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Converting Low-Density Polyethylene (LDPE) and Polypropylene (PP) into Fuel in Togo

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Abstract: Demographic growth and the expansion of economic activities are leading to an increase in the production of waste, particularly plastic waste, which generates a high level of pollution. In Greater Lomé, plastic waste accounts for around 10% of the total waste produced. As a result, the need to develop more sustainable waste management policies has led to excellent research into ways of recovering this waste. The reuse of plastic waste into reusable plastic articles has long been a common way of solving this problem. Other alternatives for managing plastic waste have also been developed. These include mechanical recycling and energy recovery, which have drawbacks such as labour-intensive sorting and air pollution. However, pyrolysis has received more attention and is a promising way of eliminating this waste while at the same time obtaining useful products as fuels. The aim of this study is to pyrolyse a mixture of LDPE and PP plastic waste. The oil resulting from this pyrolysis has improved properties compared with conventional diesel fuel, with a high cetane number (63.8), a low sulphur content (33.33 ppm) and an approximately equivalent calorific value (45.777 MJ/kg). Further processing of this plastic oil could lead to its use in conventional diesel engines. Converting plastic waste into fuel holds great promise, both environmentally and economically.

Keywords: Plastic waste, pyrolysis, fuel, LDPE and PP

1. Introduction

Thanks to their many uses, plastics have become indispensable. Since 1950, the rate of plastics production has only increased. Between 2000 and 2019, global plastic production doubled to 460 million tonnes, generating 353 million tonnes of plastic waste (OECD, 2022).

In Togo, especially in Greater Lomé, waste production has increased in recent years, reaching 35,0000 tonnes per year (Mélanie, 2022). This increase is due to demographic growth, the development of economic activities and changing lifestyles. Among this waste is plastic waste, at an annual rate of 10% (Sizing, 2023). This plastic packaging, which can take billions of years to degrade because of its stability (Sharuddin, 2016), is a crucial problem for society (Aguado, 2008). Once left in the environment, it clogs gutters, leading to stagnation of wastewater and rainwater, flooding and the development of water-borne diseases and malaria.

To this end, the management of plastic waste is taken into account in all development policies, and so the procedures for managing plastic bags and packaging in Togo have been set out in Article 2 of Decree No. 2011-003/PR of 5 January 2011. One of the objectives of this decree is to recover and recycle plastic waste. However, plastic recycling is considered to be one of the ways in which sustainable development can be taken into account (Traore, 2018). Thus, several stakeholders are committed to sustainable management through recovery in different forms. Two types of plastic waste are produced in Greater Lomé: hard plastics (polyethylene terephthalate, high-density polyethylene, polyvinyl chloride, polypropylene, polystyrene) and soft plastics, which account for 85.76% of plastic waste and whose recovery is very limited (Sizing, 2023). It is therefore important to set up a recovery system for these flexible plastics.

With this in mind, this project was initiated to pyrolyse these materials in order to considerably reduce their impact on the environment. To this end, a 50-50 LDPE-PP mixture was introduced into the pyrolyser in order to extract the plastic oil. The plastic oil was characterised to determine the quality of the oil produced.

2. Materials and Methods

Plastic material

The concern is to recover LDPE, since other types of plastic are reused or undergo mechanical recovery, but LDPE are often single-use and are found everywhere. However, the residence time of LDPE in the reactor is relatively longer than for PP, according to the experiment carried out. When they are mixed, we realise that the time it took to obtain the plastic oil alone with LDPE is reduced. So, as the PP and LDPE monomers are unsaturated hydrocarbons (alkenes), and their density is also close to each other (0.91-0.92) (Fontanille, 2014), we can nevertheless mix them and obtain similar properties in the final product.

Production equipment

We used:

- butane gas as a heating source.
- protective equipment (gangs, closed shoes, mufflers),
- a needle thermometer to take the temperature,
- a stopwatch to monitor the duration of the process
- a chisel to shred the plastic material
- a locally manufactured pyrolysis device,

The pyrolyzer, made from stainless steel, is cylindrical in shape, 51 cm high, 20 cm in diameter and has a capacity of 16,103 cm3. The device can hold at least 1.5 kg of soft plastics or 1 kg of hard plastics. Figure 1 shows the pyrolysis prototype used.

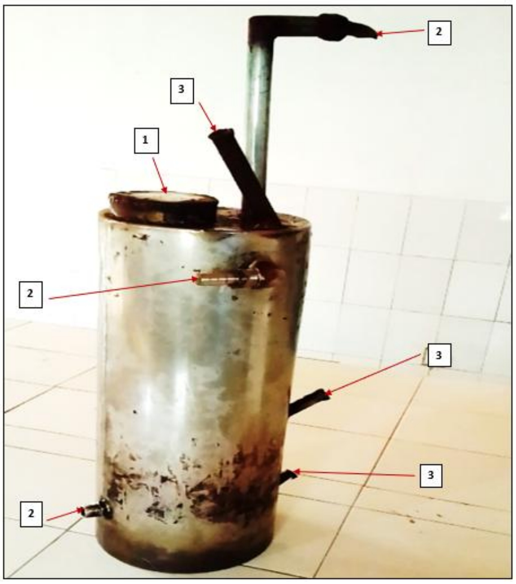

Figure 1: Diagram showing the pyrolysis system
1: Opening; 2: Gas outlet; 3: Thermometer location

Methods

Preparation of raw materials

Once the waste had been collected, it was emptied of its contents, the labels removed, washed and dried to avoid any presence of water, which could reduce the yield of the product to be obtained. The plastics were then manually cut into small pieces to facilitate melting. For our experimental study, a mixture of LDPE and PP plastics was used, each weighing 250g. Figure 2 shows the weighing of this waste.

a. PP

b. PEBD

Figure 2: Plastic weighing

Heating

Once the plastic (50% LDPE and 50% PP) had been introduced into the pyrolyser, it was hermetically sealed and the whole unit was heated to a temperature of between 200°C and 400°C for approximately 1 hour. The vapour collected was condensed by a water cooling system. The uncondensed gas was collected by an exhaust system and then burnt.

During heating, a temperature reading was taken to determine the temperature at which the product was obtained until heating stopped. Plastic oil is obtained at 350°C after 20 minutes of heating. Apart from the plastic oil produced, a by-product (coke) is generated at the bottom of the device. Figure 3 shows the pyrolytic device. Figure 4 shows the location of the thermometer and the plastic oil collected at the end of the operation.

Figure 3: Device for heating


a. Taking the temperature


b. Plastic oil

3. Results and Discussion

The plastic oil obtained from the blend of 50% LDPE and 50% PP was analysed to determine its properties and to compare it with diesel fuel. The results obtained are shown in Table 1.

Table 1: Comparison between the physicochemical properties of plastic oil and conventional diesel (Singh, 2020; Mangesh, 2020; Gu, 2018)

Properties	Methods	Plastic Oil	Diesel	Method
Density 15°C (kg/ m^3)	ASTM-D-1298	784.2	820 - 850	ASTM-D-1298
Cetane Index	ASTM-D-4737	63.8	55	ASTM-D-4737
Total Sulphur (ppm)	ASTM-D-4294	33.3	3000	ASTM-D-4294
Flash Point (°C)	ASTM-D-93	Flames below 35	50	ASTM-D-93
Gross Calorific Value (MJ/kg)	ASTM-D-240	45.777	46	ASTM-D-240
Kinematic Viscosity 40°C (cSt)	ASTM-D-445	1.8	2.31	ASTM-D-445
Pour Point (°C)	ASTM-D-97	8	-15	ASTM-D-97
Cloud point (°C)	ASTM-D-2500	12	-21	ASTM-D-2500
Ash Content (%wt)	ASTM-D-482	0.2	0.01	ASTM-D-482
Distillation	ASTM-D-86			ASTM-D-86
Temperature:				
Initial boiling point (°C)		56.1		
10% evaporated (°C)		123.5	196	
50% evaporated (°C)		251.3	267.6	
90% evaporated (°C)		376.3	334.1	
Final boiling point (°C)		384.1		

The table shows that the density of the plastic oil obtained is lower (784.2 kg/m3) than that of the diesel fuel (820 kg/m3). Density is an important parameter to take into account when using fuel, as it can have an impact on engine performance and fuel consumption. The plastic oil obtained from the LDPE-PP blend (50-50) gives a density that is not too far from the standard; the difference is 4.36%, which can be considered tolerable. Since this value is neither higher nor lower than the standard, it will have no impact on engine performance or fuel consumption. In fact, a density that is too high can lead to incomplete combustion of the fuel, thus reducing engine performance and increasing fuel consumption. Similarly, too low a density can lead to increased wear on engine parts. The kinematic viscosity (1.8 cSt) determined at 40°C is low compared with conventional diesel (2.31 cSt), so the plastic oil can spread easily in the engine. This low value is due to the composition of the plastic. When plastic is manufactured, additives are added to give it the shape the manufacturer wants (Bitisch, 2003). This addition of additives will affect the viscosity of the fuel.

The 10% distillation temperature of the plastic oil obtained (123.5°C) is lower than that of diesel (196°C), which shows that this oil contains a significant quantity of lighter compounds (shorter hydrocarbon chains). On the other hand, distillation at 90% gives a temperature (376.3°C) higher than that of diesel (334.1°C); this indicates that the plastic oil contains not only light compounds but also heavier products (Gu, 2018). The amount of sulphur found in plastic oil is low (33.3 ppm) compared with diesel fuel (3000 ppm). The use of this plastic oil in the engine will improve the quality of the environment, as the value indicated by the plastic oil is negligible compared with diesel. The calorific value of plastic oil (45.777 MJ/kg) is roughly equal to that of diesel fuel (46 MJ/kg). As a result, boilers can easily use this oil to generate electricity. Moreover, limiting ourselves to this parameter, we can say that diesel engines can run on this oil without any problem (Damodharan, 2019).

The cetane number of plastic oil is higher (63.8) than that of diesel fuel (55). The cetane number is a very important parameter for diesel fuel, describing the ability to self-ignite and trigger the combustion process. Being higher than that of diesel fuel, it indicates that the ignition delay when this oil is introduced into a diesel engine will be shorter. As a result, using this oil can be beneficial both in terms of maintaining engine performance and improving the quality of the environment. As the cetane number is high, peak pressures in the engine will be lower and combustion periods will be shorter, reducing emissions of nitrogen monoxide (NOX), sulphur monoxide (SOX) and carbon monoxide (CO) (Gu, 2018).

In view of all the results obtained, plastic oil can be used as a fuel in diesel engines. But mixing it with conventional diesel fuel will be even better. In fact, Awasthi (2017) had carried out a study by introducing a mixture of plastic oil and diesel into a four-stroke monocyclic diesel engine (VCR) and found satisfaction. Singh (2020) goes further by proving experimentally that mixing plastic oil with diesel up to 50% can be used in diesel engines.

4. Conclusion

The resulting oil fraction has improved properties compared with conventional diesel fuel, with a high cetane number (63.8), a low sulphur content (33.33 ppm) and an approximately equivalent calorific value (45.777 MJ/kg). The results of this study are encouraging and have prompted us to carry out in-depth studies to improve the quality of the product. Improving the quality of this oil could lead to its use in conventional diesel engines. Converting plastic waste into fuel holds great promise, both environmentally and economically.

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Declaration of Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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