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Thermal - Decomposition and Conversion of Plastic Wastes to Diesel Fuel

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ABSTRACT
Plastic waste materials were thermally digested and the vapor condensed to diesel fuel, using a self-fabricated pyrolysis reactor. This investigation was carried out as a means of energy recovery and provision of feed stock for both, domestic and industrial applications. Enormous demand, production, utilization, and non-degradability of plastic waste materials, had resulted into their accumulation in the environment, posing great threat to the life of both flora and fauna. The pyrolysis reactor used in this research consists of large incineration chamber, feed hopper, condenser, and thermostat to regulate the operational temperature. The percentage yield of the diesel fuel was 30.78 %, the viscosity was 2.9 Pa.s using ASTMD445 specification, flash point (73^{0}C), flammability of 185 ^{0}C, specific gravity(759.8) and ash content of 0. 11 %, all compared favorably to the commercial (OMEGA) diesel fuel grade. The distillation temperature for Plastic Waste Diesel Fuel (PWDF) was determined between 185 to 200 ^{0}C. The quality control parameters carried out on PDWF confirmed it as an alternative source of energy, suitable for diesel engines and a means of plastic waste management.

KEYWORDS:*Diesel fuel, Pyrolysis, Plastic wastes, Non-biodegradable, Properties.*

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I. INTRODUCTION

Thermal decomposition of plastic waste materials had been taught of, as an alternative source for energy recovery, feed stock for industrial applications, an eco-friendly method of eradicating municipal waste materials and converting them to diesel fuel,(Kim, 2004).Diesel fuel is a hydrocarbon composition that is made from the by-product of petroleum. They are mainly used in heavy cars, like, construction machines, public buses, trucks, trains, boats, military vehicles, and even generators.

Petroleum compounds can occur naturally from crude oil, but the final product, diesel fuel, is a man made product. Diesel fuel is usually distilled at the lower end of distillation tower during refining of crude oil. The chemistry of individual component of crude oil fraction is important in the refining process, because, scientists need to know the boiling point, the number of hydrogen and carbon atoms in each compound that is being separated. Studies had shown that, the major component of diesel oil are, 75%, paraffin, consisting ofabout 10 to 20 carbon atoms and 22 to 42 hydrogen atoms. About 25% of aromatic hydrocarbon of diesel oil consist of naphthenes, with about 10 to 20 carbon atoms and 8 to 34 hydrogen atoms,Anton, et al, (2017). Other components found as impurities are sulfur and nitrogen. Diesel fuel had been known as consisting of mixture of hydrocarbons, with boiling points in the range of 150 to 380°C. They have the ability to be transformed from chemical energy to mechanical energy which can get automobile engines functional. The mechanical energy helps to move the pistons up and down inside cylinders, in which the pistons, which are connected to the engine's crankshaft, changes their linear motion into the rotary motion needed to propel the vehicle's wheels, Quiming, et al, (2016). Energy is released in a series of small explosions (combustion) as fuel reacts chemically with the oxygen from the air and this gets the engine moving. The chemical equation for diesel fuel combustion reaction can be represented as follows:

$$C_{13}H_{28} + 20O_2 \rightarrow 13CO_2 + 14H_2O$$

Diesel oil + Oxygen = Carbon (iv) oxide + Water

Thermodynamically, the combustion reactions are spontaneous, yielding a -ΔG (enthalpy change) which is negative. The reaction proceeded from 20 moles of O2 gas to 13 moles of CO2 yielding a -ΔS (entropy change to be negative). This mean that heat energy which evolved could be recovered by condensation. Reports had shown that combustion reactions are exothermic as the chemical bonds between the molecules broken, Quiming, et al, (2016). They concluded that the evolving heat energy is the force propelling automated enginesinto motion.

Thermal decomposition of most conventional plastic waste materials like Polyethylene$(C_2H_4)n$, polystyrene $(C_8H_8)n$, Polypropylene $(C_3H_6)n$, Polyvinylchloride$(CH_2 = CHCl)n$,Poly-ethylene-terephthalate$(C_{10}H_8O_4)n$, etc, could be converted to gas, liquid (oil), and solid residue or wax. Merve, et al (2017), had suggested that recovered liquid fuel can be used as an alternative energy source or chemical feedstock for automobile and other industrial applications. Kan, et al (2016) and (Kim 2004) demonstrated that, unlike recycling, land -filling or incineration, pryolysis had been proved to be environmentally friendly, because, it does not cause water or air contamination. They considered plastic waste pyrolysis as a green technology, because, the by-product is gaseous with substantial calorific value and can be used to compensate the overall energy requirement for both industrial and domestic purposes.

Plastic materials play vital roles in enhancing the living standard of human being for over 50 years ago. It is a key product in various industrial sectors, such as construction, healthcare, electronic, automotive, packaging and others. The demand for commodity plastics had been increased due to the rapid growth of the world population, innovation in science and technology etc. This had made the global production of plastics rise to about 299 million tons in 2013 and has increased by 4% more as against 2012, (Sarkerm, et al, (2012). The continuous rising of plastic demand led to the increase in their waste generation and accumulation. It had been reported that 33 million ton of plastic waste are generated in the USA based on 2013 statics (Monuddin and Rashid, (2013). Studies had shown that plastics take up to millions of years to degrade (Moinuddm and Rashid, 2013), therefore, a large percentage or plastics waste end up in landfill, and occupy a huge land space or carelessly littered around the environment. The inter and intra- molecular bonds in plastics chains are the reason for their non-degradability. Other approach of controlling the wastes, such as recycling is not a good option, because, it is more expensive, due to the process of cleansing of the reactor after each stage, cutting of the wastes, washing the waste before processing, energy consumption and poor quality of end-products. Separation is also needed, since plastics are made of different resin compound and other additives.

Some records had shown that the increased demand and utilization of plastic materials had resulted into reduction in fossil fuel, especially petroleum. This is becausethey are derived from one common natural source, the crude oil. Energy recovery from plastic wastes has been taught of as a good approach to solving plastic pollution problems and increased energy supply for auto mobile applications, (Woje and Carma, 1986).

Khan, et al, (2016), had suggested that, since plastics are one of the lowest grade of petrochemicals from crude oil, they could be further distilled and thermally treated to obtain liquid fuel, via the pyrolysis method. Many plastic materials had been investigated upon to determine the best method to be adopted, for better yield and quality. Shafferina, et al (2016) reviewed on the pyrolysis of many plastic wastes, and discovered the effect of temperature, type of reactor, pressure, residence time and catalyst on the quality of liquid fuel converted.

Sogancioglu, et al (2017) discovered that liquid oil from high density polyethylene and low density polyethylene have higher calorific values like that ofpyrolysised oil from wood and coal types.

Thermal decomposition or pyrolysis process can also be applied on other municipal wastes, garden wastes, etc to convert them to conventional fossil or liquid fuel, for both industrial or domestic source of energy, Czajczynska, et al, (2017).

Pyrolysis is the process of thermal-decomposition of long chain polymer molecules into smaller, less complex molecules through application of heat and pressure. Researchers had discovered that pyrolysis is able to produce high amount of liquid oil, about 80 wt. % at moderate temperature of 500℃, (Onwudili, et al, 2009). The process can be manipulated to optimize and improve the product yield (Shatterine, et al 2016). The liquid oil they produced was used in multiple applications, such as furnaces, boilers, turbines, and diesel engines, without the need of upgrading or treatment.

Diesel fuel is a liquid fuel which it’s ignition takes place without a spark was invented by a German scientist and is known as Rudolf Diesel (Alfred, and Rudolf, 1913). He investigated on redesigning internal compression engine, that was using coal dust to the use of liquid fuel, which he recognized to be better fuels than coal dust. It has been observed that any engine running on diesel compresses air inside the cylinder under a high temperature and pressure.The high cost of petroleum by-products has attracted the attention of researchers, to look otherwise for other sources of producing suitable fuel oil for Diesel engines.

Our target therefor, is to thermally digest, and condense the vapour to obtain diesel fuel from plastics waste, which is a derivative of crude oil. This will not only help in controlling the menace of plastic wastes but also convert the waste to wealth, create more jobs for youths and increase our economy.

II. MATERIALS AND METHODS

i. The Waste Plastic

The plastic wastes were carefully selected from the waste bins, around marketareas, hostels and around university environment. The plastics with the brand number "5" or letter "pp", which indicates polypropylene(5- carbon atoms) were sorted out from the wastes, washed with soap to remove dirt and dried under the atmospheric air for a period of two hours. These plastics were cut into chips to increase their surface areas, for faster rate of heat transfer during thermal treatment.

ii. Pyrolysis Plant (Thermal Reactor)

The pyrolysis plant (thermal reactor) used in this waste conversion was designed and fabricated by Nedu's Engineering Ltd, No 2 Nweke

Nwobuchi lane, off Zik's Avenue Awka, in Anambra State. This fabrication of the reactor was developed, taking recognition of its eco-friendliness and gaseous pollution control. Heat and gas emission were prevented by sealing both the reaction chambers and the cooling tube with layers of insulator (CaO). The major parts of the pyrolysis plant includes, the 400 cm^3 volume feed hopper, used to introduce the plastic chip into the reactor chamber. A double walled calcium oxide coatedincinerator were the thermal decomposition of the plastic waste chips took place. The Condenser was used to convert hot gas into liquid oil. Cold water was allowed to circulate round the condenser to lower the temperature of the vapour and convert to liquid reduced temperature. Heat Exchanger was attached to regulate the temperature. Control switch serves as the key to either "ON" or "OFF" the pyrolysis plant.The lid handle, is an iron handle used to loosen or tighten the incinerator to ensure no lose of heat. Metallic framewas used to assemble all the parts of the reactor into an organized system.

Other apparatus and materials used in this research includes; an electronic digital weighing balance., 500cm^3 glass desiccator with desiccant, viscometer, Crucibles**,** Flash point tester,Density cup used to determine the specific gravity of the diesel fuel, glass dish, spatula, thermometer, litmus papers (blue and red), etc.

2.2Pyrolysis (Thermal Decomposition) Process of the plastic waste chips

1 kg of the plastic chips were stuffed into the incinerator via the feed hopper covering it tightly to prevent discharge of hot gas to the surrounding. The temperature of the reactor was maintained between 185 to 200^{0}C with the use of a thermostat. The hot gas produced after incineration was converted to liquid energy after cooling inside the condenser. The liquid fuel was collected through the discharge pump and stored for further analysis.

2.3 Properties of the Sample Diesel as Compared to the Commercial grade

2.3.1 Physical Properties:

Some of the physical properties determined include: visual colour, percentage yield, flash point, viscosity, flammability, litmus test and specific gravity.

Percentage Yield Determination

This was carried out and calculated using a standard according to(Khanacademy 2018). Using the formlar:

$$\%\ \text{yield} = \frac{\textbf{plasticwaste} - \textbf{PlasticResidue}}{\textbf{PlsticWaste}} \times \frac{100}{1}$$

Visual Colour Testing, was donein the laboratory under ultraviolet light and compare to the commercial grade.

Acidity Test: This was done using a pH meter and compared to the commercial diesel fuel.

Flash Point: This was carried out by passing a glowing paper over a container of the diesel oil and noting the time and temperature of ignition. The ignition time was recorded and compared to that of the commercial diesel fuel .

Viscosity Test

This was carried out under at room temperature using Kinematic Viscometer, of ASTMD445 standard, andrecorded in mm^2 per second (mm^2/sec).

Specific Gravitydetermination were also carried out and calculated accordingly,

Proximate Analysis

Some simple chemical analytical properties were carried out to ascertain the quality and grade of the PWDF (Plastic Waste Diesel Fuel) and compared to the CDF(Commercial Diesel Fuel). Among the properties tested

are, ash content determinationaccording to (ASTMD2584)specification. **Distillation (Volatility)** of the fuel was determined using ASTM – D 86 – 17 standard method:
Centane Index (Number) ;. Thecetane index was calculated (CI) using ‘’2’’ point method and density according to ASTM – D976 specification under 50 % recovery temperature.The cetane index was estimated according to Joshua eta, (2012).

III. RESULTS AND DISCUSSION

The analytical properties of our plastic waste diesel fuel exhibited, some comparative values to the conventional commercial diesel fuel. Some of the tests were carried out according to ASTM (American Standard Tests).
The private-fabricated, eco friendly and potable pyrolysisreactor was able to convert the vapour from the plastic waste to characteristic liquid diesel fuel, at the temperature range between 185 to 200 ^{O}C, as had also been reported by Shafferine et al(2016).

The Percentage Yield
The Percentage yield(30.78 %) of the sample diesel fuel as shown on Table 1, confirmed that considerable quantity of fuel could be recovered from plastic wastes. We observed that the polypropylene waste (5 carbon plastic), used in this research yield more quantity of liquid fuel, as compared to polyethylene(Shafferine, et al, 2016).

Flammability of diesel fuel
The plastic waste diesel fuel (PWDF) gave up flame at the temperature of 40^{0}C while commercial diesel fuel (CDF) gave up flame at 60^{0}C. This shows that PWDF can ignite at a very low temperature compared to CDF. This value, can enable us to take all necessary precaution during transportation, since, PWDF is more flammable and combustible than CDF according to Behm, (2004).

Flash point
The flash point value of 73^{o}C for PWDF as against 80^{0}C for CDF which was higheraccording to, Australian AS1940 – 2017 standard. The variations in this value could be attributed to some additives incorporated to the CDF diesel fuel specie in order to improve their quality according, Khan, et al (2016).

Visual Colour
The diesel fuel samples give a uniform Brownish Yellow colour when observed over a white light radiation. This can be used to confirm that, the composition of both PWDF and CDF are relatively the same.
The distillation temperature of 185 ^{0}C is in close range to the commercial of 180^{0}C. It could be concluded that, the variation was because, the analysis on the research diesel was carried in an open laboratory without any, professional supervision. The percentage recovery of 63% from PWDFwas made at 185^{0}C, while 68% of CDF (commercial diesel fuel) was recovered at 180^{0}C.

Ash Content
The percentage ash content of 0. 11 % as against 0.07 % for that commercial diesel are within the range for an organic diesel fuel, according to D 975 specification, which is ranges between 0 to o.1 %. The increased ash content of the plastic waste diesel fuel could be attributed to some additives originally used during the plastic production.

Viscosity
The viscosity of 2.6 Pa.s for PWDF as shown on Table 1.was within the acceptable range for plastic fuel according to Shafferine et al(2016). They studied on fuel from several plastic materials and suggested that their viscosity were between 1 and 5 Pa.s. The viscosity value of our plastic waste diesel fuel shows that, its flow or delivery rate, atomization during injectionare good and cannot cause damage to fuel pumps.

Cetane Index
The values for the cetaneindex of40.10 and 41.32 for PWDF andCDFrespectivelyas shown in Table 1 are acceptable for a good quality diesel, as estimated byCataluna, and Silva, (2012). Cetaneis a hydrocarbon with $(C_{16} H_{34})_n$, chemically referred to as hexadecane and is assigned a cetane number or index of 100, which is used to rate the ignition rate of diesel oils. Studies has shown that diesel fuel with higher cetane number exhibits better combustion capacity, reduced engine ignition noise and reduced carbon monoxide or hydrocarbon emission, according to, Cataluna, and Silva, (2012). The value of our plastic waste diesel oil is on the average range, therefore is of a good quality for most automobile engines operation.
The pH range of 6.35 and 8.80 for both research diesel and commercial diesel fuel respectively indicate that our research fuel cannot cause corrosion when in contact with metallic parts of automobiles.

Table 1.0: Showing Results on some properties of Plastic waste Diesel Fuel as compared to the commercial Diesel Fuel

Tests	Plastic Waste Diesel Fuel (PWDF)	Commercial Diesel Fuel (CDF)
Percentage yield	30.78%	-
Visual Colour	Bromish- yellow	Browmish-yellow
Colour on: - red litmus - Blue litmus	No colour change	No colour change
Flammability	Flammable(40 ^{0}C)	Flammable(60 ^{0}C
Specific gravity at 27 ^{0}C	759.8 kg/cm ^{3}	882.5 kg/cm ^{3}
Flash point (^{0}C)	73 ^{0}C/3 sec.	80 ^{0}C/5 sec.
Viscosity	2.9 Pa.s	3.2 Pa.s
Ash-content	0.11 wt.%	0.08 wt.%
Distillation-temperature	185 ^{0}C	180 ^{0}C
pH Range	6.35	8.80
Cetane index	40.10	41.32

IV. CONCLUSION

Plastic waste material as one of the major petrochemicals that can pose great threat to the environment had been investigated, forits benefits in the production of diesel fuel. Pyrolysis of plastic material helps to convert waste to energy that worth billions of dollar. This method is technologically innovative and will not only protect our environment, but provide us with enough liquid fuel for automobile industries or domestic energy source.The utilization of diesel fuel from plastic wastes has to be recommended to the public, since, it compares well with the commercial grade diesel.

We therefore recommend thepyrolysisof plastic wastes because, it is eco-friendly, provided that the reactoris well designed to avoid escape of hotgas to the surroundings. A continuous process pyrolysis plant is recommendable to shorten the time wasted on batch process, as it involves removal of residue from the reactor chamber, cooling the system for another unit operation, etc. Researchers should also investigate more on liquid fuel from other sources to compliment the petro –diesel and this will help to lower the high prize of this essential commodity.

The Pyrolysisof plastic wastes will aid to curb down the negative impacts of these wastes in our ecosystem and willalso generate income, revenue and sources of employment for some of our job-seeking graduates. This is an innovation toward good direction and Federal Government is called upon to adopt the production of liquid energy through plastic waste pyrolysis.

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