

**EVALUATION OF FUEL OIL PROPERTY PRODUCED BY PYROLYSIS USING PLASTIC WASTES****Osajiele, Mike Irenen^{*1}, Akuma, Oji² & Chukueggu Providence Chinedu³**^{*1}NLNG, Center for Gas Refining and Petrochemical Engineering, University of Port Harcourt, Port Harcourt, Nigeria,²Department of Chemical Engineering, University of Port Harcourt, Port Harcourt, Nigeria,³Department of Chemical Engineering, Faculty of Engineering and Technology Alex Ekwueme Federal University, Ndufu-Alike, Ikwo, Nigeria**DOI: 10.5281/zenodo.4764454****KEYWORDS:** Plastic waste, Pyrolysis, Fuel oil, Polypropylene, Polyethylene terephthalate.**ABSTRACT**

This paper evaluated fuel oil produced from selected plastic wastes using a pyrolysis unit. The produced pyrolysis oil was characterized and compared with commercial diesel. From the results, it was observed that polypropylene (PP) produced more liquid product yield than polyethylene terephthalate (PET) and the oil from PET has a higher density than the oil from polypropylene. However, both oils are still not within the standard density range when compared with commercial diesel. The pyrolysis oil from PP and PET have higher API gravity values than the commercial diesel and as such are lighter fuel oils. The viscosities from the three oil samples were within ASTM D97 Standard of 1.6 to 5.5cst. The pyrolysis oil from PP has a lower pour point than the oil from PET and commercial diesel. PP oil has a higher calorific value when compared to PET oil or Diesel. But the oxygen composition in the PP oil is lower compared to the other two oil samples. Due to the BTEX content, the use of PP oil and PET oil could cause the release of carcinogens, which could lead to food poisoning and other health challenges. Sequel to this, the study recommended that the produced fuel oil from plastic waste such as PP and PET be treated/purified to reduce the heterocyclic amines and the BTEX content to prevent its carcinogenic effect before it is used in combustion engines and be blended with commercial diesel for higher performance.

INTRODUCTION

Currently, the energy demand and environmental degradation, which are due to growing population and rapid industrialization, are of top concern (Danon *et al.*, 2015). Initiatives are being taken to overcome the fossil fuel crisis by looking for alternatives to replace gasoline and diesel fuel. Millions of dollars are being invested in the search for alternative fuels. Waste plastics constitute a global and growing environmental issue. We must deal with their recycling and/ or disposal in an environment-friendly manner. According to reports from the largest associations of rubber manufacturers, about 1 billion new units of waste plastics are turning into waste annually and must be properly managed. In some parts of the World, hundreds of millions of waste plastics are stockpiled and are posing severe health problems: *"They are breeding grounds and havens for mosquitoes and other vectors, resulting in the spread of dengue fever, yellow fever, encephalitis, West Nile virus, and malaria. Once ignited, tire fires are difficult to extinguish. When water is applied to fight the fire, serious air, ground water, and surface water contamination may result. Toxic emissions from plastic fires, such as sulfuric acid and gaseous nitric acid, can irritate the skin, eyes, and mucus membranes, and can affect the central nervous system, cause depression, have negative respiratory effects and, in extreme cases, cause mutations and cancer"* (EPA, 2010). In better regulated geographies, waste plastics are used either in recycling (granulation) or in energy generation. However, recycling is just a palliative care which does not address the absolute removal of the waste. On the other hand, the demand for waste plastics from the recycling industry is not sustainable and reliable. From the literature, current methods used for dealing with the waste plastics problem have not adequately dealt with the problem due to low product quality, low market demands for products and subsequent low selling prices for the products. None of the existing processes have shown to be a pathway for converting the waste plastics into high value products (Mulaudzi, 2017). This, therefore, presents an opportunity to utilise the waste plastics available for conversion into high value chemicals. This paper investigated the feasibility of setting up a plant for this opportunity and producing valuable products.



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Pyrolysis is a method that could be used to valorise the waste plastics through conversion into valuable products. Pyrolysis of waste plastics has been gaining popularity as an attractive (alternative) method of recycling waste plastics (Sastin, 2014). Pyrolysis is a thermal process that decomposes an organic material into low molecular weight compounds under inert conditions. During waste plastic and plastic pyrolysis, the organic rubber material is broken down into a gas (pyrolysis gas), liquid (pyrolysis oil) and a solid product (pyrolysis char) (Zhang *et al.*, 2016). Waste plastics have a high volatile content, which gives high yields of pyrolysis gas and pyrolysis oil (Martinez *et al.*, 2013). The pyrolysis gas has a high calorific value and it is mostly used as alternative fuel for the pyrolysis process. Of the pyrolysis products, the pyrolysis oil is the most interesting fraction. Pyrolysis oil is a complex mixture of aliphatic and aromatic compounds which can be attributed to a wide variety of formulations used in plastic manufacturing (Choi *et al.*, 2014).

MATERIALS AND METHODS

Materials

Pyrolysis unit

The materials used for the pyrolysis unit design were locally sourced for from house hold items that were not in use anymore and other components were bought from the commodity market at Mile 3, Port Harcourt, Nigeria:

Waste Plastic Materials

Two plastic types were selected (polyethylene terephthalate and polypropylene).

These materials were bought from road side plastic collectors at a price of 3 PET bottles for ten naira. The collectors gathered these PET bottles from Woji community in Port Harcourt, Nigeria, from homes, offices, business centers and by the road side.

Methods

The methods are in four systematic order as below:

1. Identification and collection of waste plastics
2. Assembling the pyrolysis unit
3. Subjecting the waste plastic to pyrolysis process
4. Physiochemical properties determination of the pyrolysis fuel oil.

Identification and collection of waste plastics

The collection of waste plastic is quite an easy task as compared to other wastes, the plastic wastes are abundant and can be obtained in large quantities from households, roadsides, hospitals, hotels etc.

Assembling the pyrolysis unit

The various components used for the design of the pyrolysis unit were collected and fabricated to specification. The components included:

Reactor

The reactor is a batch reactor with a capacity of 9litres. It carries out thermal decomposition of the feed in the absence of oxygen at a very high temperature and low pressure. The reactor is made of stainless steel which is a simple design and can be powered by a gas burner or an electric stove. The dimensions are:

Top Diameter =24cm

Bottom Diameter = 24cm

Depth = 18cm

Volume = 9000cm³

Diameter of outlet =3cm

Heater

The heater provides the entire system the necessary heat required for it to run. A gas burner, electric stove or charcoal can be used as heating source but in this paper an LPG Burner was used.

**Condenser**

The condenser is the cooling section, it helps to convert the vapor flowing from the reactor through the connecting pipes into pyrolysis liquid fuel. In this study the condenser was operated at a temperature range of 25-30°C.

Connection/Transfer Pipe

The connection/ transfer pipe is a high temperature resistant steel pipe used to transfer the vapor from the reactor to the condenser. The diameter of the transfer pipe used in this paper was 3cm and it was improvised from bath shower water heater hose.

Pyrolysis of plastic waste to produce pyrolysis fuel oil

Figure 1 illustrates the pyrolysis process schematic.

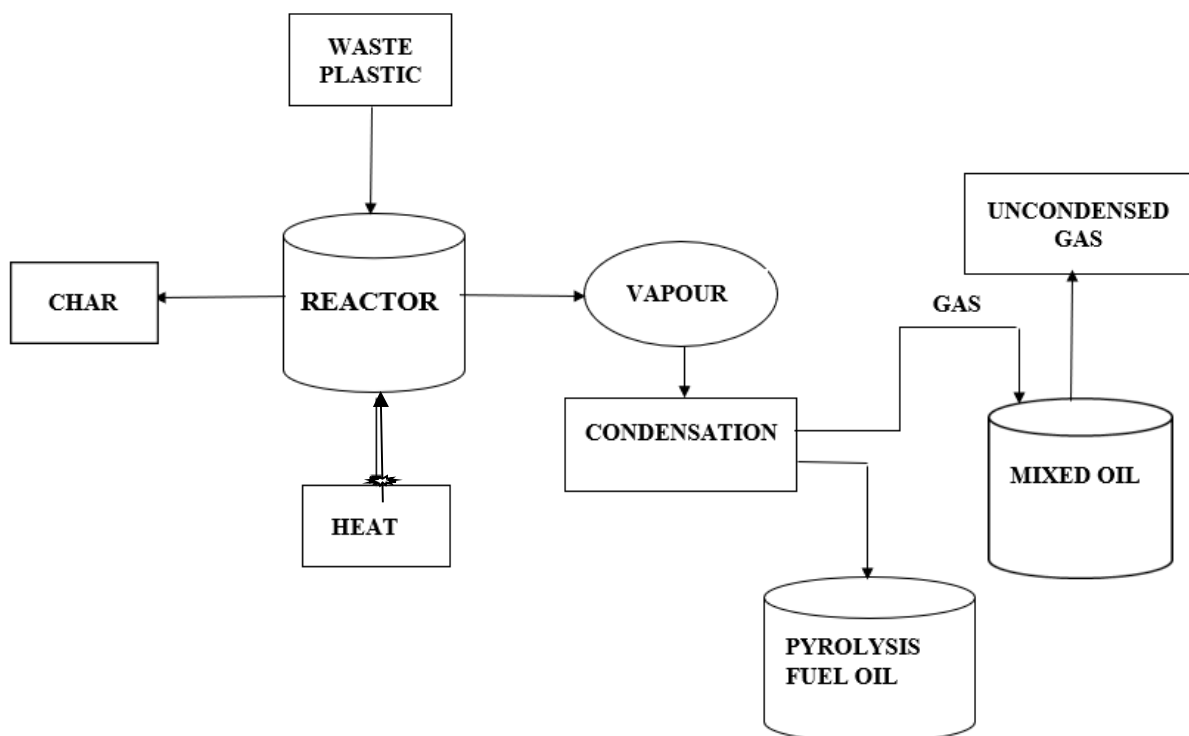


Figure 1: Pyrolysis Process Schematic

The pyrolysis process involves the break down of large molecules to smaller molecules. The thermochemical conversions of plastic to pyrolysis oil were conducted using a pyrolysis batch reactor. Pyrolysis was performed in a pyrolysis plant plastic-to-oil system containing a 9 L reactor and oil collection system using approximately 300g of plastic each time. The pyrolysis plant was operated with a non-catalyst. The plastics were fed into and burnt in the reactor. Briefly, these plastics are heated up to 350-400°C by using an LPG stove at atmospheric pressure and the reactor was heated without oxygen in a residence time of 55mins. The gaseous products are condensed to liquid oil in a condenser tank at 25-30°C. When the liquid has cooled down, it forms the pyrolysis fuel oil. The oils produced from the two plastics are shown below Figure 2.

**Polypropylene****Polyethylene Terephthalate (PET)***Figure 2: Pyrolysis Oil for Plastics*

The condensed products were measured and the gas products was determined by comparing the weight of the collected material by the weight of fed plastics.

Physiochemical properties determination

The pyrolysis oil is to be 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 performed included: Density, Specific gravity, Viscosity, Flash Point, Pour Point, Ultimate analysis, BTEX content, and Fourier Transform Infrared (FTIR) Spectroscopy Test.

Density

Density of plastic waste oils and commercial was measured using the DA-300M digital density meter in the laboratory. The sample was poured in a 45ml beaker up to the 40ml mark and the temperature measured using a thermometer. The sample temperature was 30°C, this temperature value was inputted into the density meter. The weight calibration was done using a glass weight plumb of 100g and then the weight mode was changed to L. The beaker containing the sample was placed under the sensor shelf. A pothook was placed at the center point on the shelf and used to suspend the glass weight and the end part of the pothook was submerged into the sample. The standard glass weight was not allowed to touch with beaker and no bubbles on the surface. After stable sign 0 showed, the enter key was pressed and the machine calculated the density of the sample.

Specific gravity

The specific gravity of the fuel oils were calculated using the equation (1) below.

$$SG = \left[\frac{\rho}{\rho_w} \right] \quad (1)$$

Where

ρ_w = Density of water (1g/cm³)

**API Gravity**

The America Petroleum Institute (API) gravity was calculated mathematically using Equation (2)

$$API = \left[\frac{141.5}{SG} \right] - 131.5 \quad (2)$$

Where

SG = Specific gravity of the sample.

Dynamic Viscosity

The dynamic viscosity was determined using thermo-viscometer with ASTM D445. The viscometer was turned on at the back panel and the spindle was removed to enable calibration. The required spindle type was selected and attached then the viscometer was raised to the highest level using a screw and a beaker with the sample of 40ml was placed under the spindle. The viscometer was lowered until the spindle was submerged to the spindle's mark. A thermometer was submerged in the sample to measure its temperature which was 30°C.

The spindle was operated at 60rpm and after 1 minute the viscosity reading was read.

Kinematic Viscosity

The kinematic viscosity was calculated using Equation (3)

$$v = \frac{\mu}{\rho} \quad (3)$$

Where

μ = dynamic viscosity

v = Kinematic viscosity

ρ = Density of the sample

Analysis of Pour Point

The pour point chamber of NPC 1026 was used to determine the pour point of the sample with some apparatus such as a test jar, cork carrying thermometer, water bath with heater and crushed ice. The sample of oil was poured into the test jar and filled to the level mark. The test jar was tightly closed by the cork carrying the test thermometer and placed in a bath of crushed ice. The test jar was inspected at an interval of at three (3) minutes by holding in a horizontal position for a few seconds before returning it to cool. The pour point was reached when the oil surface stayed in the vertical position for a period of 5 seconds without sagging. At this point the thermometer was inserted to cool for 10 seconds and the temperature of the oil was taken.

Analysis of Flash point

In this paper, the test method used was a Cleveland Closed Cup (the CCC apparatus method). The oil was heated gradually, apertures were opened in the lid to allow air into the cup. As the vapors come, fire was put to it and it was done continuously until a flash was observed, that is flash point temperature and the temperature at which the vapors start catching fire is the fire point temperature.

Ultimate analysis

The ultimate analysis was carried out on the different pyrolysis oil and commercial diesel to determine the carbon, hydrogen, oxygen, nitrogen and sulphur contents.

Sulfur Determination

The sample was placed in the beam emitted from the ray's source. This excited characteristics of the ray was measured and the accumulated count is compared with the count of the previously prepared calibration standard. ASTM D 4249 was used as the standard with a test range of 3mg/kg to 4.6wt% having standard accuracy of 50± 5.9R = 50± 9.8mg/kg.

Carbon Determination

The LECO CHN 2000 Elemental Analyzer with ASTM D5291 was used in the elemental determination of Carbon, Hydrogen, Nitrogen while Oxygen was determined by the difference.

**Fuel oil production yield percentage**

The fuel oil production yield percentage for each pyrolysis oil sample gotten from the different plastic types (PP & PET) were determined after measuring the mass of the pyrolysis oil and the mass of the residue (char) and comparing it with mass of the feedstock plastics. The mass of the fuel oil, feed in plastic and the residue were measured using an electronic weighing scale.

The mass of the light gases was gotten by using equation (4)

$$\text{Light Gases} = \text{Feedstock} - (\text{Liquid oil} + \text{Solid Residue}) \quad (4)$$

Fourier transforms infrared spectroscopy

The fourier transform spectroscopy was carried out using the Nicolet iS10 FTIR spectrometer. (Perkin Elmer Spectrum 100 Series)

Analysis of Benzene, Toluene, Ethylbenzene and Xylene (BTEX) Content

The BTEX content of the oil samples was determined using Gas Chromatography System (model 7890A GC system).

RESULTS AND DISCUSSION**Results**

The physiochemical properties of the fuel oil were evaluated and the fuel oil production yield of the pyrolysis plant. The results are presented in this chapter.

Density/Specific Gravity/ API Gravity

Table 1: The Produced Fuel Density/Specific Gravity/API Gravity from Individual Plastics.

Physical Properties	PP	PET	Commercial Diesel	ASTM Standard
Density (g/cm ³)	0.758	0.772	0.841	0.820 (min) 0.860 (max)
Specific Gravity	0.758	0.772	0.841	0.820 0.860
API Gravity	55.18	51.79	36.75	33.034 - 41.061
Fuel Colour	Reddish Orange	Yellow, not transparent	Purple	-

Dynamic Viscosity

Table 2: Dynamic Viscosity

Fuel oil Type	Dynamic Viscosity(mm ² /sec)
PP	1.972
PET	2.342
Commercial Diesel	2.640

Kinematic Viscosity

Table 3: Kinematic Viscosity

Fuel oil Type	Kinematic Viscosity(cst)
PP	2.602
PET	3.034
Commercial Diesel	3.139



Flash Point

Table 4: Flash Point/Pour Point

Fuel oil Type	Flash Point(°C)	Pour Point (°C)
PP	82	-20
PET	64	-17
Commercial Diesel	105.80	-15

Ultimate Analysis

Table 5: Ultimate Analysis

Fuel Oil Type	C(%)	H(%)	N(%)	O(%)	S(%)
PP	85.62 ± 0.3	10.08 ± 0.3	0.79 ± 0.1	3.40 ± 0.2	0.11 ± 0.3
PET	76.50 ± 0.1	8.96 ± 0.3	4.24 ± 0.2	10.50 ± 0.1	0.11 ± 0.1
Com. Diesel	75.82 ± 0.3	8.98 ± 0.3	4.29 ± 0.1	10.80 ± 0.2	0.11 ± 0.3

Fuel oil Production Yield Percentage (%)

Table 6: Individual Waste Plastic to Fuel oil Production Yield Percentage

Name of Waste Plastic	Fuel oil production yield%	Light Gas %	Solid Residue %
PP	67.133	14.864	18.003
PET	52.157	28.412	19.432
literature value	80	13	7

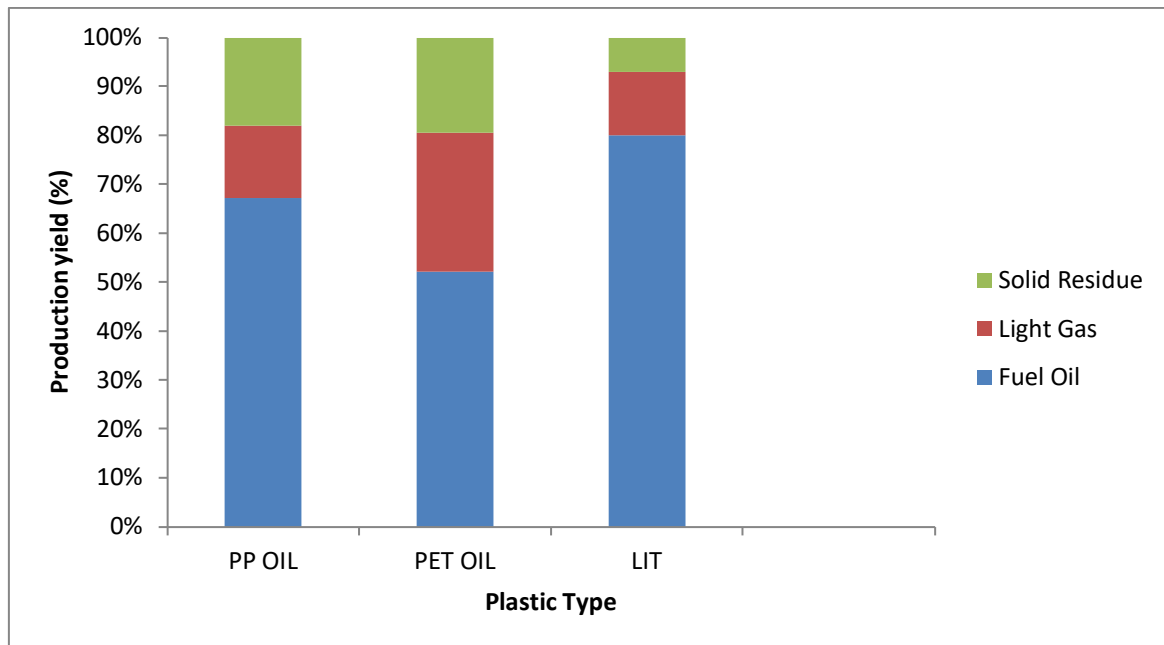


Figure 3: Individual Waste Plastic to Fuel oil Production Yield Percentage



BTEX Content

Table 7: BTEX compounds in pyrolysis oil (PP & PET) and commercial diesel.

S/N	Compound	PP (wt%)	PET (wt%)	Commercial Diesel (wt%)
1	Benzene	0.38	0.12	0.00152
2	Toluene	0.94	0.63	0.08095
3	Ethylbenzene	1.11	0.71	0.17232
4	Xylene	1.52	1.05	0.83877
	Total	3.95	2.51	1.09306

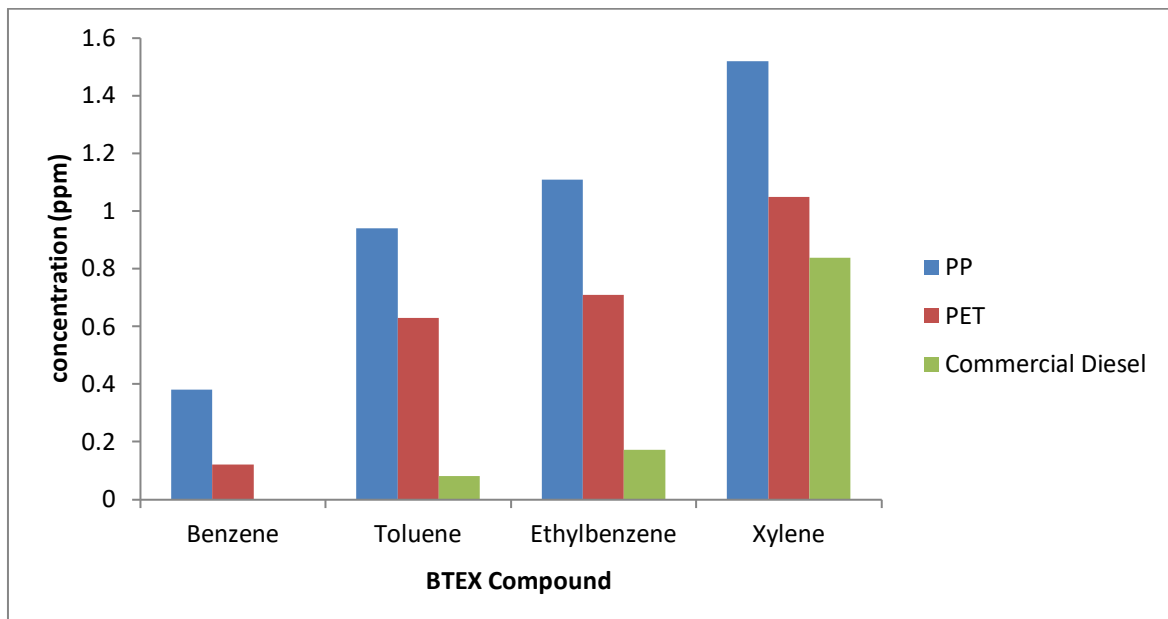


Figure 4: BTEX Content Comparison

Fourier Transforms Infrared Spectroscopy (FTIR)

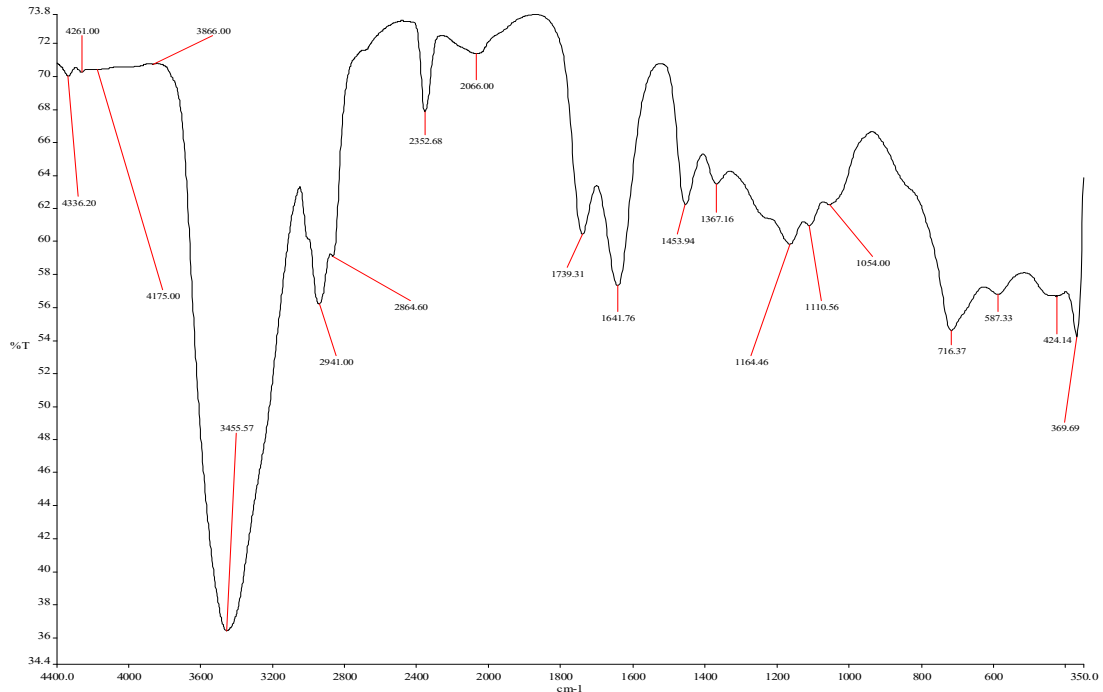


Figure 5: FTIR Spectrum for Polypropylene (PP) Oil.

Table 8: Wave number and functional groups of the characteristic peaks obtained from the PP Oil Spectrum.

Wave Number (cm ⁻¹)	Functional Group Name	Intensity
3455.57	OH/N-H (HCA)	Strong
2941.00	C-H	Medium Narrow
2352.00	C≡C	Weak Narrow
1739.31	C=O	Medium Narrow
1641.76	C=C	Medium Narrow
1164.76	Aryl Suffones	Weak Narrow
587.33	Disulfides C-S	Weak Narrow

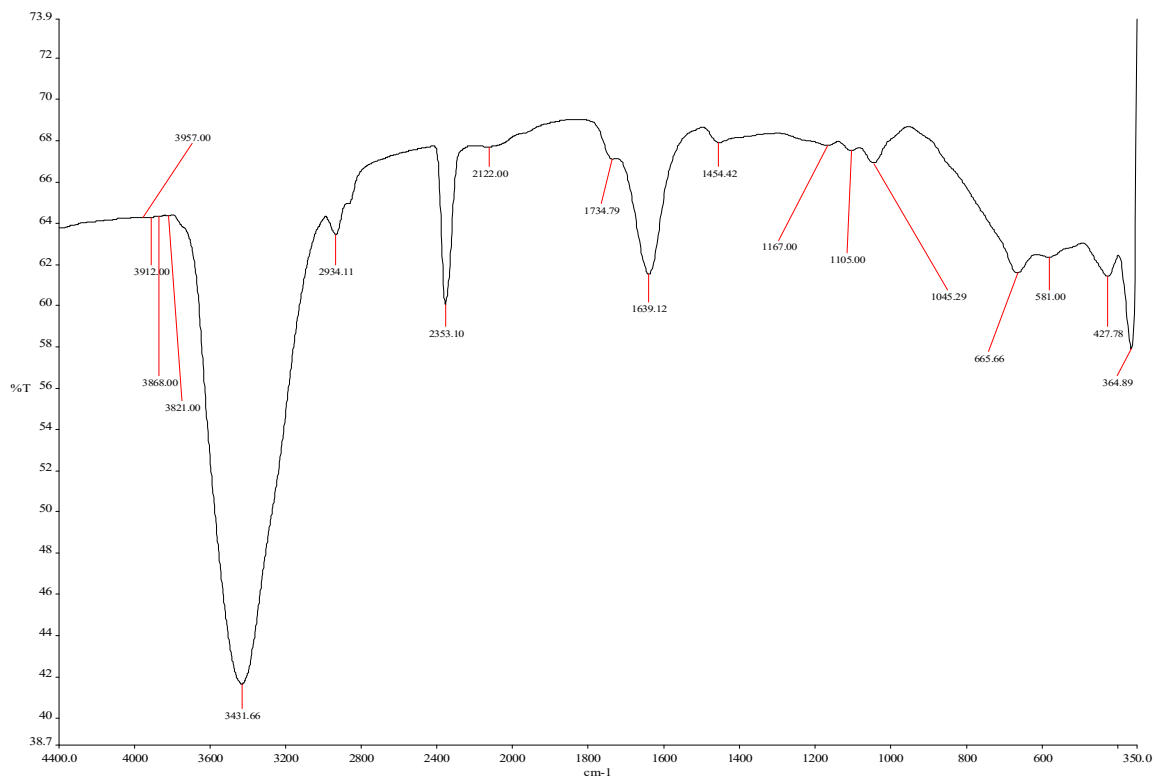


Figure 6: FTIR Spectrum for Polyethylene terephthalate (PET) Oil

Table 9: Wave number and functional groups of the characteristic peaks obtained from the PET Oil Spectrum.

Wave Number (cm ⁻¹)	Functional Group	Intensity
3431.66	OH/N-H (HCA)	Strong
2934.11	C-H	Weak, Narrow
2353.10	C≡C	Medium, Narrow
1734.79	C=O	Weak, Narrow
1639.12	C=C	Medium, Narrow
665.66	Alkyne C-H bend	Weak, Narrow
581.00	Disulfide (C-S)	Weak, Narrow

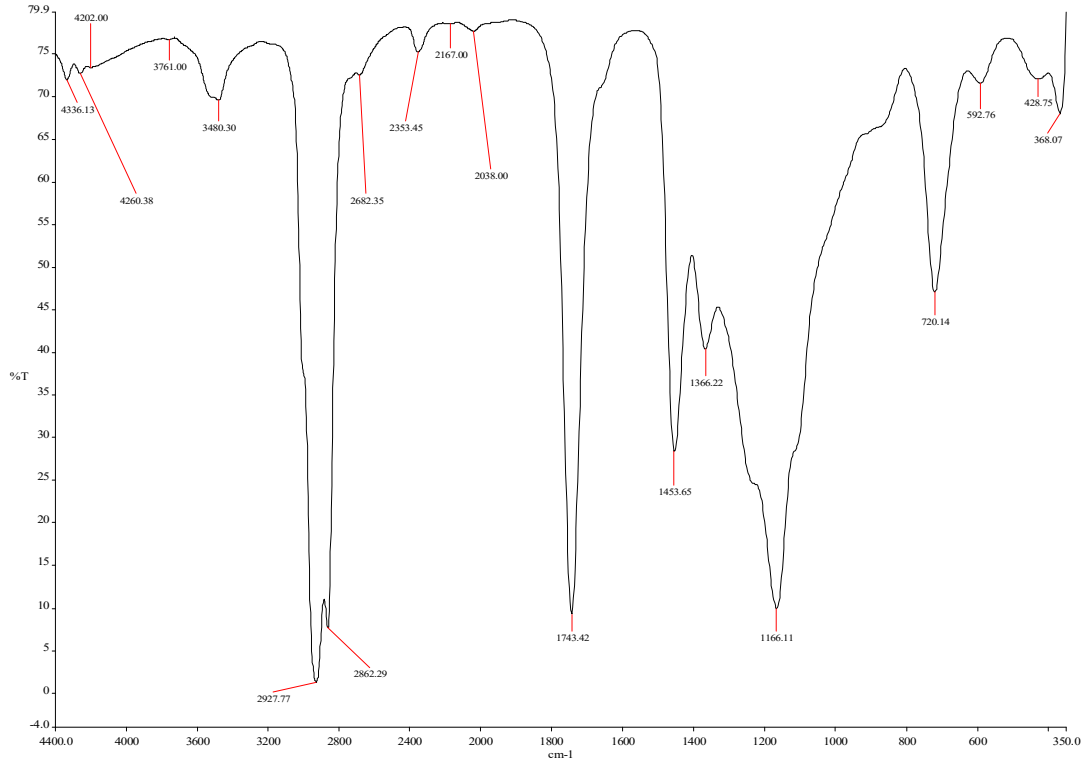


Figure 7: FTIR Spectrum for Commercial Diesel

Table 10 Wave number and functional groups of the characteristic peaks obtained from the Commercial Diesel Spectrum.

Wave Number (cm ⁻¹)	Functional Group	Intensity
2927.77	C-H	Strong
1743.42	C=O	Strong
1453.65	C=C-C	Medium
1366.22	N-O	Medium
1166.11	N-H	Strong
720.14	C-Cl	Medium

DISCUSSION

Density/Specific Gravity/ API Gravity

The density of the oil obtained from polypropylene is 0.758 g/cm³ whereas, the oil produced from polyethylene was 0.772g/cm³. For the commercial diesel, the density was 0.841g/cm³. It can be seen that the oil from PET has a higher density than the oil from PP but only the commercial diesel falls within the standard density range(See table 1). The API gravity from the pyrolysis oil gotten from PP was 55.18° while PET was 51.79°. The commercial diesel happen to be 36.75°. Both pyrolysis oil from PP and PET have higher API gravity values than the commercial diesel and as such the commercial diesel will have lesser value in the market.

Dynamic Viscosity

The dynamic viscosity obtained from the experiment was 2.320mm²/sec, 1.972mm²/sec, and 2.640mm²/sec, for pyrolysis oil (PET), pyrolysis oil (PP) and commercial diesel respectively. The result in table 2 shows that the commercial diesel has a higher dynamic viscosity when compared to the PP oil and the PET oil. This implies that the commercial diesel will possess the highest resistance flow.



Kinematic Viscosity

The kinematic viscosity values obtained were 3.034cst, 2.602cst, and 3.139cst for PET Oil, PP Oil and commercial diesel respectively (See table 3). The viscosity of the PP oil is the least which means that it will have the least resistance to flow. It can also be deduced that the viscosities of the three samples was within ASTM D97 Standard of 1.6 to 5.5cst.

Pour Point

The pour point for the pyrolysis oil gotten from PP was -20°C , PET -17°C and commercial diesel -15°C (See table 4). The results shows that pyrolysis oil gotten from PP has a lower pour point therefore it will flow better in lower temperature conditions than the oil from PET or commercial diesel.

Flash Point

From the results obtained, it can be deduced that the pyrolysis oil from PET is more volatile than PP or commercial diesel. This implies that at lower temperature the PET oil will burn faster compared to PP oil or commercial diesel (See table 4).

Ultimate Analysis

From the result, PP oil has a carbon composition of 85.62 %, hydrogen composition of 10.08%, nitrogen 0.79%, oxygen 3.40%, sulphur 0.11% while PET oil has a carbon composition of 76.50 %, hydrogen composition of 8.96 %, nitrogen 4.24 % , oxygen 10.50% and sulphur 0.11%. It can be deduced from the carbon and hydrogen composition of PP oil and PET oil that PP oil will have a higher caloric valued when compared to PET oil or Diesel. But it can also be observed that the oxygen composition in the PP oil is lower compared to the other two. It therefore means that the fuel oil from PP is more likely to have an incomplete combustion and release more carbon monoxide into the environment compared to PET oil or commercial diesel (See table 5).

Fuel oil Production Yield Percentage (%)

The fuel oil production yield percentage (%), PP gave a Pyrolysis liquid fuel of 67.133%, light gas 14.864% and solid residue 18.003 %. PET gave a pyrolysis liquid fuel of 52.157%, light gas 28.41%, solid residue 19.432% as shown in table 6 and Figure 3. It can be seen that PP gives us more liquid fractions which is more valuable and a minimal residue. Comparing the yield percentage of this experiment to previous literatures, it can be deduced that none of the products used actually reached the literature values. This could be as a result of the experimental conditions and reactor efficiency.

BTEX Content

The BTEX test carried out shows that both PP oil and PET oil contain high amounts of Benzene, Toluene, Ethylbenzene and Xylene. The total BTEX content for the different fuel oils were PP oil 3.95 wt%; PET oil 2.51wt% and commercial diesel 1.0931wt%, as shown in Figure 4 and table 7. This indicates that PP oil contains more amount of BTEX but both PP and PET oil have a very high BTEX content when compared to the commercial diesel. High BTEX content in fuel is very harmful and the release of these sort of chemicals into the environment is carcinogenous, can result to food poisoning and other health challenges.

Result of Fourier Transforms Infrared Spectroscopy (FTIR) of Polypropylene Oil (PP Oil)

From the spectrum in figure 5, it can be deduced that the number of absorption bands are above five therefore, the sample is a complex molecule. In the single bond region ($2500\text{--}4000\text{cm}^{-1}$) there are several peaks. A narrow absorption band of peak wave number 3455.54cm^{-1} was found in this region. This indicates the presence of a hydrogen bond. This band shows the existence of hydrate (H_2O), hydroxyl (O-H) and ammonium.

The peaks observed at 1453.94cm^{-1} , 1164.46 and 716.37cm^{-1} further verifies the presence of the hydroxyl group. Compounds which contain the hydroxyl group usually have spectra at frequencies of $1600\text{--}1300$, $1200\text{--}1000$ and $800\text{--}600\text{cm}^{-1}$ following the hydroxyl group.

The wave number of the peak shows it is a heterocyclic amine ($>\text{N-H}$). The sharp intensity absorption in areas of wave number 4261.00 , 4175.00 , and 3866.00cm^{-1} indicates the presence of oxygen related bonding. The narrow absorption band at 2941 indicates the presence of long chain linear aliphatic group (C-H). For the triple bond



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region ($2000\text{-}2500\text{cm}^{-1}$) there is a characteristic of a triple bond ($\text{C}\equiv\text{C}$) present in the sample, which is indicated by the peak of wave number 2352.68cm^{-1} . In the double bond region ($1500\text{-}2000\text{cm}^{-1}$) there are several peaks. The peak with wave number 1739.31cm^{-1} indicates the presence of a carbonyl group ($\text{C}=\text{O}$) while the peak with wave number 1641.76cm^{-1} indicates the presence of an alkene group ($\text{C}=\text{C}$). For the finger print region that lies below 1500cm^{-1} , several peaks can be observed. One of which is the peak at 1164.76cm^{-1} which shows the presence of trace amounts of aryl sulfones and the peak at 587.33cm^{-1} indicating the presence of trace amount of disulfides.

Result of FTIR of Polyethylene Terephthalate Oil (PET Oil).

From the result, it can be deduced that the spectrum (Figure 6) has more than five absorption bands. The presence of more than five absorption bands on the PET oil spectrum indicates that the sample being analysed is a complex molecule because for simple molecules, the absorption band on the entire IR is usually not more than five. In the single bond region ($2500\text{-}4000\text{cm}^{-1}$) there are several peaks.

A narrow absorption band of wave number 3431.66cm^{-1} is observed on the spectrum and it indicates the presence of a hydroxyl group and this can be further verified by the presence of peaks at 1454.42 , 1167.00 and 665.66 . The sharp intensity absorption in areas with wave number of 3821.00cm^{-1} , 3868.00cm^{-1} , 3912.00cm^{-1} implies the existence of oxygen related bonding.

The wave number of the peak shows it is a heterocyclic amine ($>\text{N-H}$). The narrow absorption band at peak 2934.11cm^{-1} indicates the presence of a linear aliphatic group. In the triple bond region ($2000\text{-}2500\text{cm}^{-1}$), there a characteristic peak of a triple bond ($\text{C}\equiv\text{C}$) present in the sample and indicated at peak 2353.10cm^{-1} . For the double bond region ($1500\text{-}2000\text{cm}^{-1}$), there is a narrow sharp peak of wave number 1639.12cm^{-1} that indicates the presence of an alkene group in the sample. The peak at 1734.74cm^{-1} also tells us that there is another double bond group which in this case is a carbonyl group precisely an ester because of its wave number and intensity. In the Finger print region, which is below 1500cm^{-1} , a peak at 665.66cm^{-1} can be observed, which indicates the presence of an alkyne C-H bend. Still in the finger print region, a peak of 581.00cm^{-1} implies the presence of aryl disulfide (C-S).

FTIR of Commercial Diesel

From the spectrum (Figure 7), it can be deduced that the sample is a complex organic molecule because it contains more than five absorption bands through the entire IR. In the single bond region ($2500\text{-}4000\text{cm}^{-1}$) of this spectrum, several peaks can be observed. There is no broad absorption band in this region, which indicates that there is no strong hydrogen bonding. This implies the absence of the hydroxyl group and indicates that the sample does not contain alcohols or hydrates. The narrow absorption band present at 2927.77cm^{-1} shows the presence of long chain linear aliphatic compounds (C-H). In the triple bond region ($2000\text{-}2500\text{cm}^{-1}$), it was found that there is no characteristic peak in this region. This indicates the absence of a characteristic triple bond group in this sample. However, taking into cognizance the insignificant peaks present in this region, there is a trace amount of the triple bond.

Considering the double region ($1500\text{-}2000\text{cm}^{-1}$), there is a characteristic peak at wave number 1743.42cm^{-1} . It is a strong absorption band and indicates the presence of the carbonyl group ($\text{C}=\text{O}$). For the finger print region, which is below 1500cm^{-1} there is a characteristic peak at 1453.65 which implies the presence of an aromatic ($\text{C}=\text{C-C}$).

In the finger print region also another characteristic peak is observed at 1166.11cm^{-1} , which indicates that secondary amines are present (N-H). The peak at 720.14cm^{-1} within the finger print region indicates the presence of a trace amount of an aliphatic chloro compound in the sample. The chloro compound may be as a result of additives in the sample.

CONCLUSION

This study evaluated fuel oil produced from selected plastic wastes. In the process, a pyrolysis unit was assembled and the pyrolysis oil produced was characterized. From the results, it was observed that the density of the oil



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produced from polypropylene was 0.758 g/cm³ whereas, the oil produced from polyethylene terephthalate (PET) was 0.772g/cm³. This implies that the oil from polyethylene has a higher density than the oil from polypropylene. However, both oils are still not within the standard density range when compared with commercial diesel with a density of 0.841g/cm³.

The API gravity of the pyrolysis oil from PP was 55.18° while that of PET was 51.79°. Comparing these values with that of commercial diesel, which has an API value of 36.75° implies that the pyrolysis oil from PP and PET have higher API gravity values than the commercial diesel and as such have more market value than the commercial diesel.

The kinematic viscosity obtained for pyrolysis oil (PET), pyrolysis oil (PP) and commercial diesel respectively showed that the viscosity of the PP oil is the least, which means that it will have the least resistance to flow. However, all the viscosities from the three samples were within ASTM D97 Standard of 1.6 to 5.5cst.

The commercial diesel has a higher dynamic viscosity when compared to the PP oil and the PET oil, implying that the commercial diesel possesses the highest resistance to flow. The pyrolysis oil from PP has a lower pour point, hence will flow better in lower temperature conditions than the oil from PET and commercial diesel.

Per the flash point results, the pyrolysis oil from PET is more volatile than PP or commercial diesel. This implies that at lower temperature, the PET oil will burn faster compared to PP oil or commercial diesel.

From the ultimate analysis, PP oil has a higher calorific value when compared to PET oil or Diesel due to the carbon, hydrogen content. But the oxygen composition in the PP oil is lower compared to the other two oil samples, implying that oil from PP would most likely have an incomplete combustion and emit more carbon monoxide into the atmosphere compared to PET oil or commercial diesel.

The results also suggested that PP produced more liquid fractions, which is more valuable with a minimal residue. The BTEX analysis showed that both PP oil and PET oil contain high amounts of Benzene, Toluene, Ethylbenzene and Xylene compared to the commercial diesel. This implies that the use of PP oil and PET oil could cause the release of carcinogens, which could lead to food poisoning and other health challenges. Based on these findings, it is advised that produced fuel oil from plastic waste such as PP and PET be treated/purified to reduce the heterocyclic amines and the BTEX content to prevent its carcinogenic effect before it is used in combustion engines.

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