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DEVELOPMENT OF HYBRID RENEWABLE ENERGY–POWERED LABORATORY–SCALE PLASTIC BOTTLE WASTE CONVERTER

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Abstract: This paper is about the development of a hybrid renewable energy–powered Laboratory–Scale plastic bottle waste converter for the conversion (pyrolysis) of plastic (PET) bottle wastes into useful petroleum products such as Diesel, kerosene, gasoline, etc. Waste plastic disposal and indiscriminate use of fossil fuels have caused environmental and health concerns in our societies. This is not unconnected with the ever–increasing consumption of products packaged in plastics by the teeming population the world over. Plastics are non–biodegradable products that pollute our environments, clog our canals and drainages, and eventually end up in the seas where they pollute and affect marine ecological systems. The process of converting waste plastic bottles into useful petroleum products is one of the viable solutions for the recycling of plastic bottle waste and turning the problems of plastic bottle careless disposals into an opportunity to make wealth from waste and also save the ecosystem. Heat is provided externally to the heating chamber that runs at high temperatures in the absence of oxygen by a DC heating element. The waste plastic bottles are shredded to reduce their volume–to–weight ratio and filled into the heating chamber where it is subjected to excessive heat to depolymerize, pyrolyze, and thermal cracking. The resulting gases are passed through a condenser to obtain different products such as petrol, kerosene, diesel, etc depending on the operating temperature of the chamber. The fuel obtained is useful in firing boilers and furnaces directly without any analysis or purification. It can be scaled up for commercial applications.
Keywords: converter, environmental pollution, petroleum products, plastic waste bottles, wind energy

1. INTRODUCTION

Plastics are being utilized daily throughout the world and are one of the basics in our daily lives nowadays. Plastic is a unique material because of its toughness, lightweight, air and water–tightness, low electrical and heat conductivity, versatility, strength, and viability in its various applications. The use of plastics and its derivatives has now become problematic due to its non–biodegradability nature [1]. The utilization of plastics does not generate concern but the afterlife of these products does, since they are non–biodegradable and may not be properly disposed of. Only about 9% of plastics utilized are been recycled at present [2]. Nearly half of the plastics produced worldwide have ended up in landfills or the environment. Figure 1. (a & b) are recovered marine plastics, (c & d) are plastics at dump sites, and (e) is a shoreline pollution. It is believed that around 8 million metric tons of plastic waste end up in the seas [3].

(a) (b) (c) (d) (e)

Figure. 1. (a &b) Recovered marine plastics, (c & d) Plastics at various dump sites, (e) Shoreline pollution

Thus, changing waste plastics into unrefined petroleum products will have two advantages; the menace and the havoc caused by plastic wastes can be reduced and petroleum products could be obtained from it. These resulting products can be used to run engines and machines. This can reduce dependence on refined petroleum products, and eventually decrease its demand to some extent. Therefore, converting waste plastic bottles to petroleum products should be commended and recommended especially when renewable energy sources are being used to supply the electricity for heating up the reactor chamber. It is possible to convert plastic wastes into petroleum products because they are obtained from crude oil which

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has a high calorific value [2]. There are so many methods that can used to convert waste plastic bottles into petroleum products but pyrolysis is one of the best and successful methods. The underlying volume of the waste is fundamentally decreased, more energy will be recovered from the plastic waste by creating assortments of items, and it requires lower disintegration temperature and low capital expense [4].

Pyrolysis is the thermally debasing of long–chain polymer atoms into more modest, or less perplexing particles through heat. The cycle requires extraordinary heat with more limited time in the absence of oxygen. The three significant products that are obtained during pyrolysis are fuel, gas, and char which are important for businesses, particularly production and processing plants. Pyrolysis is a preferred option by many because the process delivers a high measure of fluid oil up to 80 wt. % at moderate temperature of around 500 ⁰C [5]. Also, pyrolysis is truly adaptable since the process can be controlled to upgrade the item yield dependent on inclinations. The fluid oil obtained can be useful in many areas like heaters, boilers, turbines, and diesel motors without the necessities of treatment or purifications. The oil obtained from plastic pyrolysis has been given positive appraisals as an all the more environmentally amicable fuel since it reduces the pollution especially the measure of CO_2 in the air. The heat needed for the process is obtained from hybrid renewable energy sources (wind and solar) which are stored in batteries in other to ensure availability and reliability at all times when needed.

The rapid economic growth and utilization of plastics and their derivatives for packaging across the globe have been creating a negative impact on the environment and human health. More than 100 million tons of plastic are manufactured globally each year, and used items have become a common sight at drainages, canals, seas, bins, and landfills. Primary plastics production in 2015 was 407 million tons and about 75% (302 million tons) ended up as waste [6]. It has become problematic to successfully dispose off these plastic materials because they are non–biodegradable. Also, the consumption trend of natural fossil fuels and other non–renewable energy resources indicates that these resources can be depleted in the near future. There is no energy security in developing countries like Nigeria. Consequently, finding some other alternative energy sources will be a welcome idea. This project is justified by the fact that:

- it helps to clean up the environment,
- reduce the harmful effects the plastic waste is causing to the environment by providing effective and eco–friendly ways of recycling them and converting them into some other desired (petroleum) products and
- creating wealth from the waste.

The multiple uses of plastics have brought about severe plastic contamination in the environment. About 6, 300 million tons of plastic waste are believed to have been produced somewhere in the range between 1950 and 2015, out of which just about 9% were believed to have been recycled, and 12% burned, leaving almost 80% to amass in landfills or the common habitat [2]. Plastic contamination is a common feature in almost all the world's significant seas, including distant islands, the posts, and remote oceans, and an extra 5 to 13 million tons are added each year [3]. It is observed that around 10% of worldwide plastic waste (or 30 Mt) was bungled in 2010 [3]. G7 nations are thought to represent under 2% of this material: around half starts in ten huge rising economies. Natural life is hurt through the ingestion of plastics or entrapment, with negative effects on biological systems' well–being and the general maintainability of fisheries. The travel industries are additionally impacted as fun seekers and sightseers try to keep away from seashores known to have high concentrations of plastic litter. Plastic contamination in the seas presents adverse effects on human well–being. The presence of plastics in fishes, including shellfish, and their eventual consumption by humans in general has generated concerns about synthetic bio–collection in the evolved way of life [7]. Investigation has revealed traces of plastic tainting in regular water and filtered water across various nations and plastic pollution has additionally been found in ocean salts [8]. Aside from marine pollution, open burning is the other option for plastic disposal. The burning of plastics is usually done in unregulated, or unapproved places thereby polluting and contaminating the atmosphere. Plastic materials have some harmful synthetic compounds that once incinerated are noticeable all around, and it present a threat to the environment as well as serious health concerns for life. "Burning of plastic waste in the open air will increase the risk of heart disease, aggravates respiratory ailments such as asthma and emphysema and cause rashes, nausea or headaches, and damages the nervous system," says the study. Burning plastic also releases black carbon (soot), which contributes to climate change and air pollution. Bioplastics are typically plastics made from bio–based polymers. They stand to contribute to more sustainable commercial plastic life cycles, as part of a circular economy, in which virgin polymers are produced from renewable or

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recycled raw materials. In a survey carried out, the benefits and difficulties of bioplastics in the transition towards a circular economy were evaluated. Bio–based plastics can have advantageous material properties and have a lower carbon footprint than fossil–based plastics; in addition, they can be viable with existing reusing streams, and some proposition biodegradation as an EOL situation whenever acted in controlled or unsurprising conditions. However, these advantages come at the expense of negative effects on agriculture, competition with food production, unclear EOL management, and increased costs. Therefore, existing life cycle assessment guidelines and (bio)plastic identification standards require revision and homogenization in order to assist converters and consumers in making purchasing decisions [9]. The investigation of product properties and bio–crude yield, resulting from HTL of plastic waste mix, and polypropylene at the lab scale by conventional heating and solar energy–aided was carried out. Heating was provided by an electric heater and an in–house solar simulator for two different units used. A solar setup was designed and constructed with ceramic insulation and a stainless–steel support shell for testing in a solar simulator. It was observed that the crude yield achieved exceeded 50% in the case of polypropylene and it was increased by 5–10% when treated under the solar simulator. Higher heating values of products were increased by 30–45% compared to the feedstock for the plastic waste mix, while for the resulting PP bio–crude further treatment would be needed to reach a similar increase [10]. A standard plastic milk bottle was redesigned based on a shape factor that was previously developed for the sustainability of forms, about 13% reduction in material was achieved. Global environmental benefits were evaluated using hybrid life–cycle assessment (LCA) in the countries where the original plastic bottles were used and other countries in the supply chain. The results obtained using hybrid LCA were 17.3% higher than those obtained using process–based LCA. It was discovered that the environmental benefits from the countries in the upstream supply chain were twice as much as those in the countries where the original bottle is used [11].

Several researchers have worked on the conversion of solid municipal wastes into useful oil fuels through pyrolysis. Some designed, optimized, and evaluated biomass pyrolysis reactor products [12 – 13]. Some designed, fabricated, and tested the performance of fixed bed batch–type pyrolysis reactors for pilot–scale oil production [14 – 15]. Some researchers designed and fabricated plastic waste converters for the pyrolysis process [16 – 19]. In [16], the waste plastic converter was designed and fabricated with a pyrolysis process as the main aim of the design and manufacture. It has a treated steel reactor, that has a holding limit of 200g/cluster of waste plastic. Five preliminary trials were carried out using 200g of type 6 plastics for each trial. The temperature was controlled at 380 °C for 2 hours. The test outcome showed that the converter is useful with change effectiveness (wt %) of 78.1%, waste decreases productivity (wt %) of 94.3%, and oil recuperation of 883 ml oil/kg of type 6 waste plastic. A machine to convert waste plastics into mixed oil for domestic purposes was designed with the aim to be able to convert waste plastics such as polyethylene, polypropylene, or ordinary plastic conveying packs into blended oil for domestic uses [17]. A mechanical system to convert waste plastic into crude oil was fabricated and analyzed in [18]. A system to convert waste plastics into crude oil was designed and fabricated in [19]. The system deals with the extraction of oil from the waste plastics in the absence of oxygen and at a high temperature of around 250 °C. The waste plastics are depolymerized, pyrolyzed, cracked, and fractional distilled to obtain different products which are sold at competitive prices below market value prices. The objective of this paper is to develop an environmentally friendly Laboratory–Scale plastic bottle waste converter to convert plastic waste to fuel, that operates on the principle of thermal pyrolysis for the conversion of plastic bottle wastes to petroleum products (fuel) and using hybrid renewable energies as sources of power.

2. MATERIALS AND METHODS

Materials

Material selection for the development of the reactor chamber and other components is a very important factor in its safety and economic viability. The material selected must be suitable enough to withstand the process' operating temperatures and pressures etc. else there may be a huge catastrophe if the material selected fails.

— Reactor: The reactor is fabricated with a thick steel metal sheet, rolled into a hollow cylinder sealed at the bottom but the top has an opening to feed in shredded plastics. The reactor is double–walled and insulated with fiberglass to reduce heat loss to the surroundings to the barest minimum. The reactor can be used for the pyrolysis of substances like plastics, biomass, scraps, vehicle tires, and so forth. This reactor can be classified as a fixed–bed reactor. The reactor's top part can be opened to feed raw

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material through it before being sealed. Some assumptions were taken in the material balance for the design of the reactor. It is assumed that every plastic feed gives the same fuel output yield and composition. There is no leakage from the reactor chamber. There is no gas accumulation inside the reactor. The following considerations were made in the material selection such as operating conditions (temperature, pressure, corrosion resistance); corrosion resistance; ease of fabrication; market availability; and design life.

- Heating Unit and Heater (heating) Element: The heating unit, Figure 2, is a 48 V DC, 5,000 W heating element in a refractory material. This is attached to the reactor chamber for heating purposes.
- Water–cooled condenser (Heat exchanger): The condensing unit converts the gas vapor from the reactor to liquid by cooling and reducing the pressure and the temperature using running water at room temperature. The condensing unit is fabricated with steel as the shell while the inner tube is made of stainless steel with 12 coils.

Figure. 2: Heating Unit

- Vertical axis Wind Turbine generator: The wind turbine generator is a 5,000 W 24/48 V generator mounted on a pole. It has a start–up wind velocity of 2 m/s.
- Solar PV panels: The solar panels are 4 number, 500 W, 37.6 V solar PV panels mounted on the roof in a convenient place for security purposes. Two panels are connected in parallel and then connected in series to charge a 48 V battery bank.
- Batteries: The batteries are the power back–up. It consists of 4 no, 200 AH Deep cycle batteries connected in parallel to give 48 V output.
- Charge controller: The charge controller serves as an intermediary between the solar panels, the wind generator, the batteries, and the heating element (load). It is a 160 A MPPT charge controller.
- Water pump: This is used for the circulation of water used in cooling in the condensing unit.
- Others: A K–type thermometer is used to measure the operating temperature. A Chemical weighing balance is used in measuring the mass of the feedstock, and the product. Stop stopwatch was used to measure the time taken during the process. Cables, cable locks, screws, nuts, etc. were part of the accessories for the installation and connection of the whole set–up.

Table 1. Cost list of the project.

S/N	Equipment/Description	Quantity	Unit Price	Total Price NGN Naira
1	500 W Monocrystalline Solar PV Panels	4	124,750.00	499,000.00
2	8000 W Vertical Axis Wind Generator	1	391,000.00	391,000.00
3	200 AH Solar Batteries	4	149,500.00	598,000.00
4	120A MPPT charge controller	1	169,050.00	169,050.00
5	5,000 W, 48 V DC Electric Heater unit	1	92,000.00	92,000.00
6	750 W DC water pumping machine	1	74,750.00	74,750.00
7	Reactor construction	1	115,000.00	115,000.00
8	Heat exchanger (condenser)	1	92,000.00	92,000.00
9	Collector	1	34,500.00	34,500.00
10	Shredding Machine fabrication	1	138,000.00	138,000.00
11	Cables, cable locks, bolts screws, nuts, etc	1	92,000.00	92,000.00
12	Mounting poles and installation of the wind and solar	1	92,000.00	92,000.00
13	Contingencies/others	1	200,000.00	200,000.00
	Total			2,587,300.00

Table 1 is the list and the cost of all the items used for this project.

Methods

The conversion of waste plastic bottles to fuel consists of many processes and stages. The plastic bottles will have to be picked, collected, and collated. If they are wet, they will need to be sun–dried, if dirty, they will need to be washed and dried in the sun, after which they will be shredded to reduce the volume and increase the density for greater yield. Then, the shredded plastic will be loaded into the reactor. The reactor will be heated with an electric heater that is 5,000 W, 48 V DC supplied by solar PV panels and wind turbine through the arrays of batteries and charge controller. (The use of a 48 V DC electric heater will eliminate the need to acquire a 220 V inverter/charger). The flue gas from the reactor chamber will be passed many times through the water–cooled condenser. The final product is then collected at the end of the condenser to be tested for quality. The temperature of the reactor chamber will be controlled as per the desired end product depending on what end product is expected, whether it be diesel, petrol, or kerosene.

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Experimental Set–up:

The plastic bottle wastes were shredded into pieces and all the impurities including labels and bottle covers were removed. The chips were washed and dried in the sun before being fed into the reactor chamber unit. The feedstock is externally heated up in the reactor in the absence of oxygen. The pyrolysis reactor chamber design for the experiment is a cylindrical chamber that is fully insulated. The process of heating is carried out at 450 – 650 °C. The heating rate is maintained at the desired value suitable for the desired product yield (petrol) with the aid of a thermostat. The residence time of the feedstock in the reactor is measured and recorded. The products of pyrolysis in the form of vapor are sent to a water–cooled condenser and the condensed liquid fuel is collected. Three products are obtained during the pyrolysis process, namely, liquid oil, flue gas, and char. At the beginning, the amount of feedstock used to produce a particular amount of liquid fuel is measured while at the end, the amount of fuel is also measured. The experimental set–up diagram is shown in Figure 3.

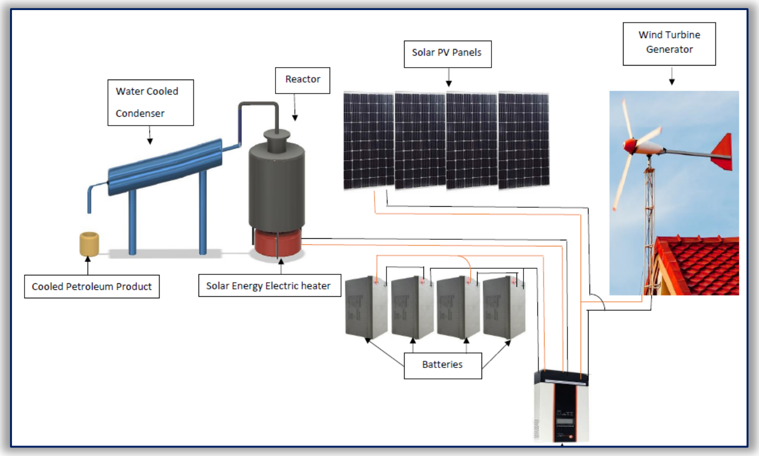

Figure. 3. Experimental Set–up

3. RESULTS AND DISCUSSIONS

The pyrolysis of plastic bottle wastes was achieved in the reactor chamber. The flue gas is then passed through the condenser to condense into liquid fuel. The fuel was collected at the end of the condenser and water was separated from the fuel using a separating funnel. Water and fuel are immiscible fluids. Each of the end products (water and fuel) was weighed on the weighing balance, measured, and recorded, as shown in Table 2.

Table 2. Product Sample from the pyrolysis process.

S/N	Feedstock (g)	Residence time (Secs)	Mass of gas (g)	Mass of Water (g)	Mass of Oil (g)	Mass of Char (g)	Vol of water (ml)	Vol of Oil (ml)
1	1200	8,400	943	28	147	82	16	4
2	1200	8,700	932	26	155	87	19	3.8
3	1200	9,000	938	28	152	82	17	4
4	1200	9,000	940	32	147	81	16	4.5
5	1200	9,900	964	34	135	67	15	4.7
6	1200	10,800	946	40	128	86	14	5.5
Mean	1200	9,300	943.83	31.33	144	80.83	16.17	4.42

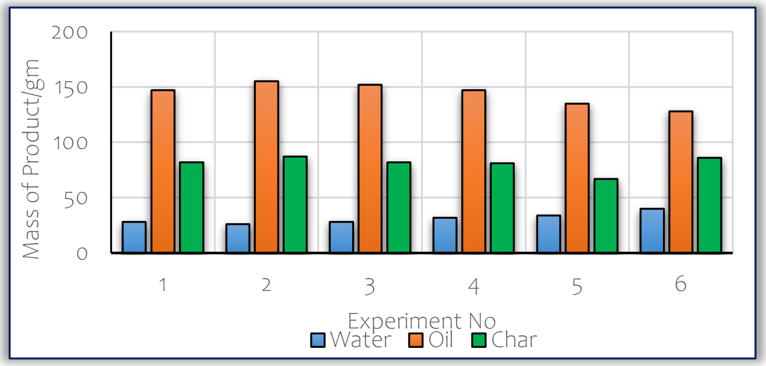

Figure. 4. Product Sample from the pyrolysis process.


Figure. 5. Sample petrol fuel obtained from the converter

The masses of the final products are shown in the bar chart in Figure 4. The process times were noted and recorded. The char that was left behind in the reactor was collected and weighed after the process. Figure 5 below shows the fuel samples collected in plastic bottle wastes. The fuel recovered gave an average of 56.21 % weight of the total weight of all the products recovered.

4. CONCLUSION

A hybrid renewable energy–powered laboratory–scale converter for the conversion of plastic bottle wastes to fuel has been developed. The sources of heat used were renewable energies from solar PV

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panels and a wind turbine generator. Although, the renewable energies generated and used for this process could have been used for other purposes but for the sake of a clean environment, especially the marine environment, it is worth the effort. It was discovered that waste plastic bottles can be safely converted into petroleum products depending on the operating temperature of the reactor chamber. It is also concluded that renewable energies can be used as the heating source. This converter can be scaled up for commercial production of fuel and the fuel produced can be sold to third parties to run machines, engines, vehicles, and generators. Other plastic materials such as HDPE, LDPE, PET, PS, PP can be converted to fuel with this converter. The menace of plastic bottles in blocking canals and drainages are so enormous, hence the focus on PET bottles in this project.

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