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Synthetic Oil Production from Waste Plastics

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Abstract

The increased demand and high price for energy sources are driving efforts to conversion of organic compounds into useful hydrocarbon fuels and also propels the intent of this work to derive Synthetic oil from waste plastics through pyrolysis. The waste plastics were obtained in the form of low-density polyethylene (LDPE) and polyethylene terephthalate (PET) found in dumpsites around hostels in Ifite, Awka, Anambra State, and thereafter characterized using the conventional methods of pre-treatment, pyrolysis and condensation. Batch experiments were conducted on both waste LDPE and PET samples respectively to study the specifications of their condensed effluents within the temperature range of 400°C-500°C. The result obtained revealed that PET samples was unfit for synthetic fuel oil production. The reaction rate, quality and quantity of the major product from the pyrolysis of the LDPE sample changed with increase in temperature. The maximum yield of the diesel oil obtained was 70.82% in 60mins from a 12-liter reactor. Series of test were carried out after production such as, the FTIR test, which tells the functional groups present in the synthetic oil, and fuel property tests such as color (brown), density (775.28kg/m^3), viscosity (1.5cm^2/s), ash content (0.15%), flash point (28°C), cloud point (26ºC) which revealed its relatively close comparison to diesel and its suitability for use as fuel.

1. Introduction

Plastics have been woven their way into our daily lives and now pose a tremendous threat to the stability of a conducive environment. The increase in the world population and subsequent living standards have caused a rapid increase in municipal solid waste generation of up to 1.3 billion tons per annum [1]. All plastics are polymers mostly containing carbon, hydrogen and few other elements like chlorine, nitrogen etc.

The growth of waste plastics has occurred rapidly in the last six decades due to the characteristic property of plastics such as light weight and non-corrosivity [2]. However, this increase has turned into a major challenge and is responsible for solid waste related problems at large because most of the waste plastic is neither collected properly nor disposed appropriately to avoid its negative impacts on environmental and public health. On the other hand, waste plastic recycling can provide an opportunity for the proper collection and disposal of waste plastics in the most environmentally friendly way and can be converted into useful resources [3]. A very large part of plastics ends up in municipal waste and poses problems with waste management. Monomers used in plastic production come from fossil fuels and they are non-biodegradable by nature. Hence a strong plastic waste management is crucial. The European commission is planning to implement a circular economy with a key focus on plastics. The objective is to ensure that all plastic packaging is reused or recycled by the year 2030 [6]. Because these plastics are parts from petroleum, the oil produced by pyrolysis process has high calorific value, which can be used as an alternative fuel. Its price and production are determined by the petrochemical industry and the availability of oil and with oil being limited in nature, the most sustainable option is to reduce crude oil consumption so that waste plastics can be reused and recycled as much as possible [7].

The pyrolysis process consists of the thermal degradation of organic materials under an inert atmosphere [5], in other words, Pyrolysis is the thermal decomposition of long chained hydrocarbons into smaller ones in absence of oxygen at a temperature of 350℃-600℃. The thermal decomposition starts at 350ºC, however, if the desired output is other liquid, then the operating temperature should be above 550ºC, which helps producing gas and char [8]. Since no oxygen is present, the organic material does not combust; instead, the chemical compounds that make up the material decompose into combustible gases and charcoal. Thermal degradation is not only used for polymer but it is also used for aromatics and gas. The properties of the synthetic oil obtained by waste plastic pyrolysis have been studied by many authors [9-16], are suitable to be used in vehicle engine although the performance and emission characteristics were much inferior to diesel fuel [4].

On the other hand, it has been demonstrated from doctor test, that the synthetic oil obtained through pyrolysis has very low Sulphur content and the quality of the obtained oil is comparable with the values of the regular diesel. Approximately 85%-90% of waste plastic from our daily life can be recycled or used for the production of synthetic fuel oil in order to decrease the volume of non-biodegradable waste plastics.

2. Materials and Experimental Methods

2.1 Materials

Material of construction is of utmost importance in all Engineering designs. The material selected must have sufficient strength, good resistance to corrosion and be easily worked on. The most economical material was one which satisfied these requirements and gave the lowest cost over the working life of the plant, allowing for maintenance and replacement.

Important properties to consider when selecting a material include:

a. Mechanical properties such as tensile strength, toughness, hardness, fatigue, resistance, creep resistance, and stiffness.
b. Effect of high and low temperature on the material.
c. Corrosion resistance.
d. Any other special properties required such as thermal conductivity, electrical resistance and magnetic properties.
e. Ease of fabrication – forming, welding, and casting.
f. Cost.

Based on the above information, the following process equipment were fabricated and used:

Reactor: The reactor was made from a standard non-pressurized 6kg gas cylinder of about 28cm in length. This cylinder was improvised to suitable working condition as shown in Fig. 1.

Three openings were perforated at the top of the cylinder for purposes of, charging in the raw materials, fitting of the thermometer, and for effluent transfer into the condensation chamber. The reactor is also perfectly sealed to avoid the escape of gas causing heat loss and pressure drop which will consequently lead to a reduction in the yield of the end product.

Furnace: The furnace was made from a standard non-pressurized 12.5kg gas cylinder of about 40cm in length. This chamber houses the heating source which in this case is coal. The reactor is place into this heating chamber and receives its heat supply from here.

An opening was perforated at the bottom of the heater to pass in air from the blower to sustain the heat supplied from the coal. Four seating irons which functions as a balance for the reactor and to create some space for heating source were fixed from the sides of heater. Also, four holes were made in strategic places to allow for supply of air and aiding the supply of heat.

Condensation chamber: This chamber was made from a reformed car radiator consisting of numerous pipes through which the condensable fluid flows and is being condensed as a result of the radiator being submerged in cooling water. The cooling water is changed periodically.

Other proprietary equipment used includes:

Blower: This is powered by the battery and its nozzle is directed into the heating chamber from the base of the furnace. Its supplies sufficient air needed to sustain the heat in the furnace.

Rechargeable battery: The battery is used to power the blower.

Thermometer: The thermometer helps to regulate the temperature in the reactor.

Observations

It is pertinent to note that the following observations through the duration of the equipment testing. These also contributed to the improvements made on the plant its outlook.

First test

- ❖ Leakages were noticed on the reactor and the condensing unit which prompted the use of Teflon in strategic places.
- ❖ The required temperature of above 400°c wasn't attained at first. This was as a result of poor air circulation within the furnace and consequently yielded low Synthetic Fuel oil. This was however fixed by creating openings in strategic places around the furnace to allow for sufficient air passage.
- ❖ The temperature of the cooling water in the condensation chamber was raised rapidly by gaining heat from the furnace by convection. This was fixed by installing an insulator between the furnace and the condensing chamber.

Second Test

- ❖ A test was carried out using PET bottles as feedstock.
- ❖ Wax with a pungent odor was obtained and this led to the clogging of the pipes (wax deposits on the walls of the piping).

- ❖ Steam was used to purge the entire equipment removing the wax deposits and this conformed to the theory that PET bottles are not good feedstock for fuel oil.
- ❖ The steam purge was done by heating water above 250ºC, closing the exit and opening at intervals for pressure.

The fuels produced from this pyrolysis process contain little or no Sulphur content according to the Doctor test because there is no Sulphur in the waste plastic feedstock. This is an advantage compared with the classic fossil fuels such as diesel because Sulphur content in the fuels could form SO_2 after combustion. SO_2 is a pollutant causing severe air pollutions, which affects people health and damages the concrete structure. Therefore, this technology is environmentally friendly and has significant positive impact on the local government and community. In Fig. 1 the materials for construction were coupled into a unit working medium which can be disconnected for mobility and reconnected for use as shown below.

Figure 1: Coupled Pyrolysis Plant

2.2 Experimental Methods

❖ ***Fuel Synthesis***

The unit operations and processes for fuel synthesis is illustrated in a simple unit process diagram in Fig. 2 below.

Pre-treatment

This process involves washing of waste plastic to ensure the removal of dust and dirt. After which the waste plastics are dried (sun drying) to remove moisture content.

Pyrolysis process

This pyrolysis experiment underwent some procedures which were carefully observed. The detailed procedures are given below:

- 1.02kg of the sample was prepared and stuffed inside the reactor.
- Heating source was ignited.

- Blower switched on to sustain the heating source by supplying air.
- The temperature was set on the controller for the pyrolysis to start.
- When the first drop of liquid came out the temperature was noted.
- The weight of the waxy residue left inside the reactor after the process was noted.
- The maximum liquid yield is expected to be recorded at a temperature of 550˚C. The liquid product yield increases from temperature 400˚C to 550˚C.
- The condensable liquid products were collected through the water-cooled condenser and weighed. After pyrolysis, the solid residue left out inside the reactor was weighed. Then, the weight of gaseous product was calculated from the material balance.
- The pyrolysis experiments were repeated three times to obtain reproducible results.
- Steam was used for Purging inside the reactor batch wise.

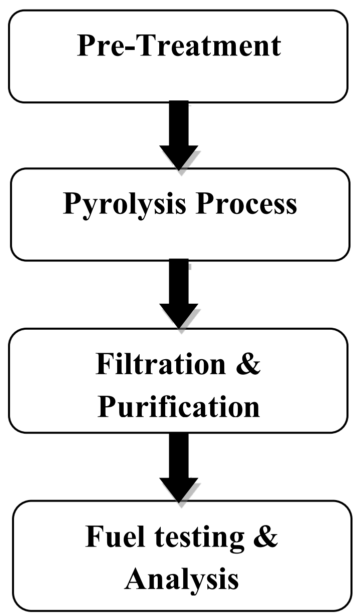

Figure 2: Process diagram for fuel synthesis through pyrolysis

Filtration and purification

The fuel collected in the collection chamber was impure. It consisted of wax, grease, and other impurities. Therefore, to remove the impurities, the following processes were carried out;

- **Gravity separation**:

Gravity separation is a basic process. In this process the impure fluid was poured into a separating funnel. After the fluid was poured, the denser liquid settled below. Finally, most of the oil was seen above in the topmost layer. The top oil was then carefully decanted and further processed.

- **Filtration with filter paper**:

In filtration process, the substances which are in colloidal state is removed. The filter paper will allow the molecules which are smaller than its pores. So, the various size of smaller pores gave cleaner fuel. After this, the collected samples were tested by appropriate methods.

Fuel testing and analysis

The purified fuel was tested to find out its characteristics. In order to interpret the quality and properties of fuel, various tests were carried out in the laboratory under various testing conditions. The tests include the following:

Color, Density, Viscosity, Flash Point, Ash Content, Cloud Point, FTIR Test (FTIR - Fourier Transform Infrared Spectroscopy).

3. Results and Discussions

The experiment was carried out on LDPE and PET wastes and the oil, gas and solid yield is shown below in Table 1. The yield of oil gotten from pyrolysis of 1.02 kg of LDPE at a temperature of 450°C, 1 ATM for one hour for the oil yield, gas yield and solid yield as 0.7204, 0.2834 and 0.0162 respectively. The table shows no oil was gotten from PET. The effluent and remnant were all waxy substances which turned solid after some minutes.

Also, on the aftermath of oil extraction through pyrolysis of waste plastics, the synthetic oil gotten was analysed and the ASTM values was compared to those of diesel as shown in Table 2 below.

Table 1. Yield comparison of synthetic oil got from LDPE to PET

Yield	LDPE	PET
Oil	0.7204	Not suitable
Gas	0.2834	Not suitable
Solid	0.0162	Not suitable (was sticky and hardly measurable)

Table 2. ASTM values of Synthetic Oil from LDPE compared to diesel

Property	Synthetic Oil	Diesel
Colour	Brown	Bright yellow
Density (kg/m^3)	775.28	850
Flash point (^{o} C)	28	38
Cloud point (^{o} C)	-26	-35
Ash content (%)	0.15	<0.01
Viscosity (cm^2/s)	1.9	2.6

- By comparing the corresponding value of Synthetic Fuel oil and diesel using the above listed parameters, it can be observed that Synthetic Fuel oil has a density within the range for diesel as postulate by the ASTM and less dense than diesel.
- The flash point for the Synthetic Fuel oil obtained is lower than the ASTM recommendation for diesel, hence the Synthetic Fuel oil can be improved to suit the standard requirements of diesel.
- The test results also show that Synthetic Fuel oil is less viscous than diesel and this implies that the rate of consumption of the Synthetic Fuel oil will be higher than that of diesel.
- The Synthetic fuel is flammable and combustible at room temperature
- The Synthetic fuel has an ash content of 0.15% as compared to diesel that has ash content of less than 0.01%, and this is a result of being unable to trap or separate non-condensable gases.

- ❖ The flash and cloud point of the oil were gotten as 28°C and -26°C respectively which gives it good flammability
- ❖ The viscosity of the oil was found to be 1.9 cm^2/s which was lower than that of the diesel and shows that the oil gotten from the pyrolysis is a light fuel and flows easily.
- ❖ From above comparative analysis, it is clear that the properties of pyrolysis oil are similar to that of diesel.
- ❖ Hence plastic pyrolysis oil can be used as an alternative fuel for diesel engines and oil-fired furnaces. Char is the material that is left once the pyrolysis process is complete and the fuel recovered.

Generally, the Synthetic Fuel oil has an objectionable odour, low flash point which require careful handling so as to avoid flash fire. The sample results showed that the extract did not ideally meet the specification for diesel, and this is because the experiment was carried out in a closed system without a distilling medium which meant that most of the volatile substances were captured into the synthetic oil, resulting to an increased ash content, and reduced flash point, cloud point and viscosity as shown in the bar chart in Fig. 3 below. This synthetic oil can be further treated by distillation to get an oil with ASTM values even closer to those of diesel.

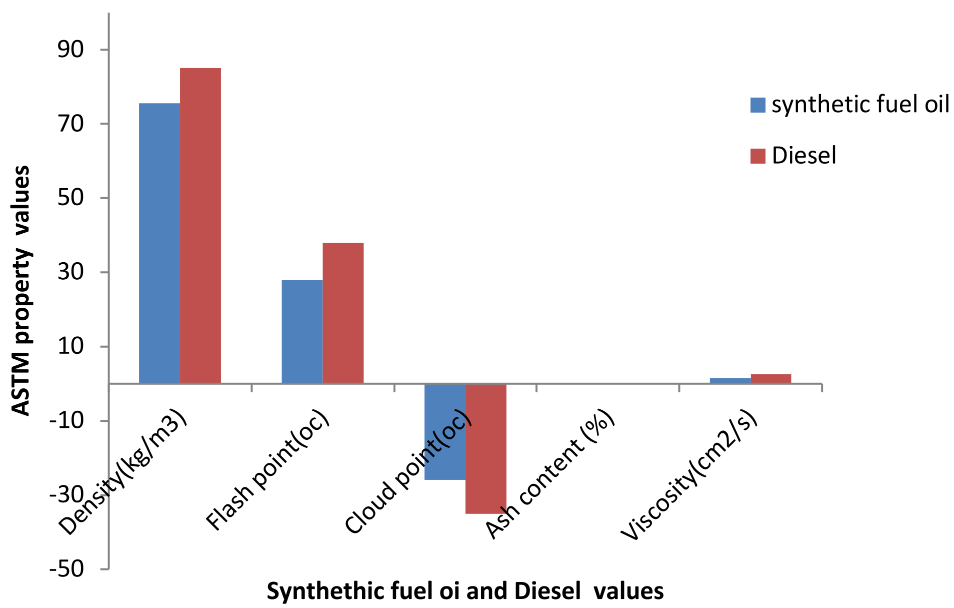

FIG 3*:* Plot of ASTM property values for Synthetic oil against Diesel

- ❖ With density being directly proportional to mass, Synthetic oils have lower density when compared to diesel, because it has smaller or less heavier particles than diesels.
- ❖ Synthetic oils have lower flash point when compared to diesel, because it contains more lighter particles than diesels, and these lighter particles have higher tendencies to ignite quicker at lower temperatures.
- ❖ With cloud point being the point when crystal formation starts, diesel has a lower cloud point because it has heavier particles and would tend to clog less easily than synthetic.

- The higher ash content in synthetic oils can be attributed to the process through which it is prepared, Pyrolysis, which means that because of absence of air, carbon is not combusted but reduced to char, and could be particulate in the finished Synthetic oil product.
- Viscosity is directly related to the intermolecular forces between the particles of the fluid. And with diesel having the weightier molecules and smaller intermolecular distances between its particles makes for its higher viscosity compared to the larger intermolecular distances between Synthetic oil.

Effect of time on the yield of liquid synthetic fuel oil

From this experiment, it can be ascertained that reaction time has a direct relationship with the yield of the liquid product. The yield of the Synthetic Fuel oil increased appreciably with time which implies that for effective pyrolysis of LDPE, maximum yield is dependent on the length of time allowed for the process as shown in Table 3 below.

Table 3. Shows the relationship between time spent in the reactor and the yield of oil

Time (Mins)	Mass (Kg)	Yield (%)
2	0.0816	8
25	0.1224	12
30	0.1530	15
35	0.1836	18
40	0.2550	25
45	0.3060	30
50	0.3876	38
55	0.5304	52
60	0.7204	70.82

Also, a plot was made on time (plastic wastes spent in reactor) against yield (synthetic oil) which shows the progressive increase in yield with increase in time as shown in Fig. 4 below.

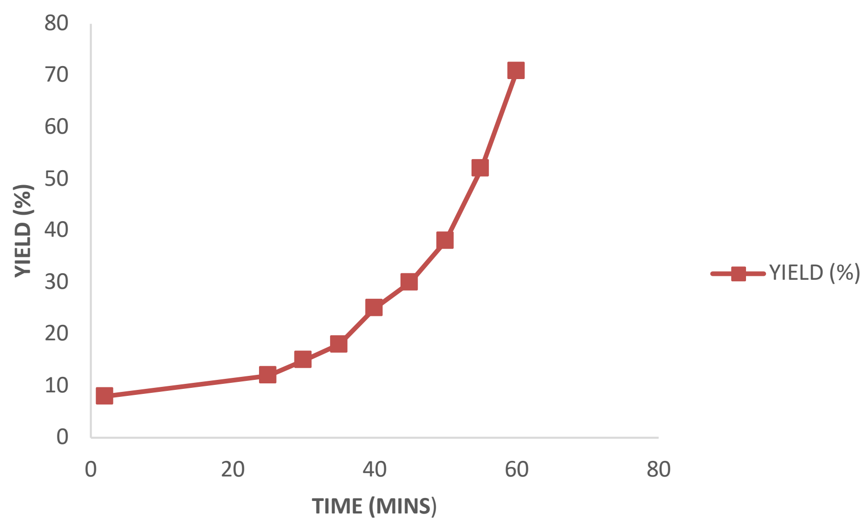

Figure 4: Plot of yield (synthetic oil) against time (spent in reactor); which shows progressive increase in yield with increase in time spent in the reactor.

4. Conclusions

Pyrolysis process was chosen by most researchers among other thermal treatment technologies mainly because of its potential to convert the most energy from plastic to valuable synthetic fuel oil, gas and char. The flexibility that it provides in terms of product preference could be achieved by adjusting the parameters accordingly. The pyrolysis could be done in both thermal and catalytic process. With the pyrolysis method, the waste management becomes more efficient, less capacity of landfill needed, less pollution and also cost effective. Moreover, with the existence of pyrolysis method to decompose plastic into valuable energy fuel, the dependence on fossil fuel as the non-renewable energy can be reduced and this solves the rise in energy demand. Reaction chamber, which operates at 450°c was fabricated for the purpose of producing synthetic fuels from thermal degradation of waste plastics without using a catalyst. We fed the collected LDPE into the reactor and as a result heating gas and liquid fuel were generated and came out of the reactor at different temperature ranges based on their boiling points. This technology would significantly reduce the environmental concern since the rapid rate of plastic consumption throughout the world has led to the creation of increasing amounts of waste and poses greater difficulties for disposal and it also generates fuel from waste.

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