The steam that comes out of the pyrolysis reactor is then flowed and cooled in a heat exchanger. Water is used as a cooling medium that flows in the opposite direction to the flow of steam (counter flow) from the pyrolysis process. The steam will condense and then be accommodated in a container. The result is measured the volume and weight of the oil to determine the density of the oil produced. Viscosity testing using a Viscometer (ASTM D88). Flash point testing using Flash & Fire point Tester (ASTM D93). The calorific value test uses Bomb Calorimeter (ASTM D7843).

3. Results and discussion

The results of making fuel using the pyrolysis method with mineral water packaging glass (PP) and plastic bags (LDPE) as raw materials are shown in Figure 2. The fuel color of PP plastic is clear yellow while the fuel of LDPE plastic is darker. The maximum temperature of the pyrolysis process, volume, and final mass of the resulting fuel is shown in Table 1.

Figure 2 Pyrolysis fuel

Table 1 Data of fuel properties

	Sample	m_s (kg)	T_{max} (°C)	V_{bb} (ml)	m_{bb} (kg)	ρ_{bb} (kg/m³)
LDPE	LDPE.1	1	310	1150	0.883	761.23
	LDPE.2	1	310	1100	0.845	763.88
	LDPE.3	1	310	1120	0.861	762.98
	Average	1	310	1123.33	0.863	762.69
PP	PP.1	1	305	1220	0.912	742.88
	PP.2	1	305	1210	0.903	741.09
	PP.3	1	305	1215	0.909	742.58
	Average	1	305	1215	0.908	742.18

The yield of fuel produced from PP-type plastic is more than LDPE-type plastic. The average volume of fuel from PP material is 1215 ml with a mass of 0.908 kg, then from LDPE plastic raw material is 1123.33 ml with a mass of 0.863 kg. This means that in each test, not all plastic waste can be converted into fuel, but some are lost in the form of non-condensable gas/steam due to the non-optimal heat exchanger installed on the test equipment to condense the steam generated in the heating process of the plastic waste. And there is also a residue in the test tube in the form of ash that cannot be decomposed into fuel. The resulting fuel density is 742.18 kg/m³ for PP oil and 662.69 kg/m³ for LDPE oil, this is in line with research Papari et al. [12].

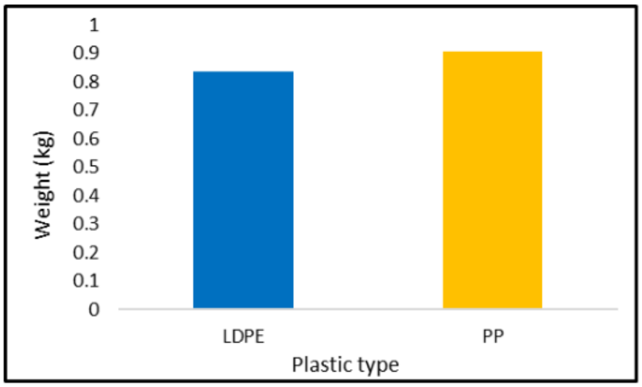


Figure 3 Weight of plastic waste fuel

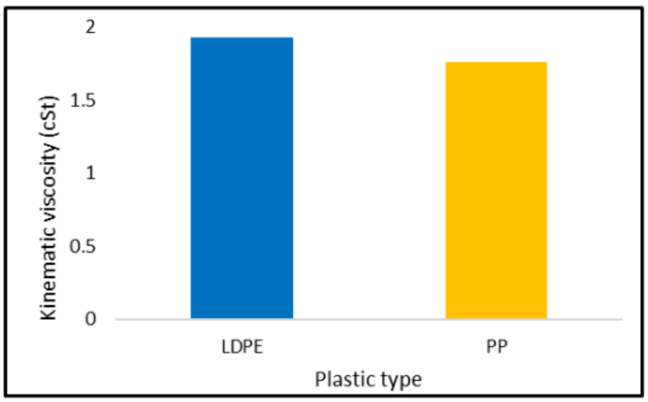


Figure 4 Viscosity of plastic waste fuel

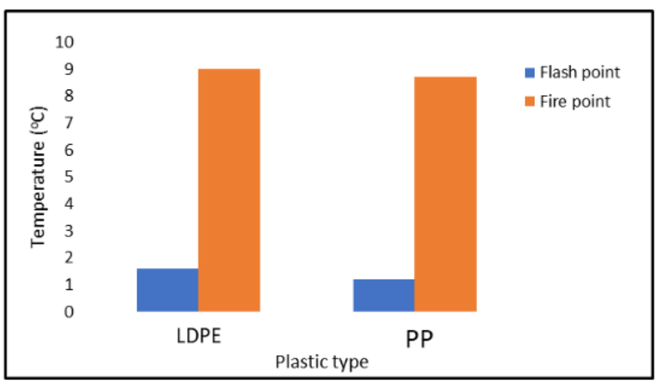


Figure 5 Flash and fire point of plastic waste fuel

The kinematic viscosity of oil from LDPE plastic and fuel from PP plastic ranges from 1.75 to 1.93 cSt. As shown in Figure 4. This result is by the research [calorific value] with a kinematic viscosity range of 1.7-2.3 cSt. The magnitude of the viscosity is also due to the cohesive force in the liquid, namely the attractive force between molecules in the particles that make up the liquid, where the greater the cohesive force of a liquid, the greater the viscosity.

Figure 5 shows the results of the flash and fire point of fuel from the plastic waste produced. Flash pints are in the 1 – 2 °C range and fire points are in the 8 – 9 °C range. This value is in line with the results Syamsiro et al. [10], which state that the flash point value of plastic waste fuel is less than 10 °C. These results indicate that the fuel from the plastic is flammable, so it needs safer storage. The flash and fire point values of oil are closer to gasoline than the flash and fire points of diesel fuel.

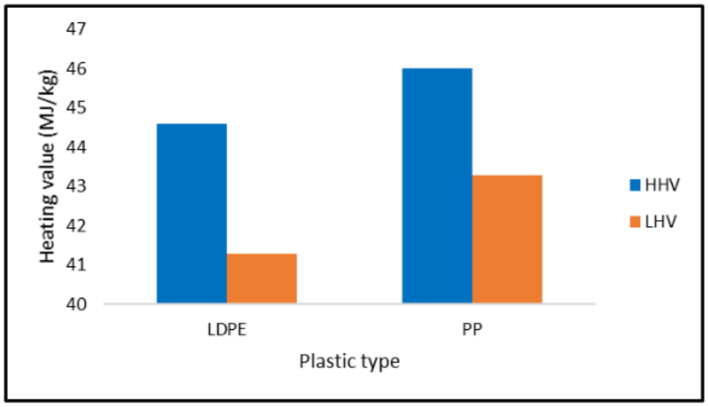


Figure 6 Calorific value of plastic waste fuel

Figure 6 shows the lower heating value and the high heating value of the plastic waste fuel. The calorific value of fuel from PP plastic is higher than that of fuel from LDPE plastic. The lower and high heating values for PP plastic fuel are 46 and 46.3 MJ/kg, while for LDPE plastic fuel are 44.6 and 41.3 MJ/kg. These results are in agreement with Syamsiro et al. [10]; Nugraha et al. [13] the calorific value is equivalent to the calorific value of gasoline fuel.

4. Conclusion

Producing fuel from waste plastic types LDPE and PP with the pyrolysis method can convert 90% of raw materials into fuel. 1 Kg of raw materials produces 0.863-0.908 kg of fuel or the equivalent of 1.12-1.21 liters of fuel. Analysis of the physical properties of the fuel obtained the density, kinematic viscosity, flash and fire point as well as heating value. The density of plastic fuel oil is 742 – 761 kg/m^3. The kinematic viscosity of the fuel is between 1.75-1.93 cSt. Flash points 1-2 °Cand fire points 8-9 °C. The high heating value is 44.6-46 MJ/kg and the lower heating value is 41.3 – 43.3 MJ/Kg. The volume of fuel from plastic bottled mineral water is more and has a higher calorific value when compared to the fuel from plastic bags.

Compliance with ethical standards

Acknowledgments

The author also wishes to thank the Department of Mechanical Engineering, University of Mataram for facilitating the implementation of this research.

Disclosure of conflict of interest

The authors declare no conflict of interest.

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The hot plastic vapor flows into a heat exchanger to be condensed. The cooling process uses water with a counter flow direction of the steam flow. The results of the steam condensation process are then analyzed for their physical properties. The fuel obtained from 1 kg of raw materials is 0.863-0.908 kg, with a density of 742 – 761 kg/m3. The kinematic viscosity of the fuel is between 1.75-1.93 cSt. Flash points 1-2 oC and fire points 8-9 oC with HHV of 44.6-46 MJ/kg. The volume of fuel from plastic bottles of mineral water is more and has a higher calorific value when compared to the fuel from plastic bags waste. Keywords: Plastic Waste; Fuel; Pyrolysis; Physical Properties 1. Introduction Plastic is a polymer that has unique and extraordinary properties. A polymer is a material consisting of molecular units called monomers [1]. The use of plastic is often found in the community because it has several advantages such as: easy to shape according to needs, easy to carry, and low price. However, plastic has the disadvantage of being difficult to decompose by the soil so that it can pollute the environment. Plastics can be divided into two types, namely thermoset plastics and thermoplastic plastics. Thermoset plastic cannot be recycled because the polymer composition is in the form of three-dimensional bonds. such as PU (Poly Urethane), UF (Urea Formaldehyde), MF (Melamine Formaldehyde), polyester, epoxy, and so on. While thermoplastic plastic is plastic that can be molded repeatedly in the presence of heat. Thermoplastic plastics include PP, PE, PS, ABS, SAN, nylon, PET, BPT, Polyacetal (POM), PC, and so on [2]. Indonesia is in the 2nd position as a producer of plastic waste after China [3], so it has the potential to cause considerable environmental damage. The Indonesian government has begun to commit to reducing plastic waste through the 3R (Reduce, Reuse, Recycle) program, and the Government is targeting a reduction of up to 70% by 2025 [4]. 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Cracking is the process of breaking polymer chains into lower molecular weight compounds. The results of this plastic cracking process can be used as chemicals or fuel. There are three types of cracking processes, namely [7]: 1. Hydro Cracking. Hydrocracking is a cracking process by reacting plastic with hydrogen in a closed container equipped with a stirrer at a temperature between 423 K – 673 K and a hydrogen pressure of 3–10 MPa. The hydro-cracking process is assisted by a catalyst. To assist the mixing and reaction, 1-methyl naphthalene, tetralin, and decalin are usually used as solvents. Some of the catalysts that have been studied include alumina, amorphous silica-alumina, zeolite, and sulfate zirconia. 2. Catalytic Cracking. This catalytic cracking process uses a catalyst to carry out the cracking reaction. In the presence of a catalyst, it can reduce the temperature and reaction time. 3. Thermal Cracking. 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The operating temperature is 150 oC and 420 oC. The result is that plastic oil is equivalent to kerosene, which is approximately 30% of the pyrolysis product and contains a high element of sulfur. The manufacture of fuel from LDPE- type plastic material uses a pyrolysis technique without a catalyst [11]. The experiment was carried out at atmospheric pressure with a temperature range of 150-420 oC. The result is that the fuel obtained is a type of kerosene. Composition of sulfur content and calorific value using ASTM method and analyzed using gas chromatography. In this study, fuel will be made from waste plastic bottles of mineral water (PP) and plastic bags (LDPE), the results will be tested for physical properties such as; density, viscosity, and calorific value. This test is carried out to compare the properties of the fuel to other fuels. 2. Material and methods The research method used is experimental, namely making fuel from plastic waste with the pyrolysis method and then testing the physical properties of the resulting fuel. The raw materials for making fuel from plastic waste are mineral water bottles (polypropylene/PP) and plastic bags (low-density polyethylene/LDPE). 1. Pyrolysis reactor; 2. Heater; 3. Thermometer; 4. Cover; 5. Heat exchanger; 6. Pump; 7. Cooling bucket; 8. Condensate container; 9. Condensate cooling bucket; 10. Hose; 11. LPG cylinder; Figure 1 Pyrolysis apparatus First, the plastic waste is cleaned, then cut into pieces, dried in the sun, then weighed (1 kg of plastic waste for each fuel production). The raw materials are then fed into the pyrolysis reactor to be heated. The steam that comes out of the pyrolysis reactor is then flowed and cooled in a heat exchanger. Water is used as a cooling medium that flows in the opposite direction to the flow of steam (counter flow) from the pyrolysis process. The steam will condense and then be accommodated in a container. The result is measured the volume and weight of the oil to determine the density of the oil produced. Viscosity testing using a Viscometer (ASTM D88). Flash point testing using Flash & Fire point Tester (ASTM D93). The calorific value test uses Bomb Calorimeter (ASTM D7843). 3. Results and discussion The results of making fuel using the pyrolysis method with mineral water packaging glass (PP) and plastic bags (LDPE) as raw materials are shown in Figure 2. The fuel color of PP plastic is clear yellow while the fuel of LDPE plastic is darker. The maximum temperature of the pyrolysis process, volume, and final mass of the resulting fuel is shown in Table 1. Figure 2 Pyrolysis fuel Table 1 Data of fuel properties Sample ms (kg) Tmax (oC) Vbb (ml) mbb (kg) ρbb (kg/m3) LDPE.1 1 310 1150 0.883 761.23 LDPE LDPE.2 1 310 1100 0.845 763.88 LDPE.3 1 310 1120 0.861 762.98 Average 1 310 1123.33 0.863 762.69 PP.1 1 305 1220 0.912 742.88 PP PP.2 1 305 1210 0.903 741.09 PP.3 1 305 1215 0.909 742.58 Average 1 305 1215 0.908 742.18 The yield of fuel produced from PP-type plastic is more than LDPE-type plastic. The average volume of fuel from PP material is 1215 ml with a mass of 0.908 kg, then from LDPE plastic raw material is 1123.33 ml with a mass of 0.863 kg. This means that in each test, not all plastic waste can be converted into fuel, but some are lost in the form of non- condensable gas/steam due to the non-optimal heat exchanger installed on the test equipment to condense the steam generated in the heating process of the plastic waste. And there is also a residue in the test tube in the form of ash that cannot be decomposed into fuel. 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Conclusion Producing fuel from waste plastic types LDPE and PP with the pyrolysis method can convert 90% of raw materials into fuel. 1 Kg of raw materials produces 0.863-0.908 kg of fuel or the equivalent of 1.12-1.21 liters of fuel. Analysis of the physical properties of the fuel obtained the density, kinematic viscosity, flash and fire point as well as heating value. The density of plastic fuel oil is 742 – 761 kg/m3. The kinematic viscosity of the fuel is between 1.75-1.93 cSt. Flash points 1-2 ℃and fire points 8-9 ℃. The high heating value is 44.6-46 MJ/kg and the lower heating value is 41.3 – 43.3 MJ/Kg. The volume of fuel from plastic bottled mineral water is more and has a higher calorific value when compared to the fuel from plastic bags. Compliance with ethical standards Acknowledgments The author also wishes to thank the Department of Mechanical Engineering, University of Mataram for facilitating the implementation of this research. 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