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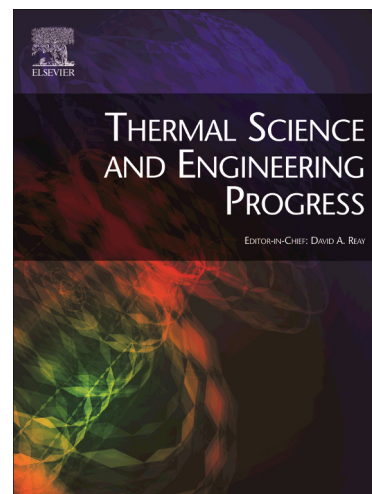
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Plastic Waste to Fuel via Pyrolysis: a key way to solving the severe plastic waste problem in Ghana

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ABSTRACT

The accumulation of plastic waste on the globe, with its harmful environmental impact is on the rise. Development of an efficient conversional method for heterogeneous plastic waste streams would not only provide a solution to this problem, but also, provide a boost to local economies. This study, seeks to exploit the possibility of employing pyrolysis as a means of converting a mixture of plastic waste materials into a resource; to recover crude fuel oil from the waste and also reduce the environmental impacts. Pyrolysis was conducted in a fixed bed reactor at 350 °C with nitrogen gas flow of 200 ml/min for 2 hours, 40 minutes cracking time. The resulted crude product was analyzed by various analytical methods such as FT-IR, GC-MS, and Kinematic Viscosity. The results from the Fourier transform infrared spectroscopy (FT-IR) analysis shows that the fuel oil produced is made up of 21 functional groups which is a blend of aliphatic and aromatic groups of compounds; aliphatic compounds are the most abundant. Also according to the GC-MS results obtained, the fuel oil contains substances that are within the diesel fuel range (C₁₂-C₂₄), with behenic alcohol as the highest peaked compound. The crude fuel oil has a kinematic viscosity of 1.036 mm²s⁻¹, which decreases with increasing temperature. The results show that the crude fuel oil obtained has the possibility to be used as an alternative fuel for wide range of purposes in the future. In this regard, pyrolysis of mixed plastic waste studied here presents an efficient, clean and effective means of removing plastic debris from the environment. Plastic waste isn't the whole problem, how we handle it also count. Thus the responsibility is on us to be smart on how we handle plastic; as pollution, or as an economical resource.

Keywords: Plastic waste; crude fuel oil; diesel; pyrolysis; aliphatic compounds, Gas chromatography–Mass Spectrometry

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1. Introduction

A world without plastics, or synthetic organic polymers, seems unimaginable today, yet their large-scale production and use only dates back to the 1950s [1]. The term “plastic” is derived from the Greek word "plastikos", meaning fit for molding; into a variety of shapes - such as films, fibers, tubes, bottles, etc. [2]. Plastic materials are a wide range of synthetic or semi-synthetic materials that are used in a huge and growing range of applications. The ensuing rapid growth in plastic production is extraordinary, surpassing most other man-made materials [3]. Today, most synthetic plastics are produced from oil or natural gas [4], nevertheless, plastics can be made from any feedstock containing carbon and hydrogen, e.g. sugar, corn etc. It is reported that plastic production uses only 4% of the global oil and gas produced [5]. Although, about 20 distinct groups of plastics exists; there are five high-volume families of plastics. They include; Polyethylene; thus low density (LDPE), linear low density (LLDPE) and high density (HDPE)), Polypropylene (PP), Polyvinylchloride (PVC), Polystyrene (i.e. solid PS and expandable PS) and Polyethylene terephthalate (PET) [2]. Owing to its excellent properties such as; lightweight, high durability, etc., plastics have gradually become prevalent in its use for product packaging, manufacture of numerous valuable products such as protective packaging, lightweight and safety components in automobiles, mobile phones, insulation materials in buildings, medical devices, etc. [5]

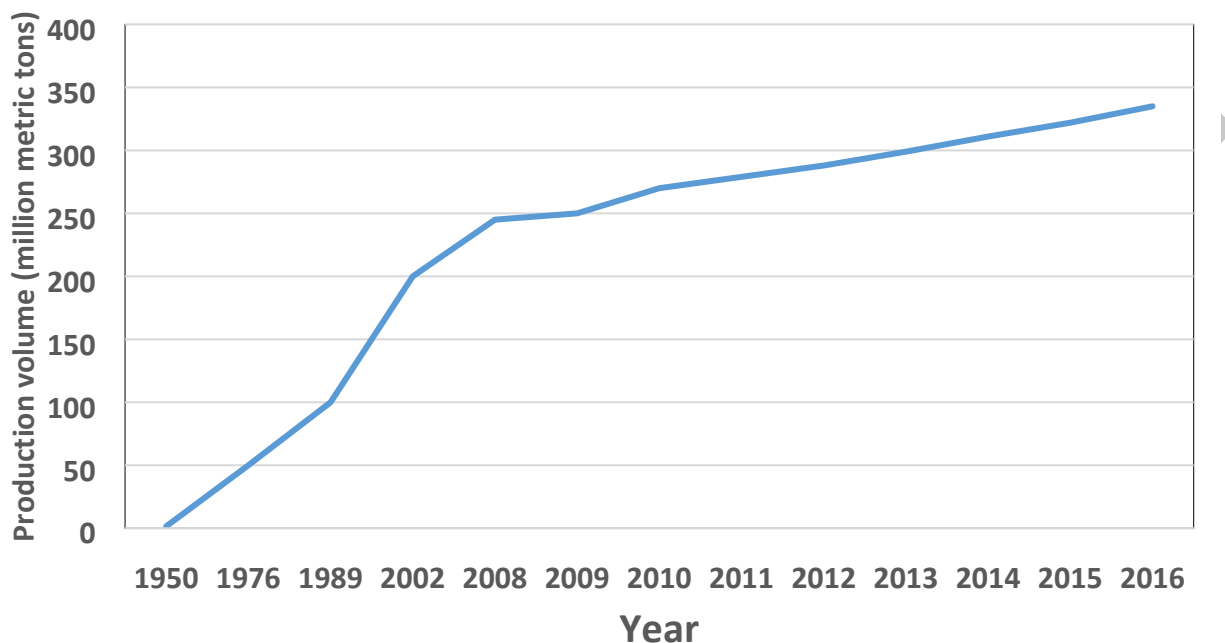


Fig. 1 - Global plastic production. [7]

The above statistic shown in figure 1 depicts the global plastic production from 1950 to 2016. In 2016, world plastic production totaled around 335 million metric tons, with 60 million metric tons produced in Europe alone. China is one of the largest producers of plastics in the world, accounting for around one quarter of the global production. [7]. In Ghana; by the turn of this century, it was reported that there were about 40 plastic manufacturing companies producing about 26,000 metric tons of assorted plastic products annually, with 90% of the companies in the Kumasi and Accra-Tema Metropolitan Areas. Additionally, over 10,000 metric tons of finished plastic products are imported annually into Ghana [8]. The trend seems clear, that production of plastic, its applications and uses will continue to increase globally [9].

In a larger extent, it can be said that the changing consumption and production patterns in the world is resulting in a proportionate rise in plastic waste [10, 11, 8]. The analysis of the

historical trend of plastic waste composition in the waste streams in Ghana shows that in 1979, the percentage by component was 1.4 % and by 1999/2000 its proportion increased to 8 % [8]. Statistics released by the KMA (Kumasi Metropolitan Assembly) Waste Management Department indicated that about 16.5 % of waste which is generated daily, are plastic related [12]. The above statistics tells us that on one hand, more resources are being used to meet the increased demand for plastic, and on the other hand, more plastic wastes are being generated.

Plastic waste over the years has become one of the major causative factors of flooding in some cities in Ghana [13, 14]. Plastic wastes, virtually chokes the drainage systems in many areas, to such an extent that, e.g.; it took just an average of one or two hours of rain in Accra, on 3rd June, 2015, which led to flooding in certain parts of the city. The same intensity and duration of rain, a decade ago, would not have resulted in flooding [14]. Table 1 shows Municipal solid waste composition and generation rate in some selected cities in Ghana.

Table 1-Municipal Solid Waste composition and generation rate in some selected cities in Ghana [15].

City	Waste generation rate kg/day	Organics (%)	Plastics (%)	Papers (%)	Metals (%)
Accra	0.74	65.8	10.4	5.3	3.1
Kumasi	0.75	48.4	17.6	6.5	4.5
Takoradi	0.70	60.0	11.5	7.3	2.4

Tamale	0.33	58.6	10.9	3.2	2.8
Cape Coast	0.67	63.2	10.6	4.1	2.1

These waste plastic materials poses several threats to the environment which includes; raising the risk of transmission of vector-borne diseases such as malaria [16]. When most plastics breaks down, they temporarily breaks into smaller fragments, called ‘micro plastics; when ingested by fish or other marine life, can enter the food chain, this is detrimental to human life. Micro plastics have already been found in common table salt [17] and in both tap and bottled water in some parts of the world [18].

There is no proven figure on the time that most plastics take to degrade, [19], some plastics are designed to be biodegradable and can break down in a controlled environment, such as landfill, but it is uncertain if this will occur under other conditions, especially in oceans where the temperatures are colder [20, 21]. An unfortunate truth about plastics is that; the very properties that makes them preferred to other materials, equally makes it difficult to manage them as a waste.

There are several methods for disposal of municipal and industrial plastic wastes, e.g.; landfill, incineration, material recycling and chemical recovery, gasification, bioconversion, etc. [22, 23]. However, most of these methods of disposal pose serious threats to the environment, e.g.; generation of poisonous substances such as Polychlorinated Biphenyls (PCBs) through incineration, which cause serious health problems. Unless we find a solution to the problem of increasing plastic waste in the environment, we are all being involved in a synthesis that will

throw the ecological balance out of gear and eventually lead to the doom of the ecosystems and the environment as a whole.

Pyrolysis, which is the process of thermally degrading long chain polymer molecules into shorter, less complex molecules through heat and pressure, seem to be viable for the recycling of plastic wastes. The process is able to produce high amount of liquid oil up to 80 wt. % at a moderate temperature around 300 - 500 °C [24]. Pyrolysis does not produce much environmental pollution, thus when the feed mixture is without Sulphur and chlorinated polymers, even with that, work can be done on developing the technology into a green technology. The crude oil produced can be used in multiple applications such as furnaces, boilers, turbines and diesel engines, etc.[25]. Moreover, the gaseous byproduct has substantial calorific value that it can be reused to compensate the overall energy requirement of the pyrolysis plant. Also, the process handling is also much easier and flexible, an intense sorting is not really required because a mixture of different plastics can be fed into the reactor, and thus it is less labor intensive [26].

This study focuses on the possibility of converting a mixture of plastic waste in Ghana via pyrolysis into crude fuel oil. Thus utilizing the plastic waste as resource that will be placed back into the life cycle and economy of plastics; as a way of recovering fuel oil from the waste and to reduce the environmental problems caused by this waste. Specifically this study aims to (i) produce fuel oil from a mixture of plastic waste materials, (ii) characterize the fuel oil and compares it with conventional fuel oils.

2. Materials and methods

2.1. Materials

The major types of plastics considered for the pyrolysis process includes; PP, HDPE, LDPE. Plastic wastes are virtually everywhere and can be obtained in large quantities from the households, roadsides etc. For this work, the plastics were collected from the plastic waste streams of the University of Cape Coast, Ghana. The plastics collected ranged from; bottle and bottle caps, drinking straws, yogurt sachet and containers, plastic plates, detergent bottles, shower curtains, etc.

2.2. Sample preparation

The mixture of waste plastics collected, were washed with detergent and water to clean any dirt's and oils. Oil is a hydrocarbon, and therefore it has the potential to affect the chemical properties of the fuel. The plastic waste was dried and was cut into pieces to the size of 0.5-2.0 inches using scissors.

2.3. Pyrolysis of Plastic waste

Thermochemical conversion of mixture of waste plastics to fuel oils, were conducted using a small scale externally heated fixed bed pyrolysis batch reactor. Basic components of the reactor includes; pyrolysis chamber; thermostat, condenser, thermometer, a heating coil, insulators, storage tank, valves, and gas exit line with an internal diameter and total length of 15 cm and of 38 cm, respectively. This fixed bed reactor is mobile, it has a simple design, less sensitive to variation in particle sizes and quality of feedstock, low gas exit temperature, high burnout and thermal efficiency. The experimental setup is illustrated in Fig 2, below.

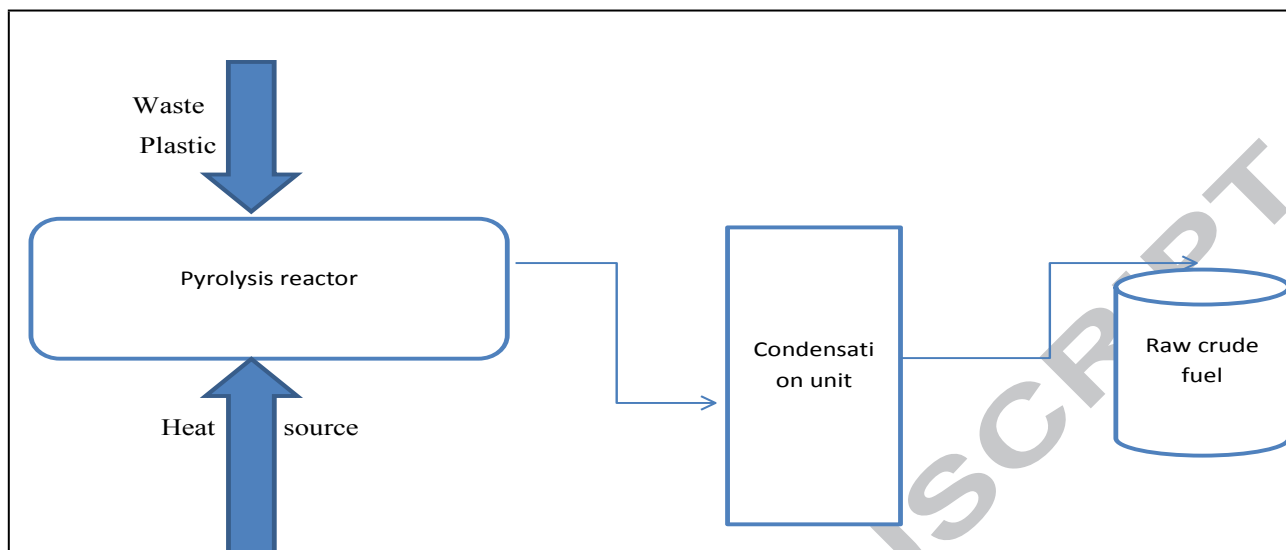


Fig. 2 - A Diagrammatic presentation of the pyrolysis process picture of the pyrolysis movable setup.

The reactor with the various types of plastics was heated up to 350 °C Nitrogen gas was passed through the pyrolysis chamber at a flow rate of 200 ml/min to provide uniform heating across the cross-section of the reactor chamber and to create inert atmosphere in the pyrolysis chamber. Once the reactor temperature reached the set limit, the process started out for about 2 hours and 40 minutes; there was no output at low temperature range. Vapours produced as a result of the thermochemical conversion were condensed over water as crude fuel oil. The upper fuel oil was separated. The reactor lid was opened once the temperature was below 40 °C to remove the residual solid material.

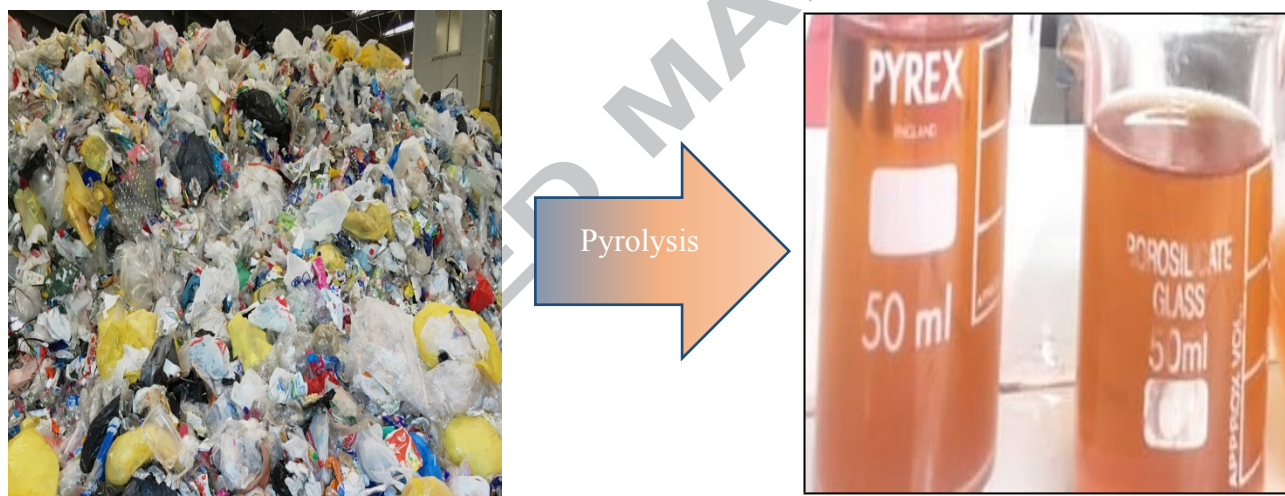


Fig. 3 - An illustration of Conversion of Plastic to Fuel.

2.4. Characterization of fuel oil through determination of kinematic viscosity

A calibrated viscometer was used in this exercise. Time was measured for a fixed volume of liquid to flow under gravity through the capillary of the calibrated viscometer under a reproducible driving

head and at a closely controlled and known temperature ranges of (40, 50, 70 and 80) °C. Below in equation 1 is the general equation for determining the kinematic viscosity; thus when the time and the calibration constants are known.

$$V = C \times t \quad (1)$$

where; V is the kinematic viscosity, mm^2s^{-1} ; t is the time, (s), and C is the calibration constant (mm^2/s^2)

2.5. Characterization of fuel oil by FT-IR analysis

FT-IR analysis was conducted to identify the various characteristic functional groups or the chemical functionality present in the crude fuel. A Perkin Elmer FTIR spectrometer (Spectrum 400) was used for this analysis. The samples were scanned in the range of $4000 - 400 \text{ cm}^{-1}$ with a spectral resolution of 4 cm^{-1} .

2.6. Characterization of fuel oil by GC-MS analysis

The primary goal of the instrument analysis is to quantify the amount of substance in the crude fuel oil. A Perkin Elmer Clarus 580 GC, USA, interfaced to a Mass Spectrometer. Perkin Elmer Clarus SQ 8 S system was used for the GC-MS analysis of the crude fuel oil. Separation was achieved with an Elite-5MS (5 % diphenyl – 95 % dimethylpolysiloxane) fused capillary column ($30 \times 0.25 \mu\text{m}$ i.d. $\times 0.25 \mu\text{m}$ d.f.). The mass-detector used in this analysis was Turbo-Mass, and the software adopted to handle mass spectra and chromatograms was Turbo-Mass version-6.1.0. For MS detection, an electron ionization system was operated in an electron impact mode with an ionization energy of 70 eV. Helium gas (99.999 %) was used as a carrier gas at a constant flow rate

of 1 ml/min, and an injection volume of 1 μ l was employed. The injector temperature was maintained at 250 °C, and the ion-source temperature at 150 °C. Mass spectra was taken at 70 eV; a scan interval of 0.5 s and fragments from 45 to 425 Da. The solvent delay was 0 to 3 mins, and the total GC/MS running time was 48 mins. Interpretation on mass-spectrum GC-MS was done using the database of National Institute Standard and Technology (NIST) having more than 62,000 patterns.

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3. Results and discussion

3.1. Pyrolysis product composition

This temperature range of 350 °C – 500 °C resulted in the decomposition reactions of the plastics, to provide hydrocarbons of different chain lengths, which yielded 81 % of liquid product referred to as crude fuel oil oil, 12 % of residual solid material and 7 % gases. Although not determined in the present paper, literature suggests gaseous products obtained from the pyrolysis of plastics, e.g. PE consisted basically of ethane and ethene compounds (27). The solid residue yield (12 %) may be due to the inorganic content and / or char content and / or unconverted HDPE. Due to the mixture of plastic feed, some plastic types; e.g., PE has higher activation energy (289-320 kJ/mol) compared to poly propylene (190-220 kJ/mol), therefore, increasing the pyrolysis temperature to certain extent could result in increased amounts of liquid fraction [27]. Further thermal cracking of the residue product by increasing the temperature and or time, could have resulted in higher yields of the desired liquid crude fuel oil oil fraction. The residue along with the crude fuel oil oil have the potential to be used as lubricant base oils etc., upon further refining such as dewaxing/wax isomerization.

3.2. Analysis by Fourier transform infrared spectroscopy (FT-IR)

FT-IR analysis technique was used to detect the various functional groups in the crude fuel oil oil.

The FTIR spectra obtained from the analysis is shown in Fig. 5 below

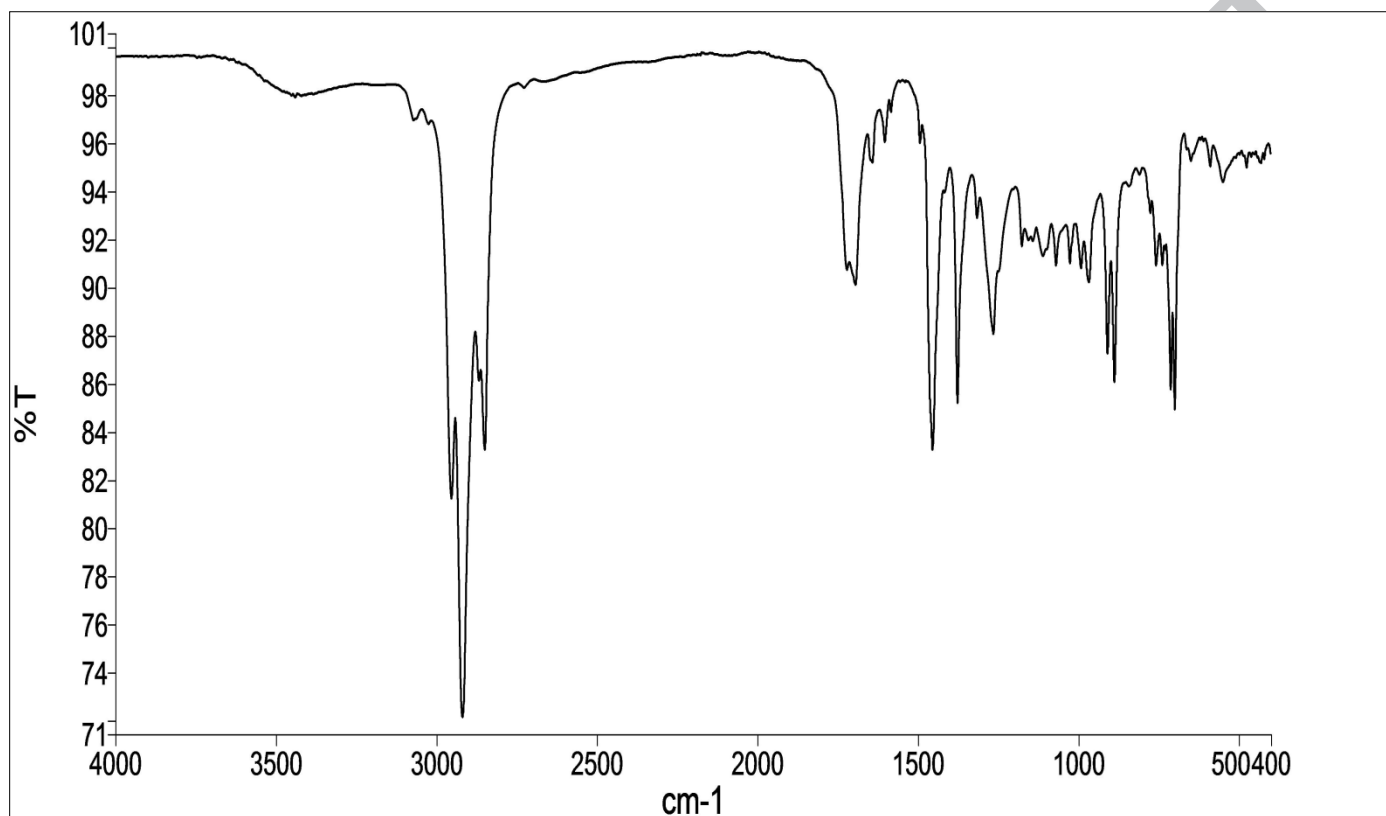


Fig. 4: FT-IR spectrum of the pyrolysis fuel oil; %T on the vertical axis represent percentage of transmittance; and cm^{-1} on the horizontal axis represent the wavelength.

Table 2-Fourier Transform Infrared spectroscopy (FT-IR) results indicating functional groups present.

Peak	X(cm^{-1})	Y(%T)	Bond	Functional group
1	2955.95	81.26	C-H stretch	Alkanes
2	2921.99	72.14	C-H stretch	Alkanes
3	2851.97	83.3	C-H stretch	Alkanes
4	1695.11	90.18	C=O stretch	Carboxylic acids
5	1642.54	95.28	C=C stretch	Alkenes
6	1603.91	96.14	C-C stretch (in ring)	Aromatics
7	1455.37	83.3	C-H bend	Alkanes
8	1377.13	85.26	C-H bend	Alkanes
9	1265.18	88.12	C-N stretch	Aromatic amines
10	1110.34	91.38	C-N stretch	Aliphatic amines
11	1060.77	90.98	C-N stretch	Aliphatic amines
12	1026.47	91.07	C-N stretch	Aliphatic amines

13	991.8	90.87	=C-H bend	Alkenes
14	967.28	90.3	=C-H bend	Alkenes
15	908.96	87.3	N-H wag	1°, 2° amines
16	887.47	86.12	C-H “loop”	Aromatics
17	757.46	90.99	C-Cl stretch	Alkyl halides
18	711.64	85.81	C-H rock	Alkanes
19	699.12	84.98	-C \equiv C-H: bend	C-H Alkynes
20	648.88	95.34	C-Br stretch	Alkyl halides
21	548.96	94.46	C-Br stretch	Alkyl halides

The FT-IR spectra of the fuel oil in table 2 and figure 6 above is showing the functional group composition present.

From the results provided in table 2 and figure 6 above, it is shown that the crude fuel oil oil sample has 21 functional groups which is a blend of aliphatic (saturated and unsaturated) and aromatic groups of compounds. Peaks associated with the presence of aliphatic compounds (Alkanes: C-H stretch- 2955 cm⁻¹, 2921 cm⁻¹ and 2851.97 cm⁻¹; C-H bend - 1455.37 cm⁻¹ and 1377.13 cm⁻¹; C-H

rock- 711.64 cm^{-1} . Alkene: C=C stretch- 1642.54 cm^{-1} ; =C-H bend - 991.8 cm^{-1} and 967.28 cm^{-1} . Aliphatic amines; C-N stretch-1265 cm^{-1} , 1110 cm^{-1} , 1060.77 cm^{-1} and 1026.47 cm^{-1} . 1^o, 2^o amines: N-H wag- 908.96 cm^{-1} . Alkyl halides: C-Cl stretch- 757.46 cm^{-1} ; C-Br stretch- 648.88 cm^{-1} and 548.96 cm^{-1} . Carboxylic acids: C=O stretch-1695.11 cm^{-1} . Alkynes: -C \equiv C-H: C-H bend- 699.12 cm^{-1}) were clearly detected in the spectra. Functional groups associated with aromatic compounds (aromatic: C-C stretch in ring; 1603.91 cm^{-1} , C-H “loop” 887.47 cm^{-1} , aromatic amine: C-N stretch; 1265.18 cm^{-1}) were also present in the crude oil. The above results shows that the oil has only three aromatic compounds, which indicate that, the pyrolysis crude fuel oil contain high percentage of aliphatic hydrocarbons. Furthermore, as shown by the FT-IR results above, the pyrolysis crude fuel oil unlike most conventional fuels is free from any Sulphur related functional groups.

3.3. GC-MS analysis of the crude fuel oil

GC-MS analysis was also conducted to identify the substances in the pyrolysis oil. This method of analysis measured the peaks in relation to one another; thus the tallest peak is assigned 100% of the value, other peaks, are assigned proportionate values. The mass-spectrum of the GC-MS was interpreted using the database from National Institute of Standards and Technology (NIST); it has more than 62,000 patterns. Figure 7 and Table 3 below shows the results of the raw crude fuel oil analyzed with+ the GC-MS.

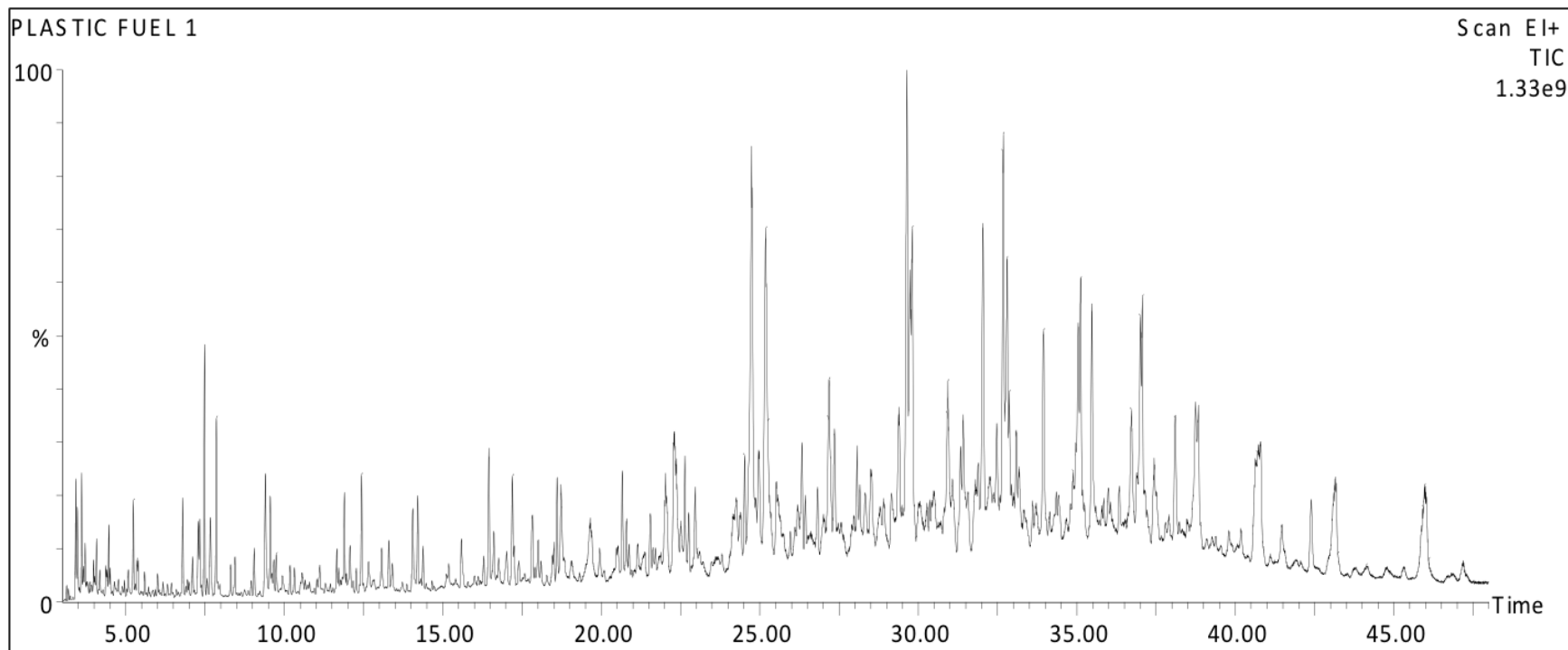


Fig. 5 – Gas chromatography- mass spectrometry (GC-MS) spectrum of oil produced from pyrolysis of Waste plastic.

Table 3 - GC-MS (Gas Chromatography- Mass Spectrometry) results for the oil obtained from pyrolysis of waste plastic.

RT	Name of compound	Molecular formula	Molecular Weight	Percentage abundance	Scan
7.485	3-Eicosene, (E)	C ₂₀ H ₄₀	280.54	24.65	897
7.855	3-Octadecene	C ₁₈ H ₃₆	252.549	18.85	971
9.396	Biphenyl	C ₁₂ H ₁₀	154.21	16.09	1279
16.449	1-Eicosanol	C ₂₀ H ₄₀ O	298.555	16.31	2689
18.730	Tert-Hexadecanethiol	C ₁₆ H ₃₄ S	258.511	16.49	3145
19.645	Thiocarbamic acid, N,N-dimethyl, S-13-diphenyl-2-butenyl ester	C ₁₉ H ₂₁ NOS	311.441	25.74	3328
22.021	1-Heptacosanol	C ₂₇ H ₅₆ O	396.73	26.59	3803
22.306	1-cyclopentyl-4-(3-cyclopentylpropyl)-11-dodecane	C ₂₅ H ₄₈	348.6486	43.55	3860
22.961	Tetradecyl-oxirane	C ₁₆ H ₃₂ O	240.4247	16.20	3991
24.257	Tetradecyl-oxirane	C ₁₆ H ₃₂ O	240.4247	30.24	4250

24.737	Behenic alcohol	$C_{22}H_{46}O$	326.609	100	4346
24.957	11-(ethylpropyl)-Heneicosane	$C_{26}H_{54}$	366.7070	13.56	4390
25.182	2-methylhexacosane	$C_{27}H_{56}$	380.745	91.85	4435
25.522	Trichloroacetic acid, hexadecyl ester	$C_{18}H_{33}Cl_3O_2$	378.81	26.52	4503
26.333	Trichloroacetic acid, pentadecyl ester	$C_{17}H_{31}Cl_3O_2$	373.783	17.57	4665
27.178	Tetradecyl-oxirane	$C_{16}H_{32}O$	240.4247	36.70	4834
27.353	Cyclohexane,[6-cyclopentyl-3-(3-cyclopentylpropyl) hexyl]	$C_{25}H_{46}$	346.6327	18.30	4869
28.493	1,1',2',1''- Terphenyl,4'-phenyl	$C_{24}H_{18}$	306.3997	15.47	5097
29.149	1-Heptacosanol	$C_{27}H_{56}O$	396.73	14.77	5228
29.389	1, 15-Pentadecanediol	$C_{15}H_{32}O_2$	244.419	34.22	5276
29.639	1-Heptacosanol	$C_{27}H_{56}O$	396.73	87.05	5326
29.729	Hentriacontane	$C_{31}H_{64}$	436.85	43.90	5344
29.804	Hentriacontane	$C_{31}H_{64}$	436.85	51.86	5359
30.929	9-(2',2'-	$C_{30}H_{42}Cl_2N_4O_3$	577.586	39.19	5584

	Dimethylpropanoilhydrazono)- 3,6-dichloro-2,7-bis-[2- (diethylamino)-ethoxy]fluorine				
31.069	Tetradecane, 2,6,10-trimethyl-	$C_{17}H_{36}$	240.475	17.56	5612
31.329	Bacteriochlorophyll-c-stearyl	$C_{52}H_{72}MgN_{40}O_4-$ 2	841.477	20.30	5664
31.415	Heneicosane, 11-cyclopentyl-	$C_{26}H_{52}$	364.6911	30.91	5681
31.800	Cis-13-Eicosenoic acid	$C_{20}H_{38}O_2$	310.522	13.62	5758
32.025	Dodecane, 1-cyclopentyl-4-(3- cyclopentylpropyl)-	$C_{25}H_{48}$	348.6486	54.96	5803
32.675	1-Heptacosanol	$C_{27}H_{56}O$	396.73	63.18	5933
32.790	Hentriacontane	$C_{31}H_{64}$	436.85	51.11	5956
32.865	1-Heneicosanol	$C_{21}H_{44}O$	312.582	16.15	5971
33.085	Acetic acid, chloro-,hexadecyl ester	$C_{18}H_{35}ClO_2$	318.922	15.93	6015
33.945	n-Tetracosanol-1	$C_{24}H_{50}O$	354.65	39.63	6187
34.881	1,15-Hexadecadiene	$C_{16}H_{30}$	222.416	13.67	6374
35.036	n-Tetracosanol-1	$C_{24}H_{50}O$	354.65	49.94	6405

35.121	Pentacosane	$C_{25}H_{52}$	352.6911	46.67	6422
35.471	1,1':3',1"-Terphenyl, 5'-phenyl-	$C_{24}H_{18}$	306.3997	41.14	6492
36.717	Octacosanol	$C_{28}H_{58}O$	410.76	27.33	6741
36.997	n-Tetracosanol-1	$C_{24}H_{50}O$	354.65	35.33	6797
37.062	Heptacosane	$C_{27}H_{56}$	380.745	40.30	6810
37.432	13-Docosen-1-ol, (Z)-	$C_{22}H_{44}O$	324.5842	26.71	6884
38.102	Octatriacontyl pentafluoropropionate	$C_{41}H_{77}F_5O_2$	697.057	25.79	7018
38.737	1-Heptacosanol	$C_{27}H_{56}O$	396.73	41.09	7145
38.827	Heneicosane	$C_{21}H_{44}$	296.583	26.96	7163
40.788	Pentacosane	$C_{25}H_{52}$	352.6911	75.71	7555
41.468	Cyclohexane,[6-cyclopentyl-4- (3-cyclopentylpropyl)hexyl]-	$C_{25}H_{46}$	346.6327	14.97	7691
42.389	Oxirane, tetradecyl-	$C_{16}H_{32}O$	240.4247	18.17	7875
43.144	Heptacosane	$C_{27}H_{56}$	380.745	49.67	8026
45.955	Hexatriacontyl pentafluoropropionate	$C_{39}H_{73}F_5O_2$	669.00	53.44	8588

After the analysis of the crude fuel oil by Gas Chromatography and mass spectroscopy (GC-MS), it was observed that majority of the various hydrocarbons present ranged from C₁₂-C₄₁. From table 3 above, the hydrocarbon present with the highest peak in reference to intensity is behenic alcohol (C₂₂H₄₆O), it has Erucic acid (C₂₂H₄₂O) as its unsaturated counterpart. The major industrial use of erucic acid is at its primary derivative, erucamide, is used as a slip agent for plastic film, such as bread wrappers, garbage bags, etc. At a level of approximately 1000 ppm in the resin, it ensures that the film is able to slide over itself. However majority of the other components were aliphatic hydrocarbon. Comparing with Table 4 below, it can be concluded that the raw crude fuel oil is within the diesel range (C₁₂-C₂₄).

Table 4 various fuels and their carbon range.

Fuels	LPG	Petrol	Kerosene	Diesel	Motor oil	Hydraulic oil
Carbon range	C ₃ -C ₄	C ₄ -C ₁₂	C ₁₂ -C ₁₅	C ₁₂ -C ₂₄	C ₁₆ -C ₃₆	C ₂₀ -C ₄₀

Overall, since the compound containing hydrogen and carbon were found abundant in the results above, this gives a clear indication that the pyrolysis oil has potential to be used as combustible fuel source. Also the results from GC-MS analysis were found to be in agreement or tally with the FT-IR results.

3.4 Kinematic viscosity of the crude fuel oil

Table 5 and Figure 8 illustrate the kinematic viscosity of the raw crude fuel oil sample at various temperatures.

Table 5 - Kinematic viscosity of fuel at different temperatures.

Temperature (°C)	Time (s)	Tube constant (mm ² s ⁻²)	Kinematic viscosity (mm ² s ⁻¹)
40	10	0.1036	1.036
50	9	0.1036	0.9324
70	8	0.1036	0.8288
80	7	0.1036	0.7252

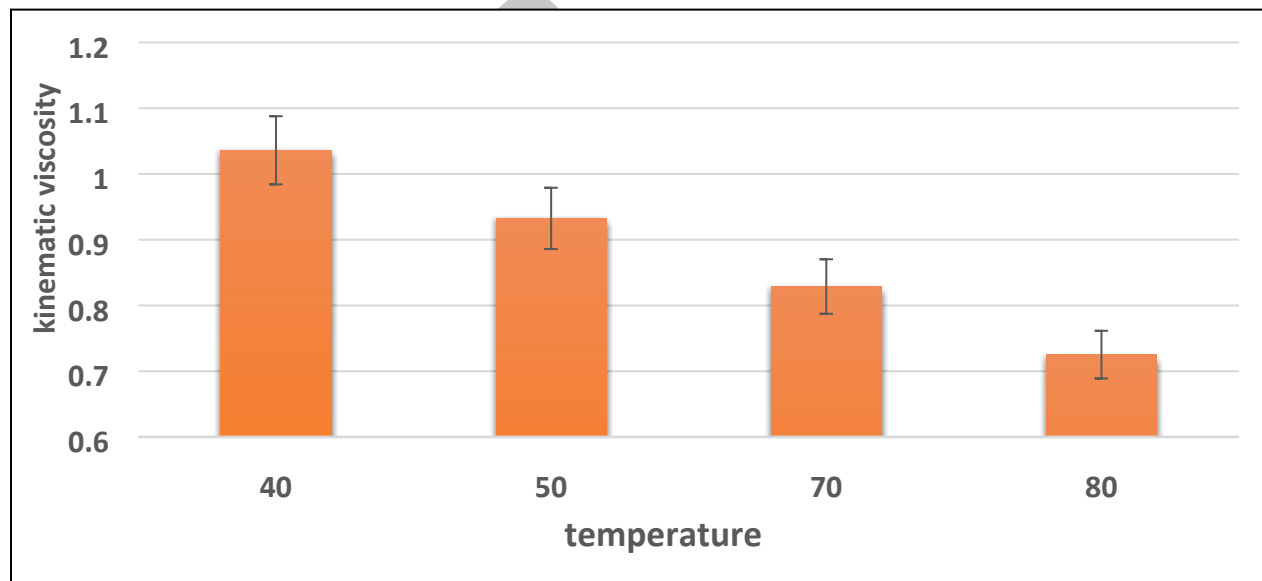


Fig. 6- Graphical representation of Kinematic viscosity of the fuel at different temperatures.

The kinematic viscosity for temperatures of 40, 50, 70 and 80 °C were observed to be 1.036, 0.9324, 0.8288 and 0.7252 mm²s⁻¹, respectively; thus the viscosity decreases with increasing temperature. The viscosity of fuel is important for the estimation of optimum storage, handling and operational conditions. It is imperative to keep viscosity of fuel in the right range in order to get the right kind of engine efficiency. A high viscosity of fuel leads to improper atomization, which in turn leads to incomplete combustion. On the other hand, fuels with a low viscosity can produce a spray that is too soft and thus does not penetrate sufficiently thereby affecting combustion [28].

4. Conclusion

From the study it has been proven that the pyrolysis technology can be used in converting the mixture waste plastics into an alternative energy source. It was observed that the oil contained more of aliphatic compounds, which is good for fuel in motor engines. Moreover, the fuel after characterization was observed to be in the diesel fuel range (C_{12} – C_{24}). Also the kinematic viscosity of the fuel oil was found to be $1.036 \text{ mm}^2\text{s}^{-1}$ at $40 \text{ }^\circ\text{C}$ and decreased with increasing temperature. In this regard, the pyrolysis of plastic waste studied here presents an efficient, clean and very effective means of removing plastic debris that are left in the environment over the last several decades. The benefit of pyrolysis of mixture of plastic waste (recovery of energy and reduction of environmental problems) though will exist only as long as the waste plastics last, it will surely provide a strong platform for us to build on a sustainable, clean and green future. Plastic waste isn't the whole problem, how we handle it also count. Thus the responsibility is on us to be smart on how we handle plastic; as a pollutant or as an economical resource.

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Dear Editor

Conflict of Interest

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.

Thank you.

Yours faithfully,

Dr.-Ing. Samuel Kofi Tulashie

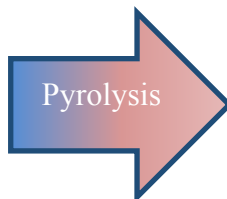
Mr. Enoch Kofi Boadu

Mr. Samuel Dapaah

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Graphic Abstract

Plastic
Waste



Crude Fuel

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Highlights

- Waste plastic to crude fuel via pyrolysis
- Crude fuel after characterization was observed to be in the diesel fuel range
- Recovery of energy and reduction of environmental problems are the benefits
- The key solution for sanitation problem in Ghana

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