

# Evaluation and Valorization of Pyrolytic Char from Commingled Waste Plastics

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## **Authors' contributions**

*This work was carried out in collaboration between both authors. Author UOA did conceptualization, methodology, experiment, analysis and interpretation of result, investigation, resources, data curation, writing both original draft and electronic draft of the manuscript. Author OSK did supervision, investigation, resources, data curation, financial support, methodology, assessment of the manuscript. Both authors read and approved the final manuscript.*

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## **ABSTRACT**

Graphitic materials can be synthesized using a plethora of transformation processes. This work utilized waste plastic slow pyrolysis as a pathway to synthesize graphitic materials. The raw materials for the pyrolysis process were collected from a dump site in Auchi environment, Edo State, Nigeria which included grocery bags, disposable cups, plates, drinking water bottles, etc. These plastics were identified as PP, PET, and HDPE, after which they were cleaned and sorted and their sizes, reduced. Two runs were carried out with comingled plastics while three other runs were conducted with HDPE, PP, and PET waste plastics singly. A locally fabricated laboratory-scale pyrolyzer was used to convert the plastic waste into char. The reaction was carried out at 300 °C, and varied reaction times between 60 and 120 mins. The five Samples retrieved at the end of the slow pyrolysis were evaluated based on their elemental composition (XRF) and Physico-chemical properties like porosity, percentage moisture, and ash content. The XRF analyzer showed that the char included SiO<sub>2</sub> (> 16%), Al<sub>2</sub>O<sub>3</sub> (6%), CaO (>19%), and some amount lost during ignition (LOI > 31%). PP was found to have the highest porosity (45.93%) while HDPE at 60 minutes of slow pyrolysis had the highest amount of moisture (0.84%) and ash content (36.78%). PP alone produced the highest quantity of solid dry-textured char (67.51%) followed by HDPE (54.67) while PET was majorly waxy with the least trace of char (12.54%). These results showed that the product formed could be considered a graphitic material, for use as a solid fuel, good adsorbent, and possible catalyst.

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**Keywords:** Valorization; pyrolytic char; graphite; waste commingled plastic; slow pyrolysis; HDPE; polypropylene.

## ABBREVIATIONS

*HDPE* : High-Density Polyethylene;  
*PE* : Polyethylene;  
*PET* : Polyethylene Terephthalate;  
*PP* : Polypropylene;  
*PS* : Polystyrene;  
*LOI* : Lost on Ignition;  
*SIM* : Secondary ion Mass Spectrometry;  
*TEM* : Transmission Electron Microscopy;  
*XRF* : X-ray Fluorescence Spectroscopy;  
*XRD* : X-ray Diffraction;  
*LIBS* : Laser-Induced Breakdown Spectroscopy;  
*NIR* : Near-Infrared Spectroscopy;

## 1. INTRODUCTION

Solid waste is generated in all sorts of ways and can be classified based on source, such as; municipal solid waste, industrial solid waste, and agricultural solid waste [1]. In most Nigerian cities, managing solid waste is a major environmental challenge because of how much waste is produced, which is largely influenced by industrial economic structures and consumption patterns. Waste from homes, businesses, institutions (such as schools, hospitals, and universities), street sweepings, and non-hazardous solid waste from industries are all crucial sources of MSW in Nigeria [2]. The generation rate in Nigeria is estimated at 0.65-0.95 kg/capita/day, giving an average of 42 million tons of waste generated annually. This is more than half of 62 million tons of waste generated in sub-Saharan Africa annually [3]. Due to her estimated 187,896,647-person population, the amount of waste produced is rising. Therefore, a major issue for the country is where and how to channel these wastes [4].

Plastics constitute over 15% of this solid waste with organic matter holding about half the overall average composition (50%) [2]. Over the past ten years, the country's plastics consumption has grown by 7.8% annually, from 578 kilotonnes (kt) in 2007 to 1,229 kilotonnes (kt) in 2017 and is estimated to be 1,533 kilotonnes (kt) in 2020 [5]. In 2015, global plastic production reached 322 million tonnes, a dramatic increase compared to the 279 million tonnes produced in 2011 [6] and currently, global production which has reached over 300 million tonnes per year, has been attributed to the mass of the entire human population [7,8]. The ongoing increase in plastic

demand, which has been described as an unofficial barometer of income [9,10], has the potential to increase waste accumulation. Nigeria is one of the largest consumers of plastics in Africa, with its plastic and packaging sector's rapid growth in recent decades, from around 50 companies at its inception in the 1960s to more than 3,000 manufacturers currently, according to the National Agency for Food and Drug Administration and Control (NAFDAC).

In Nigeria, incineration, sanitary landfills, open dumps, composting, etc. are the solid waste disposal methods currently in use with the most pronounced being Open dumps [1,11]. These options, however, have proven inefficient in converting waste plastics because they have been found to aid the distortion of the ecosystem either via aerial means (generating greenhouse gases) or planetary nuisance (aesthetic disturbance) [7,12]. As an alternative, conventional recycling which has been used has proven insufficient [12] and costly because of the restrictions on contamination of water and labor-intensive segregation of plastics before recycling, which is also laborious [11]. Unfortunately, the segregation of different plastic materials is essential since they are made of varying resin compounds for the difference in transparency and color and hence can not be skipped [13].

Thermal waste management techniques are currently common in developed countries, and they will represent a fantastic technological advance in a developing country like Nigeria. These conversion processes are combustion, pyrolysis, gasification, and torrefaction [14]. However, pyrolysis has been the most beneficial, being environmentally friendly, flexible in scale, and a helpful process in the recovery of fuels [15,16]. Pyrolysis also has economic advantages as it does not require as many feedstock pre-treatment steps as other treatment methods [17]. Pyrolysis is often referred to as a flexible process [13] because involves a change of chemical composition creating volatile products (gas & oil up to 80wt.%) and leaving a solid residue enriched in carbon, known as char at temperatures between 300 – 800°C [15]. The process parameters can be altered to generate products based on personal preferences. The interest in thermochemical conversion of plastic waste, particularly pyrolysis, has increased considerably over the last few years, primarily

since China stopped accepting post-consumer plastic waste in 2018, after having taken up to 45% of the world's plastic waste for recycling, landfilling and incineration [18]. Pyrolysis depends on a series of factors, including temperature, residence time, heating rates, feedstock composition, presence of moisture or toxic elements, and the use and types of catalysts [19].

Waste plastic pyrolysis has been widely explored both directly and with the use of various catalysts to obtain the liquid hydrocarbon fraction (oil). Rahman et al. [20] carried out the catalytic pyrolysis of polyethylene into liquid hydrocarbon using mesoporous kaolin clay with an 83wt.% oil yield and was found to be free from aromatic compounds which are potentially mutagenic and carcinogenic. Attique et al. [21] also compared thermal cracking of polyethylene with catalytic cracking using Keggin tungstoborate/kaolin clay composite as catalysts. They obtained a 99% polymer conversion with 84 wt.% as fuel oil and a negligible amount of solid char while a 22 wt.% solid residue was obtained using thermal pyrolysis. They concluded that the prepared composites were cost-effective and excellent cracking catalysts that could be recommended for the highly efficient conversion of waste plastic materials to petrochemicals at an industrial scale. Furthermore, Aisien et al. [15] compared thermal cracking to spent FCC catalyst for the breakdown of waste polypropylene into liquid oil. He concluded that thermal pyrolysis gave a higher yield of liquid oil (83.3 wt.%) while the use of the catalyst decreased the liquid oil yield to 77.6 wt.%. However, the analysis of the result showed that the liquid oil's fuel properties were like that of gasoline and diesel.

Plastics have also been listed as being highly potent in the production of graphene, carbon spheres, carbon nanotubes, and graphene nanosheets [22-32]. The solid fraction of pyrolytic products has found application as a carbon precursor in the synthesis of synthetic graphite due to its availability, sustainability, and cost-effectiveness [33]. Globally, most natural graphite is used in electrodes, refractories, lubricants, foundries, batteries, graphite shapes, decarburizing, steelmaking, and friction products such as brake linings. Refractory and high-technology applications make graphite a critical material in industrialized countries [34]. However, despite all of the excellent properties and wide application of graphite, the primary concern that arises is supply risk issues. Graphite has been

labeled as a 'supply risk' material [35] due to its vast demand and a limited reserve of natural sources. Thus synthetic graphite will be a great alternative in filling the gap between supply and demand. Production of synthetic graphite has attracted tremendous interest in recent years, considering the increasing demand each year [33]. Sharma et al. [31] synthesized graphene crystals from solid waste plastics (PE & PS) pyrolysis by the chemical vapor deposition method. They concluded that the injection rate of the waste plastics was the major determining factor for the production of graphene materials. Ruan et al. [30] also synthesized graphene from cookies, chocolate, grass, plastics, roaches, and dog feces at 1050 °C on the back of a copper foil. Garg et al. carried out catalytic pyrolysis of waste plastics for the production of graphene nanosheets (GNs). Characterization of the GNs showed low resistivity at low temperatures and an inverse relationship between resistivity and temperature. They concluded that the resulting GNs would be good for thermoelectric applications.

Among plastics PE and PP, they have been extensively researched in terms of pyrolysis because they account for the majority of PSW due to their versatility in a wide range of applications [17], [36]. PE has been reported to have a carbon content ranging between 83.9 to 86.1 %, whilst PP has a range of carbon between 85.5 to 86.1 % [37]. Due to the significant amount of carbon present in the major polymers that make up PSW, pyrolysis is a preferred treatment and method for the valorization of plastics. Ko et al. [27] upcycled waste PET at 900 °C followed by boron-assisted catalytic graphitization at 2400 °C. Their result showed that it was possible to graphitize the non-graphitizable property of PET yielding a higher crystallinity and degree of graphitization (80.6%). High char content in the pyrolysis of PE results from the presence of HDPE while high gas content results from LDPE fractions [17]. Jamradioedluk & Lertsatitthanakorn [38] pyrolyzed HDPE at 400 – 450 °C to produce char containing 51.40% volatile matter, 46.03% fixed carbon, 2.41% moisture content, and 0.16% ash. The high calorific value and density of these char briquettes made them useful as a fuel for combustion processes. They also evaluated Miandad et al. [39] evaluated waste plastic pyrolysis products from both single waste plastics and combined plastics and concluded that a PP/PE combination produced the highest amount of char (24.8%). Therefore, this research

has investigated waste plastics pyrolysis under low temperatures (slow pyrolysis) and without a catalyst for char production. The research focused on pyrolyzing PET, HDPE, and PP because of their potential high char content [8,24,35,39-42] and it hopes to address the environmental concerns of the indiscriminate disposal of these highly used and abundant waste materials while possibly also serving an alternative material for graphite, char briquettes for energy production, and/or activated carbon. It also compares the physicochemical and oxide properties of the produced char with that of local and commercial graphite to determine its substitute for graphite production.

## 2. MATERIALS AND METHODS

### 2.1 Collection of Feedstock

The plastic waste used as the raw material in the pyrolysis process was collected from the Edo State University Uzairue students' hostels. They included grocery bags, disposable juice cups, plates, and drinking water bottles. These plastic materials were selected because they are the primary source of plastic waste produced and litter the University environment. The waste plastic was pretreated as shown in Fig. 1. These plastics and methods were chosen based on their char-producing properties as discussed in the literature [43]. The pyrolysis experiment was carried out using single component materials or a mixture (co-mingled) of these plastic wastes in different ratios.

### 2.2 Experimental Set-up

A locally fabricated laboratory scale pyrolysis unit as shown below was set up for the slow thermal pyrolysis operation along with their ancillary equipment including the heating cylinder (LPG) and the inert gas cylinder (N<sub>2</sub>), the vacuum

pump, and the coolant (water). The feed material was fed into the pyrolyzer and heated to a constant 300 °C temperature with varying residence times of 60, 80, 90, and 120 mins respectively. Batch pyrolysis was carried out using 465.64g each of waste plastic samples, which was the maximum allowable mass the reactor could hold for co-mingled and single component plastic waste samples as shown in Fig. 2.

The product which contained a combination of char and wax was collected from the heating chamber at the end of each experiment after allowing the system to cool down at room temperature.

### 2.3 Characterization

The physicochemical characteristics of the recovered char were carried out along with an elemental composition using X-ray Fluorescence Spectroscopy (XRF Thermo 9900) analysis. The physicochemical properties of the char obtained, such as the pore volume, porosity, moisture content, and ash content, were determined using the ASTM standard method such as ASTM D4404-18 for pore volume, ASTM C380 for porosity, ASTM C562-15 for moisture content, and ASTM C561-16 for ash content.

## 3. RESULTS AND DISCUSSION

### 3.1 Thermal Pyrolysis

Thermal degradation of the plastic produced char with dark brown wax. Table 1 shows the percentage yield of the products at different residence times. The results also showed the variation in the mass composition of feedstock shown in Table 1 on the product.

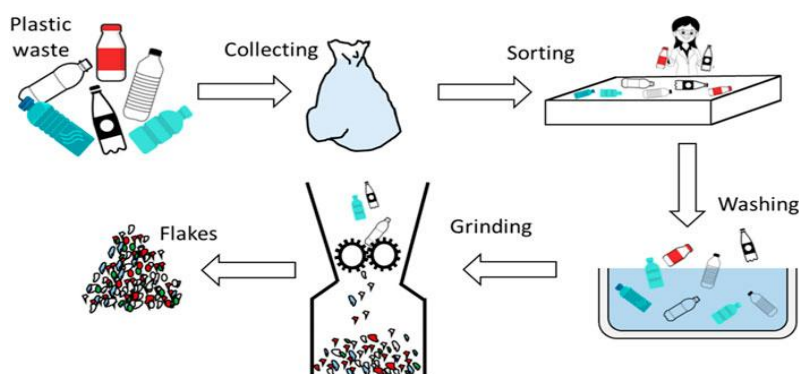


Fig. 1. Preparation of raw material



**Fig. 2. Locally fabricated pyrolyzer**

*Sample I: 40% PP, 40% HDPE, 20% PET pyrolyzed at 300 °C with a residence time of 60mins. Sample II: 40% PP, 40% HDPE, 20% PET pyrolyzed at 300 °C with a residence time of 120mins*  
*Sample III: 100% HDPE pyrolyzed at 300 °C with a residence time of 90mins.*  
*Sample IV: 100% PP pyrolyzed at 300 °C with a residence time of 90mins.*  
*Sample V: 100% PET pyrolyzed at 300 °C with a residence time of 90 minutes.*

**Table 1. Percentages of sample yield obtained**

S/N	Sample	% Solid yield	% Liquid yield	% Gas yield	Residence time (mins)
1	HDPE,PP,PET	38.23	-	-	60
2	HDPE,PP,PET	33.89	-	-	120
3	HDPE	54.67	-	-	90
4	PP	67.51	-	-	90
5	PET	12.64	-	-	90

Table 1 presents the product yield obtained for each sample at different residence times. In the work presented by Miandad et al in 2017 [39], the GC-MS results showed that different kinds of compounds were produced from pyrolysis of each plastic type individually and in a mixture. Also, Jamradloedluk & Lertsatitthanakorn, 2014 [38] concluded that with HDPE alone, it was possible to achieve a high amount of char (>50 wt.%). Results from Table 1 show that the highest yield (67.51%), was recorded at a residence time of 90mins, consisting of PP plastic alone followed by HDPE (54.67%). This result coincides with the findings from Jamradloedluk & Lertsatitthanakorn in 2014 and Miandad et al in 2017. PET on the other hand gave very little product which was waxy in nature. Ko et al. [27] already posited that PET required a two-step pyrolysis method in order to convert it to char and possible graphite. This might be the reason for the small product with its waxy nature.

In commingled forms, Table 1 showed a yield between 34% to 38% char. However, the presence of PET might be the reason for the low char-producing properties at 300°C and a residence time of 60 to 120mins. Also, it is seen that as the residence time increased from 60 minutes to 120 minutes, the amount of char reduced by 20.21g. This is supported by the principle of slow pyrolysis which is characterized by a lower temperature ( $\leq 500$  °C) [40]. Sun et al. [44] who also investigated the effect of residence time and temperature increase on the biochar products from pyrolysis concluded that at low temperatures (300 °C) and an increase in plastic residence time, the amount of biochar produced reduces gradually [45,46].

**Table 2. XRF results of char samples (material analysis)**

Component	Sample I	Sample II	Sample III	Sample IV	Sample V
SiO <sub>2</sub>	19.83	17.55	16.68	28.90	-
Al <sub>2</sub> O <sub>3</sub>	6.26	6.02	6.05	0.29	-
Fe <sub>2</sub> O <sub>3</sub>	2.47	2.22	0	5.28	-
CaO	21.22	19.08	25.20	20.98	-
MgO	0.16	0.44	0.20	0.97	-
K <sub>2</sub> O	0.20	0.19	0.08	0.03	-
Na <sub>2</sub> O	0	0	0	0	-
SO <sub>3</sub>	0.00	0.00	0.00	0.00	-
Cl	0.00	0.00	0.00	0.00	-
LOI	33.47	31.33	47.94	42.60	> 99.99
SIM	2.97	6.88	3.84	1.23	-
ALM	13.41	16.15	-	0.25	-
H <sub>2</sub> O	-	-	-	-	-

### 3.2 X-ray Fluorescence Spectroscopy (XRF)

For this characterization, four samples were prepared and tested using XRF spectroscopy, and the results, showing the percentage of elemental components are presented in Table 2 as follows.

Sample V could not be characterized using XRF because the XRF equipment required a solid sample at a temperature at which the sample always melted. The proximate analysis and XRF results of natural and synthetic graphite are compared with the results obtained from the product analysis.

### 3.3 Physicochemical Characterization

The physical properties of the sample materials were noted and compared to the actual appearance of graphite. These tests include color, conductivity, melting point solubility, and physical and morphological properties such as surface area, moisture content, pore volume, porosity, etc.

From the physical examination of samples, the following color appearances were observed.

Sample I (PP, HDPE, and PET) had a dark grey coloration with spots of colored particles, which could result from coloration used in plastics feedstock utilized. The texture was dry and powdery.

Sample II (PP, HDPE, PET) had a dark black coloration. It had a dry and powdery texture with traces of wax particles embedded in it. Also, it had a characteristic strong harsh smell.

Sample III (HDPE) had a dark grey coloration with a strong harsh smell and a powdery consistency.

Sample IV (PP) had a pitch black coloration with a strong harsh smell. However, its consistency was neither powdery nor waxy.

Sample V (PET): had a yellowish-brown coloration with a strong harsh smell. However, its consistency was majorly wax with traces of solid particles.

**Table 3. Physicochemical parameters of Samples**

S/N	Sample	Ash content	Pore vol. (ml)	Porosity (%)	%M <sub>c</sub>
1	HDPE, PP, PET	0.3678	0.532	27.96	0.84
2	HDPE, PP, PET	0.2839	0.498	25.34	0.72
3	HDPE	0.1253	0.911	43.28	0.18
4	PP	0.0342	1.015	45.93	0.05
5	PET	0.0677	0.013	0.897	0.19

**Table 4. Comparison of Graphite from various sources with this study**

Parameter	Graphite source								
	Coal ash	Natural Graphite (%)			This Study				
	[48]	[49]	[26]	I	II	III	IV	V	
Moisture %	0.5	***	***	0.84	0.72	0.18	0.05	0.19	
Ash	22.4	***	2 – 9	0.368	0.284	0.123	0.034	0.068	
Pore vol.	***	***	***	0.532	0.498	0.911	1.015	0.013	
F. Carbon %	75.1	24.2	***	-	-	-	-	-	
Porosity %	***	***	***	0.280	0.253	0.433	0.460	0.90	
SiO <sub>2</sub>	4.0 – 24	83 – 93	21 – 33	19.83	17.55	16.68	28.90	-	
Fe <sub>2</sub> O <sub>3</sub>	0 – 2.0	0 – 2.5	6 – 27	2.47	2.22	0	2.28	-	
Al <sub>2</sub> O <sub>3</sub>	1 – 12	3 – 12	10 – 22	6.26	6.02	6.05	0.29	-	
MgO	0 – 0.4	0 – 0.6	1 – 6	0.16	0.44	0.20	0.97	-	
CaO	0 – 3	0 – 0.2	0 – 5	21.22	19.08	25.20	20.98	-	
SO <sub>3</sub>	0 – 1	***	*4.72	0.00	0.00	0.00	0.00	-	
Na <sub>2</sub> O	0 – 0.5	0 – 0.5	**47.36	0.00	0.00	0.00	0.00	-	
LOI	60 – 90	1 – 2	***	33.47	31.33	47.94	45.60	>99.99	

\* upper bandwidth of oxygen composition \*\*lower bandwidth of oxygen composition \*\*\* Not reported

### 3.4 Pore Volume and Porosity

The pore volume for the samples was determined at 70°C for 5 minutes. The results obtained are presented in Table 3 show that the product char obtained had good pore volumes. Also, the pyrolytic char samples with the commingled plastics had lesser smaller pore volume (0.532ml & 0.498ml) and porosity (27.96% & 25.34%) than those of the single plastic char. PET on the other hand was waxy and would naturally have the least porosity (0.897).

### 3.5 Moisture Content

The results above showed a decreasing weight sample with the increase in heating time. However, a relationship cannot be established between the composition of the char samples and the moisture.

### 3.6 Ash Content Determination

From the results shown in Table 3, the products had high ash content with the highest being in sample I. Low ash content is indicative of a high fixed carbon value as displayed by Jamradioedluk & Lertsatitthanakorn, 2014 [35,38,47]. Hence, the low ash content in this work is indicative of either a higher volatile matter or a fixed carbon content [35,38,47] as might be seen from Table 4.

An overview of the results presented in Table 4 shows the percentage of elemental components such as SiO<sub>2</sub>, Fe<sub>2</sub>O<sub>3</sub>, Al<sub>2</sub>O<sub>3</sub>, and other oxides

common to naturally occurring graphite and synthetic graphite (coal-ash sourced and pyrolytic char from this work). Natural graphite essentially contains silicon oxide (SiO<sub>2</sub> > 83%) with traces of Aluminum oxide (Al<sub>2</sub>O<sub>3</sub> > 3%) and highly volatile matter (LOI) as reported by Jara et al., 2020 [50]. Coal-ash graphite on the other hand contains a high portion of volatile matter (LOI > 60%) with considerable amounts of silicon oxide and Aluminum oxide (Al<sub>2</sub>O<sub>3</sub> > 1%) [35]. This work shows a high combination of both silicon oxide (SiO<sub>2</sub> > 16%), calcium oxide (CaO > 19%), and volatile matter (LOI > 31%). The presence of a high combination of these metallic oxides makes the pyrolytic char a good consideration for graphite as shown in Table 4 [26,35,50], catalyst precursors as used in biodiesel production [51-57], or adsorbent materials [38]. The presence of very high LOI indicates high volatile matter and possible use as solid fuels [38].

## 4. CONCLUSION

The production and evaluation of pyrolytic char from waste plastics including PP, PET, and HDPE using a locally made laboratory scale pyrolyzer led to the following conclusions;

1. PP and HDPE had the highest percentage of char produced followed by the commingled plastics.
2. The amount of char decreased with an increase in time while using the slow pyrolysis method.

3. PET had the least amount of char produced and the highest amount of wax formed owing to the use of slow pyrolysis and possible acid formation.
4. The char under these conditions had good pore volumes and indicative good porosity (> 25%), low moisture content with the highest being 0.84% and the least being 0.05%, and low ash content (< 37%) indicative of high fixed carbon and/or volatile matter.
5. The results of the XRF characterization obtained showed the presence of major elemental oxides such as SiO<sub>2</sub> (> 16%), Al<sub>2</sub>O<sub>3</sub> (6%), and CaO (>19%), in considerably high quantities among other properties like the amount lost in the ignition of the sample (LOI).
6. Therefore, the products obtained from this process had good graphitic properties and could be modified appropriately to suit varied applications.

## 5. RECOMMENDATION

1. It is recommended that the char recovered from this process would need to undergo surface area and surface morphological characterizations before use as an adsorbent and catalyst.
2. Other graphitic carbon characterizations should be carried out like conductivity, paramagnetism, Raman spectroscopy etc.
3. The calorific value, densit, among other characterizations are recommended for use as solid fuels.
4. Gas Chromatography Mass Spectroscopy (GCMS) should be carried out on the produced char to determine the amount of each chemical present the char sample.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

## REFERENCES

1. Orhorhoro EK, Oghoghorie O. Review on solid waste generation and management in sub-Saharan Africa: A case study of Nigeria. *Journal of Applied Sciences and Environmental Management*. 2019;23(9):1729-37. DOI: 10.4314/jasem.v23i9.19.
2. Iorhemen OT, Alfa MI, Onoja SB. The review of municipal solid waste management in Nigeria: the current trends. *Advances in Environmental Research*. 2016;5(4):237-49. DOI: 10.12989/AER.2016.5.4.237.
3. Ukpe AE C Ihejirika, Akhionbare SMO. The effects of mining activities on the soil quality of Ikwo, Ebonyi State Nigeria'. 2021;7(12):13.
4. Ezeudu OB, Agunwamba JC, Ugochukwu UC, Ezeudu TS. Temporal assessment of municipal solid waste management in Nigeria: prospects for circular economy adoption', *Rev. Environ. Health*. 2021;36(3):327–344. DOI: 10.1515/reveh-2020-0084.
5. Ojogwu A, Adeleke K, Babayemi J, Chikere C, Ilechukwu I, Onaghise A. Nigerian contributions Editors: Jochen Luckscheiter, Heinrich Böll Foundation - Abuja Office Chibueze Ebii, Heinrich Böll Foundation - Abuja Office'. 2020;60.
6. Kalargaris I, Tian G, Gu S. The utilization of oils produced from plastic waste at different pyrolysis temperatures in a DI diesel engine. *Energy*. 2017;131:179–185. DOI: 10.1016/j.energy.2017.05.024.
7. UN Environment, Visual Feature | Beat Plastic Pollution. Available:<http://unep.org/interactive/beat-plastic-pollution/> (accessed Jul. 30, 2022).
8. Yansaneh OY, Zein SH. Latest advances in waste plastic pyrolytic catalysis. *Processes*. 2022;10(4):683. DOI: 10.3390/pr10040683.
9. Bichi MH, Amatobi. Characterization of household solid wastes generated in Sabon-gari area of Kano in Northern Nigeria. *Am. J. Res. Commun*. 2013;1(4):165–171.
10. Shatnawi RS. Solid waste management: Classification and public perception on management options at applied Science University, Jordan *J. Civ. Eng*. 2018;12(3):11.
11. Eze WU, et al. Plastics waste management: A review of pyrolysis technology. *Clean Technol. Recycl*. 2021;1(1):50–69. DOI: 10.3934/ctr.2021003.
12. Miandad R, Barakat MA, Aburiazaiza AS, Rehan M, Nizami AS. Process Safety and Environmental Protection. Catalytic pyrolysis of plastic waste: A review. 2016;102:822-38. DOI: 10.1016/j.psep.2016.06.022.
13. Vijayakumar A, Sebastian J. Pyrolysis process to produce fuel from different



- types of plastic—a review. In IOP conference series: Materials Science and Engineering 2018;396(1):012062). IOP Publishing.  
DOI: 10.1088/1757-899X/396/1/012062.
14. Mukherjee C, Denney J, Mbonimpa EG, Slagley J, Bhowmik R. A review on municipal solid waste-to-energy trends in the USA. *Renewable and Sustainable Energy Reviews*. 2020;119:109512.  
DOI: 10.1016/j.rser.2019.109512.
  15. Aisien ET, Otuya IC, Aisien FA. Thermal and catalytic pyrolysis of waste polypropylene plastic using spent FCC catalyst. *Environmental Technology & Innovation*. 2021;22:101455.  
DOI: 10.1016/j.eti.2021.101455.
  16. Thahir R, Altway A, Juliastuti SR. Production of liquid fuel from plastic waste using integrated pyrolysis method with refinery distillation bubble cap plate column. *Energy reports*. 2019 Nov 1;5:70-7.  
DOI: 10.1016/j.egy.2018.11.004.
  17. Constantinou A. A review on thermal and catalytic pyrolysis of plastic solid waste. *Journal of Environmental Management*. 2017;197:177-98.  
DOI: 10.1016/j.jenvman.2017.03.084.
  18. Papari S, Bamdad H, Berruti F. Pyrolytic conversion of plastic waste to value-added products and fuels: A review. *Materials*. 2021;14(10):2586.  
DOI: 10.3390/ma14102586.
  19. Miandad R, Rehan M, Barakat MA, Aburizaiza AS, Khan H, Ismail IM, Dhavamani J, Gardy J, Hassanpour A, Nizami AS. Catalytic pyrolysis of plastic waste: moving toward pyrolysis based biorefineries. *Frontiers in Energy Research*. 2019;7:27.  
DOI: 10.3389/fenrg.2019.00027.
  20. Rahman M, Roy SC, Hassan M, Mondal BK, Faruk MO, Rahman MA, Zahiduzzaman M, Sharmin A, Hosen MJ, Afroze M, Khan M. Catalytic Pyrolysis of Waste Plastics into Liquid Hydrocarbon using Mesoporous Kaolin Clay.  
DOI: 10.3329/jbas.v44i1.48559.
  21. Attique S, Batool M, Yaqub M, Goerke O, Gregory DH, Shah AT. Highly efficient catalytic pyrolysis of polyethylene waste to derive fuel products by novel polyoxometalate/kaolin composites. *Waste Management & Research*. 2020;38(6):689-95.  
DOI: 10.1177/0734242X19899718.
  22. Carrales-Alvarado DH, Rodríguez-Ramos I, Leyva-Ramos R, Mendoza-Mendoza E, Villela-Martínez DE. Effect of surface area and physical–chemical properties of graphite and graphene-based materials on their adsorption capacity towards metronidazole and trimethoprim antibiotics in aqueous solution. *Chemical Engineering Journal*. 2020;402:126155.  
DOI: 10.1016/j.cej.2020.126155.
  23. Cui L, Wang X, Chen N, Ji B, Qu L. Trash to treasure: converting plastic waste into a useful graphene foil. *Nanoscale*. 2017;9(26):9089-94.  
DOI: 10.1039/C7NR03580B.
  24. Dosodia A, Lal\* C, Singh BP, Mathur RB, Sharma\* DK. Development of catalyst free carbon nanotubes from coal and waste plastics. *Fullerenes, Nanotubes and Carbon Nanostructures*. 2009;17(5):567-82.  
DOI: 10.1080/15363830903133238.
  25. Garg KK, Pandey S, Kumar A, Rana A, Sahoo NG, Singh RK. Graphene nanosheets derived from waste plastic for cost-effective thermoelectric applications. *Results in Materials*. 2022;13:100260.  
DOI: 10.1016/j.rinma.2022.100260.
  26. Kashcheev ID, Zemlyanoi KG, Ust'yantsev VM, Pomortsev SA. Study of the structure and properties of graphites for refractory production. Part 1. Physicochemical study of graphites from different deposits. *Refractories and Industrial Ceramics*. 2016;56(6):577-82.  
DOI: 10.1007/s11148-016-9891-z.
  27. Ko S, Kwon YJ, Lee JU, Jeon YP. Preparation of synthetic graphite from waste PET plastic. *Journal of Industrial and Engineering Chemistry*. 2020;83:449-58.  
DOI: 10.1016/j.jiec.2019.12.018.
  28. Popova AN. Crystallographic analysis of graphite by X-Ray diffraction. *Coke and Chemistry*. 2017;60(9):361-5.  
DOI: 10.3103/S1068364X17090058.
  29. Qiu T, Yang JG, Bai XJ, Wang YL. The preparation of synthetic graphite materials with hierarchical pores from lignite by one-step impregnation and their characterization as dye absorbents. *RSC advances*. 2019;9(22):12737-46.  
DOI: 10.1039/C9RA00343F.
  30. Ruan G, Sun Z, Peng Z, Tour JM. Growth of graphene from food, insects, and waste. *ACS nano*. 2011;5(9):7601-7.  
DOI: 10.1021/nn202625c.

31. Sharma S, Kalita G, Hirano R, Shinde SM, Papon R, Ohtani H, Tanemura M. Synthesis of graphene crystals from solid waste plastic by chemical vapor deposition. *Carbon*. 2014;72:66-73. DOI: 10.1016/j.carbon.2014.01.051.
32. Zhang H, Yang Y, Ren D, Wang L, He X. Graphite as anode materials: Fundamental mechanism, recent progress and advances. *Energy Storage Materials*. 2021;36:147-70. DOI: 10.1016/j.ensm.2020.12.027.
33. Kamal AS, Othman R, Jabarullah NH. Preparation and synthesis of synthetic graphite from biomass waste: A review. *Syst. Rev. Pharm.* 2020;11(2):881-94.
34. Simandl GJ, Paradis S, Akam C. Graphite deposit types, their origin, and economic significance. *British Columbia Ministry of Energy and Mines & British Columbia Geological Survey*. 2015;3:163-71.
35. Badenhorst C, Santos C, Lázaro-Martínez J, Białecka B, Cruceu M, Guedes A, Guimarães R, Moreira K, Predeanu G, Suárez-Ruiz I, Cameán I. Assessment of graphitized coal ash char concentrates as a potential synthetic graphite source. *Minerals*. 2020;10(11):986. DOI: 10.3390/min10110986.
36. Kunwar B, Cheng HN, Chandrashekar SR, Sharma BK. Plastics to fuel: a review. *Renewable and Sustainable Energy Reviews*. 2016;54:421-8.
37. Encinar JM, González JF. Pyrolysis of synthetic polymers and plastic wastes. Kinetic study. *Fuel Processing Technology*. 2008;89(7):678-86. DOI: 10.1016/j.fuproc.2007.12.011.
38. Jamradloedluk J, Lertsatitthanakorn C. Characterization and utilization of char derived from fast pyrolysis of plastic wastes. *Procedia Engineering*. 2014;69:1437-42. DOI: 10.1016/j.proeng.2014.03.139.
39. Miandad R, Barakat MA, Aburizaiza AS, Rehan M, Ismail IM, Nizami AS. Effect of plastic waste types on pyrolysis liquid oil. *International Biodeterioration & Biodegradation*. 2017;119:239-52. DOI: 10.1016/j.ibiod.2016.09.017.
40. Harussani MM, Sapuan SM, Rashid U, Khalina A, Ilyas RA. Pyrolysis of polypropylene plastic waste into carbonaceous char: Priority of plastic waste management amidst COVID-19 pandemic. *Science of The Total Environment*. 2022;803:149911. DOI: 10.1016/j.scitotenv.2021.149911.
41. Miandad R, Kumar R, Barakat MA, Basheer C, Aburizaiza AS, Nizami AS, Rehan M. Untapped conversion of plastic waste char into carbon-metal LDOs for the adsorption of Congo red. *Journal of Colloid and Interface Science*. 2018;511:402-10. DOI: 10.1016/j.jcis.2017.10.029.
42. Shah AV, Srivastava VK, Mohanty SS, Varjani S. Municipal solid waste as a sustainable resource for energy production: State-of-the-art review. *Journal of Environmental Chemical Engineering*. 2021;9(4):105717. DOI: 10.1016/j.jece.2021.105717.
43. Harussani MM, Sapuan SM, Rashid U, Khalina A, Ilyas RA. Pyrolysis of polypropylene plastic waste into carbonaceous char: Priority of plastic waste management amidst COVID-19 pandemic. *Science of The Total Environment*. 2022;803:149911. DOI: 10.1016/j.scitotenv.2021.149911.
44. Sun J, He F, Pan Y, Zhang Z. Effects of pyrolysis temperature and residence time on physicochemical properties of different biochar types. *Acta Agriculturae Scandinavica, Section B—Soil & Plant Science*. 2017;67(1):12-22. DOI: 10.1080/09064710.2016.1214745.
45. Papari S, Bamdad H, Berruti F. Pyrolytic conversion of plastic waste to value-added products and fuels: A review. *Materials*. 2021;14(10):2586. DOI: 10.3390/ma14102586.
46. Zolfagharpour HR, Nowrouz P, Mohseni-Bandpei A, Majlesi M, Rafiee M, Khalili F. Influences of temperature, waste size and residence time on the generation of polycyclic aromatic hydrocarbons during the fast pyrolysis of medical waste. *Caspian Journal of Environmental Sciences*. 2020;18(1):47-57., DOI: 10.22124/cjes.2020.3978.
47. Xie W, Wang Z, Kuang J, Xu H, Yi S, Deng Y, Cao T, Guo Z. Fixed carbon content and reaction mechanism of natural microcrystalline graphite purified by hydrochloric acid and sodium fluoride. *International Journal of Mineral Processing*. 2016;155:45-54. DOI: 10.1016/j.minpro.2016.08.002.
48. Badenhorst C, Santos C, Lázaro-Martínez J, Białecka B, Cruceu M, Guedes A, Guimarães R, Moreira K, Predeanu G, Suárez-Ruiz I, Cameán I. Assessment of graphitized coal ash char concentrates as

- a potential synthetic graphite source. Minerals. 2020;10(11):986. DOI: 10.3390/min10110986.
49. Jara AD, Woldetinsae G, Betemariam A, Kim JY. Mineralogical and petrographic analysis on the flake graphite ore from Saba Boru area in Ethiopia. International Journal of Mining Science and Technology. 2020;30(5):715-21. DOI: 10.1016/j.ijmst.2020.05.025.
50. Jara AD, Woldetinsae G, Betemariam A, Kim JY. Mineralogical and petrographic analysis on the flake graphite ore from Saba Boru area in Ethiopia. International Journal of Mining Science and Technology. 2020;30(5):715-21. DOI: 10.1016/j.ijmst.2020.05.025.
51. Basu P, Achayra B, Dutta A. Study of calcination-carbonation of calcium carbonate in different fluidizing mediums for chemical looping gasification in circulating fluidized beds.
52. Kaewdaeng S, Sintuya P, Nirunsin R. Biodiesel production using calcium oxide from river snail shell ash as catalyst. Energy Procedia. 2017;138:937-42. DOI: 10.1016/j.egypro.2017.10.057.
53. Keihani M, Esmaeili H, Rouhi P. Biodiesel production from chicken fat using nano-calcium oxide catalyst and improving the fuel properties via blending with diesel. Physical Chemistry Research. 2018 Sep 1;6(3):521-9. DOI: 10.22036/pcr.2018.114565.1453.
54. Krishnamurthy KN, Sridhara SN, Kumar CA. Optimization and kinetic study of biodiesel production from Hydnocarpus wightiana oil and dairy waste scum using snail shell CaO nano catalyst. Renewable Energy. 2020;146:280-96. DOI: 10.1016/j.renene.2019.06.161.
55. Phewphong S, Roschat W, Pholsupho P, Moonsin P, Promarak V, Yoosuk B. Biodiesel production process catalyzed by acid-treated golden apple snail shells (*Pomacea canaliculata*)-derived CaO as a high-performance and green catalyst. Engineering and Applied Science Research. 2022;49(1):36-46.
56. Viriya-empikul N, Krasae P, Puttasawat B, Yoosuk B, Chollacoop N, Faungnawakij K. Waste shells of mollusk and egg as biodiesel production catalysts. Bioresource Technology. 2010;101(10):3765-7. DOI: 10.1016/j.biortech.2009.12.079.
57. Yan S, Kim M, Salley SO, Ng KS. Oil transesterification over calcium oxides modified with lanthanum. Applied Catalysis A: General. 2009;360(2):163-70. DOI: 10.1016/J.APCATA.2009.03.015.

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