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Fuel Production from the Thermal Pyrolysis of Waste Plastic Materials

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Abstract: *It can be observed that the widespread use of plastic materials as a means of packaging goods, creates huge disposal issues and environmental concerns after usage. The aim of this paper is to carry out the thermal pyrolysis of plastic materials for the production of fuel. The purpose of this work is to employ the process of pyrolysis to convert waste plastic material into fuel that can be utilised as a source of energy for several applications. The methodology used to carry out this work involves the process of thermal pyrolysis in which a specific amount of waste plastic materials was charged into a furnace and heated up to about 500^{o}C. The plastic is melted and converted into gaseous substance and subsequently condensed into liquid fuel in different condensing vessels. The calorific value and the chemical composition of the pyrolysis fuel obtained was determined using a bomb calorimeter and X-ray spectroscopy respectively. The determination of the mass balance carried out on the pyrolysis experiment reveals 82% of liquid fuel, 9.3% of gaseous fuel and 8.7% of char for HDPE. While the X-ray spectroscopy test confirms the following elemental composition; carbon 84.59%, hydrogen 15.25%, nitrogen 0.16%. Furthermore, the calorific value determine by the bomb calorimeter was 47,380 kJ/kg. The pyrolysis fuel can be utilised for powering mechanical threshers, hammer mills e.t.c.*

Keywords— *Bomb calorimeter, Calorific value, Chemical composition, Mass balance, Pyrolysis, X-Ray spectroscopy*.

1. INTRODUCTION

Petroleum is used to create plastics, which are polymers that are mostly utilized for packaging of goods. By using a process called pyrolysis, liquid gasoline can be produced once again from plastics. With this technique, the plastics must be heated to extremely high temperatures (between 400°C and 600°C). The landfill or waterways are where used plastics end up most frequently after being released into the environment. Less than 5% of manufactured plastic is recycled annually, according to some academics (Ratnasari et al., 2017). Our ocean is littered with plastic and research indicates that even if it did biodegrade, it would take more than 450 years. Polypropylene (PP-), which is used to produce items like food containers, bottles, pipes and garments accounts for close to a quarter of all plastic trash (Serrano et al., 2012).

Due to their low weight, strength, energy efficiency, rapid pace of manufacturing and design flexibility, plastics have established themselves as essential components of today's society. Plastics are used in a wide range of industrial and residential areas since they have become indispensable materials and their industrial applications are constantly expanding. In addition, due of their enormous quantities and dangers associated with disposal, waste plastics have produced a very major environmental issue (Mitan et al., 2007). By pyrolyzing waste plastic into liquid fuel (such as gasoline, diesel oil, etc.) or chemical raw materials, we are not only able to successfully address the issue of waste pollution, but we are also able to somewhat ease the energy crisis. Recycling, regenerating and using waste plastics have attracted a lot of attention from researchers both domestically and internationally and has slowly given rise to a new sector (Sahroni et al., 2021). The Pyrolysis process, which entails the thermochemical degradation of synthetic and organic materials at higher temperatures in the absence of oxygen to produce fuels, is one of the promising ways to recycle waste plastics. Typically, the operation is carried out between 300 and 500 degrees Celsius. According to Rahan et al. (2017), these pyrolytic products can be separated into liquid fraction, solid residues and gaseous fraction. Numerous research projects have been conducted in this area as a result of the disposal and decomposition of plastics becoming a problem. Landfilling, mechanical recycling, biological recycling, thermal recycling and chemical recycling are the disposal techniques now used. Chemical recycling is one of these approaches and research into it has recently attracted a lot of attention because the items created using it are actually very useful. Numerous pollutants are released during trash burning that have an impact on the residents that live close to incinerator operations. Additionally, compared to incineration, landfilling has a significantly smaller impact on the environment. However, most urban centers lack the space to continue accumulating rubbish because landfills are now full. In addition to affecting wildlife, landfilling contaminates the soil and water. According to research, waste plastic fuel can be used in place of diesel because it possesses features that are comparable to those of diesel (Gebreslassie et al., 2013).

The ecology is greatly endangered by the disposal of waste plastics, yet no practical solution has yet been developed. The main components of plastics, which are non-biodegradable polymers, are carbon, hydrogen and a little amount of other elements, such nitrogen. Plastic garbage considerably adds to the issue of waste management because it is non-biodegradable.

The ecology may suffer from an inefficient system of managing municipal solid waste due to the spread of infectious diseases, contaminating of the soil and water, clogging of drains and loss of biodiversity, among other things.

The traditional sources of fossil fuels are running out and the global demand for energy is rising to the point where there may not be enough energy available in the future to meet this demand. As a result, there may be a significant increase in the price of oil, which is predicted to double in 20 years as reported by Brady (2014), making the product unaffordable and raising the cost of production for producers.

A critical overview of current developments in waste plastic thermal pyrolysis was conducted by Bhaskar et al. (2004). They claimed that the feedstock material is typically handled by a feeding portion of pyrolysis treatment mechanisms. In a kettle-type reactor scenario, the feedstock is put in the area where the mixer runs. Such feedstock don't always need pre-treatment techniques, reactor unit assembly and product collection vessels with chemical property-based product separation lines.

A low-cost catalyst was employed in Adnan's (2014) report to catalyze the breakdown of plastic trash and produce liquid fuel. A number of low-cost catalyst types, including zeolite, clay and bimetallic were listed. The effects of each type of catalyst utilized on the features and product distribution of the manufactured products are specifically explored in this work along with other pertinent investigations. The kind of catalyst used has a significant impact on how quickly plastic trash decomposes and how well and how much oil is produced. Additionally, a number of variables, including (i) the operating temperature, (ii) the proportion of plastic waste to catalyst and (iii) the type of reactor, affect the quality and production of the oil products. For the creation of better and more efficient materials for the conversion of plastic solid waste (PSW) into oil and bio-oil products, the development of inexpensive catalysts is reviewed.

Waste oils as an alternative fuel for diesel engines was the subject of a review by Aguado in 1997. Analysis and comparison of the characteristics of the oil made from used cooking and engine oil and waste plastics revealed similarities to those of diesel. In the 1990s, it was decided to use the direct heating pyrolysis method to extract crude oil and paraffin from plastic trash. Through the process of pyrolysis, large molecules are reduced to smaller ones, producing hydrocarbons with light molecular weights (like ethane), which can then be separated through fractional distillation and used as fuels and chemicals. This method produces 75% liquid hydrocarbon, a mixture of kerosene, diesel and gasoline, along with 5–10% residual coke and the remaining LPG. Facilitation, ease and little equipment investment are attributes of the small-scale process. The system consists of a mechanism for filling the pyrolysis reactor with plastics, a feed source, a pyrolysis reactor, a fractionating tower and a heating and temperature controller.

The aim of this study is 'Thermal Recycling of Waste Plastic Materials for the Production of Petroleum Fuel'

The objectives of the study are to:

i) Generate conceptual design of the pyrolysis unit
ii) Construct the pyrolysis unit
iii) Carry out performance test
iv) Determine the composition of the plastic oil
v) Characterize the plastic oil

The significance of the study are as follows:

i) Plastics can be thermally recycled to provide resources that can be utilized again.

ii) Chemical recycling is a desirable method for lowering plastic waste and solving disposal issues. As a result, trash cleanup lowers the risk of water pollution and advances public health.

iii) Based on the volume of waste produced in the area, it generates new jobs for individuals with lower incomes.

According to research, there are numerous pyrolysis concepts, such as thermal cracking and catalytic cracking, that can be utilized to turn plastic waste into fuel. This study primarily focuses on thermal cracking, which is the process of cracking polymeric materials by heating them to extremely high temperatures.

2. METHODOLOGY

The materials and methods used in this study are discussed in this chapter. The methodology used in this study is aimed at achieving the objectives of the project.

2.1 Conceptual Design of the Pyrolysis Unit

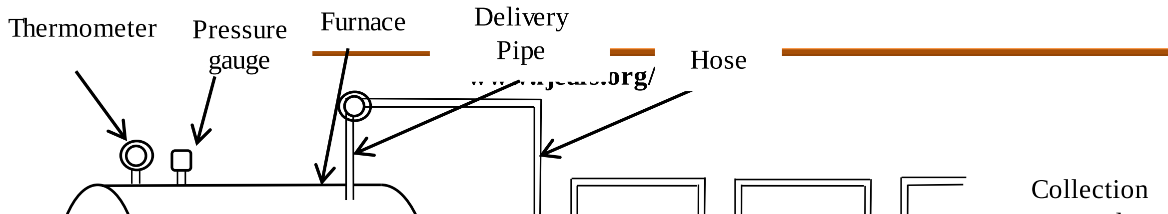
The conceptual design of the pyrolysis unit was generated; the diagram is shown in Fig. 2.1. illustrating the method for converting plastic waste to fuel.

Operation Process

The chemical conversion of waste plastic into fuel is done by a process known as pyrolysis in which the plastic is exposed to a very high temperature in an oxygen free environment.

The plastic is charged into the furnace and heated to a temperature of about 500^{o}C, the molecules of the plastic are set into vibration and as a result they are broken into smaller molecules, this results in the melting of the plastic and its subsequent conversion into gaseous state.

The gas produced flows through a hose via a delivery pipe into the first collection vessel where it is condensed into liquid. The uncondensed gas from the first vessel flows to the second vessel where condensation also takes place. The same process is repeated for the third vessel. The composition and calorific value of the liquid fuel produced will be determined using X-Ray spectroscopy and Bomb calorimeter, respectively.



2.2 Construction of the Pyrolysis Unit

The construction of the pyrolysis unit was done using the following materials:

1) Drum
2) Pipe
3) Hose
4) Collection vessels
5) Water tray

Material with a 3mm thickness made of mild steel was used to create the pyrolysis unit. Mild steel was chosen as the material because of its resistance to the pyrolysis process' high temperature. The unit was constructed using arc and gas welding technologies. It is provided with thermocouples, pressure gauges, and safety valves.

2.3 Performance Test

Performance test of the pyrolysis unit was carried out using various types of plastic materials i.e. polyethylene, polypropylene, polyvinyl chloride, polystyrene e.t.c. The procedure for carrying out the performance test is as follows:

i) 2 kg of the plastic waste was charged into the furnace and heated up to 500°C
ii) Decomposition of the plastic takes place and the vapour flows through a pipe and is collected in a vessel.
iii) Condensation of the vapour takes place in succession in each of the collection vessels.
iv) The quantity of fuel collected is measured and the residence time for the plastic to completely melt is recorded.

The result of the performance test is tabulated and discussed in Table 3.1

2.4 Determination of the Composition of the Pyrolysis Oil using X-Ray Spectroscopy

The chemical characteristics of the pyrolysis oil are dependent on the initial feedstock (plastic waste) and processing conditions, but it normally contains a sizable amount of water, carbon and nitrogen.

2.4.1 X-Ray Spectroscopy Test

The term "X-ray spectroscopy" refers to a variety of spectroscopic methods used to characterize materials using x-ray radiation. An excited electron from an atom's inner shell moves to a higher energy level due to the energy of a photon. The energy that an element previously gained through excitation is emitted as a photon with a wavelength that is particular to that element when it returns to its low energy level (each element may have a variety of characteristic wavelengths). Analyzing the X-ray emission spectra allows one to subjectively deduce the specimen's elemental composition. By comparing the specimen's spectrum to the spectra of samples with known chemical composition (after performing certain mathematical corrections for atomic number, fluorescence, and absorption), quantitative findings are obtained. Atoms can be excited by a high-energy beam of charged particles, such as protons, electrons or X-rays (in an electron microscope, for example). The pyrolysis oil's composition is presented in Table 3.2.

2.5 Determination of the Calorific Value of the Pyrolysis Oil

The calorific value (amount of energy content) of the pyrolysis oil was determined using a XRY-1A digital oxygen bomb calorimeter.

2.5.1 Bomb Calorimeter Experiment

An experiment using an XRY-1A digital oxygen bomb calorimeter (which is essentially made up of a crucible, fuse wire, combustion bomb, water bucket, stirrer, thermometer, calorimeter jacket with lid, and connected to an oxygen cylinder) is required to determine the calorific value of a material in terms of the gross heat of combustion. The sample used in the experiment was weighed before being put in a crucible with a fuse wire attached to it. The crucible was then dropped into the water bucket after being placed inside the combustion bomb. Thereafter, the lid was installed.

The formula in equation 2.1 was used to extract parameters from the experiment and determine the calorific values of the oil samples.

$$Q = \frac{C\Delta T - (e_1 + e_2 + e_3)}{m} \ldots\ldots\ldots\ldots\ldots\ldots. (2.1)$$

3. RESULTS AND DISCUSSION

The results obtained from the methodology for this study are discussed and presented in this chapter.

3.1 Mass Balance for the Pyrolysis Unit

It is crucial to understand how much waste plastic is required to make a specific amount of fuel oil under ideal circumstances, such as how much waste plastic is required to make 1 kg of fuel oil, for example. The law of conservation of mass is the foundation of mass balancing. The flow diagram of the mass balance of the plastic waste is illustrated in Figure 3.1

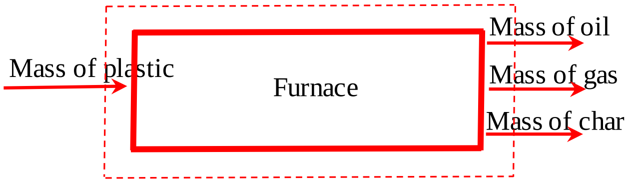


Fig. 3.1: Schematic dia. of mass balance on waste plastic

The Table 3.1 Mass Balance Analysis of the Waste Plastic

S/N	Types of waste plastic	Mass in (Waste plastic) 100%	Mass out		
			Mass of fuel	Mass of gas	Mass of char
1	**LDPE**	2kg	1.46 kg (73%)	0.402 kg (20.1%)	0.138 kg (6.9%)
2	**HDPE**	2kg	1.64 kg (82%)	0.186 kg (9.3%)	0.174 kg (8.7%)
3	**PP**	2kg	1.36 kg (68%)	0.428 kg (21.4%)	0.212 kg (10.6%)
4	**PVC**	2kg	0.26 kg (13%)	1.62 kg (81%)	0.12 kg (6%)
5	**PS**	2kg	1.37 kg (68.8%)	0.462 kg (23.1%)	0.162 kg (8.1%)

A mass balance for the system can typically be represented by equation 3.1, assuming no leaks exist and the appropriate measurements are taken.

Mass in = mass out

$$m_p = m_f + m_g + m_c \ldots\ldots\ldots\ldots\ldots(3.1)$$

where m_p = mass of waste plastic
m_f = mass of pyrolysis oil
m_g = mass of gas
m_c = mass of char

The amount of char left in the furnace is affected by the pyrolytic temperature and heating period. Reduced solid residue in the furnace is correlated with higher temperatures and times. The mass balance analysis of the waste plastic in Table 3.1 reveal 82% of liquid fuel being produced from the pyrolysis of high density polyethylene (HDPE) which indicates the dominance of alkane (CH) and alkenes (C=C) functional groups. The highest quantity of gas was produced from the pyrolysis of polyvinyl chloride (PVC) due to the high content of hydrogen chloride component in the plastic.

4.2 Chemical Composition of the Pyrolysis Fuel

The chemical composition of the pyrolysis fuel was determine using an X-ray spectroscopy and the following characterization were obtained and presented in Table 3.2

Table 3.2 reveals that polystyrene (PS) has the highest percentage of carbon which implies a high calorific value and combustion rate. While PVC has high content of chlorine and sulphur which makes the fuel a possible environmental pollutant arising from the emission it would release upon combustion. HDPE contains a high percentage of nitrogen, which generates air pollutants like ozone and ammonia that can make it difficult for us to breathe. Forests, soils and streams may suffer if too much nitrogen returns to the ground from the atmosphere. However, the percentage is relatively small compared to conventional fuel

4.3 Determination of Calorific Value

The calorific values (energy content) of the pyrolysis fuel determined from the bomb calorimeter experiment is presented in Table 3.3

The calorific value of the pyrolysis fuel obtained from the waste plastic samples reveals that polypropylene (PP) has the highest value (due to the high percentage of hydrocarbon content), this suggest a high energy content of the fuel implying the release of high heat energy upon combustion. On the other hand PVC has the lowest calorifc value (CV), this causes the amount of fuel used during combustion to be more. The heating value of pyrolysis oil is approximately half that of conventional fuel oils, due in part to its high water and oxygen content, which can make it unstable until it undergoes further processing.

The Table 3.2 Elemental Analysis of the Plastic

S/N	**Type of plastic waste**	**Pyrolytic Temp. (^{o}C)**	**C**	**N**	**H**	**O**	**C**	**S**
1	LDPE	500	84.86	0.12	15.02	ND	ND	ND
2	HDPE	500	84.51	0.21	15.28	ND	ND	ND
3	PP	500	84.42	0.19	15.39	ND	ND	ND
4	PVC	520	37.61	0.09	62.3	0.22	56.93	0.09
5	PS	500	91.52	0.08	8.4	ND	ND	ND

Table 3.3: CV of Waste Plastic Materials

S/N	**Type of waste plastic**	**Calorific value (kJ/kg)**
1	LDPE	43,350
2	HDPE	47,380
3	PVC	21,010
4	PS	42,980
5	PP	47,560

4. CONCLUSION

The thermal pyrolysis of waste plastic offers a straightforward and low-cost method for processing a big quantity of material. In terms of the environment, it lessens the risk of water pollution, greenhouse gas emissions, and garbage going to the landfill.

Additionally, liquid oil produced different types of plastic trash had higher heating values (HHV) that ranged from 21,010 to 47,56 kJ/kg, which were equivalent to conventional diesel (Table 3.3). Therefore, it has the potential to be used in a number of energy and transportation applications with further processing and refinement. For instance, trash can be converted into synthetic gas, which can be utilized in gas or steam turbines to generate energy.

The char residue produced from pyrolysis can be utilized as building materials vis-a-viz construction slag or filling landfill cover liners.

Pyrolysis may present opportunities for a long-term solution to global plastic waste problem. According to Prosper et al. (2017) a rough estimate of the amount of plastic garbage produced each day in the districts of Mubende, Wakiso, Kibaale and Iganga, Rakai, Arua and Kasese, and Mukono, Tororo, Hoima, Kampala and Kabale was 112, 85, 72, 83, 72, 58, and 62 tonnes/day. 545 851 kg of plastic garbage may be converted into 451 419 kg of fuel oil, which is equal to 582 866 L of fuel oil when processed through pyrolysis utilizing the right technology in Uganda's key districts. Seventy-eight 15kW hammer mills can be powered by this potential, producing 74 880 tonnes of maize flour annually. It can also be used to drive 234 tiny, portable threshers with 5-7 horsepower to thresh 365 000 tonnes of fresh paddy.

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