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Analysis of an Economic Pyrolysis Plant to Convert Plastic Waste to Liquid Fuel

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Abstract: Plastic is a high molecular weight substance that is used in our everyday lives and is now posing a significant danger to the environment. Tanzania generates around 60 thousand tonnes of plastic annually, leading to a common sight of discarded items filling bins and landfills. While ongoing efforts aim to create biodegradable polymers for the future, there has been limited progress in addressing the current plastic waste issue. This article proposes a potential solution by transforming waste plastic into value-added fuels, offering an alternative approach to plastic recycling. This method simultaneously tackles two widespread issues: the accumulation of waste plastics and the shortage of fuel. Plastic waste (low density polyethylene) will be pyrolyzed in this project to produce liquid fuel with the same qualities as crude fuels. Pyrolysis occurs in the absence of oxygen and at high temperatures of around 300°C, hence a reactor to generate the necessary temperature for the process was developed. Waste plastics will be depolymerized to produce various value-added fuels for instance diesel, kerosene and petrol, lubricating oil. Transforming plastic decay into gasoline yields advantages for both the environment and the economy. The conversion of plastics to fuel will now transform the difficulties into an opportunity to create income from trash.

Keywords: Pyrolysis; Plastic Waste; Liquid Fuel; polyethylene; gasoline.

1. Introduction

Plastic production uses around 4% of the crude oil that is used globally, and the manufacture of plastic uses another 4%. One of the greatest ways to recycle plastic trash is by turning it into motor oil [1,2]. This method helps us save the priceless petroleum resources while also safeguarding the environment. Waste plastics are already being converted on a large basis [3-5]. Tanzania performs considerable plastic recycling and reprocessing on uniform and contamination-free plastic trash. A sizable portion of the plastic in municipal garbage still makes its way to landfills, nevertheless [6, 7].

This research study aims to decrease the volume of non-recyclable plastic waste. The lack of homogeneity in many plastic wastes is the greatest barrier to the adoption of plastics recycling [8, 9]. The majority of recycling initiatives necessitate a predominantly pure feedstock consisting of items crafted from a single polymer type. Examples include the prevalent use of high-density polyethylene (HDPE) for milk bottles or polyethylene terephthalate (PET) for soft drink containers. [10, 11]. Plastic production uses around 4% of the crude oil that is used globally, and the manufacture of plastic uses another 4%. One of the greatest ways to recycle plastic trash is by turning it into motor oil [1,2]. This method helps us save the priceless petroleum resources

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The apparatus utilizes state-of-the-art pyrolysis technology, converting plastic decay into fuel oil and carbon black. It entails the catalytic breakdown of waste plastic into many types of hydrocarbon fuels, such as petrol, diesel, and kerosene, among others [12]. In a catalytic cracking procedure, used to recover liquid fuels, used waste plastic was fractured at extremely high temperatures [13].

In the initial step, waste plastics are introduced directly into the reactor unit of the pyrolysis plant. Subsequently, the plastic waste is melted within the reactor using heat generated from burning coal, wood, natural gas, or an electric kettle to yield liquid fuel [14]. The pyrolysis reactor unit undergoes a gradual heating process, with oil gas production commencing at approximately 250 degrees. Finally, the cooling system transforms the oil gas into liquid oil.

Fourth, the temperature of the pyrolysis reactor will drop after oil production is finished. The carbon black can be automatically expelled when the temperature drops to 40 degrees. Last but not least, the heated smoke that the reactor produces can meet national emission standards. For this project, catalysts including silica, alumina, barium carbonate, and zeolite can be employed [15,16].

2. Materials and Methods

2.1 Materials

PET, PP, LDPE and HDPE constituted the plastic decay (PD) raw material in this study. The collection of plastic waste involved the voluntary assistance of unemployed individuals who participated in gathering and sorting plastic debris. Plastic debris was collected from various sources, including market, parks homes and waterways. Specifically, plastic debris was gathered from markets, residences, roadsides, parks, and schools.

2.2 Catalyst

PP, PET, HDPE, and LDPE were among the plastic waste (PW) feedstock used in this investigation. Unesampling of plastic garbage. The clay catalyst employed belonged to the montmorillonite group and featured alumina, sodium, and iron as its primary components. Experiments were carried out using various size ranges, including 1.8 mm, 2.1 mm, 2.8 mm, and a powdered form. Local vendors were enlisted to procure the clay catalyst.

2.3 Experimental Setup

Fig. 1 shows the experimental setup with a 1-kilogram feed capacity. A band heater heats the reactor evenly over its surface. K-type thermocouples that are coupled to a PID controller with a 2-phase power supply and a contactor with a 3-phase power supply are used to measure the temperature within the reactor. Insulation jackets are used with glass wool filling in the annulus gap to prevent heat losses. A hemispherical dome-shaped reactor head built of GI pipe is linked to an outlet and placed straight into an open jar for quenching, where condensed oil is collected as supernatant.

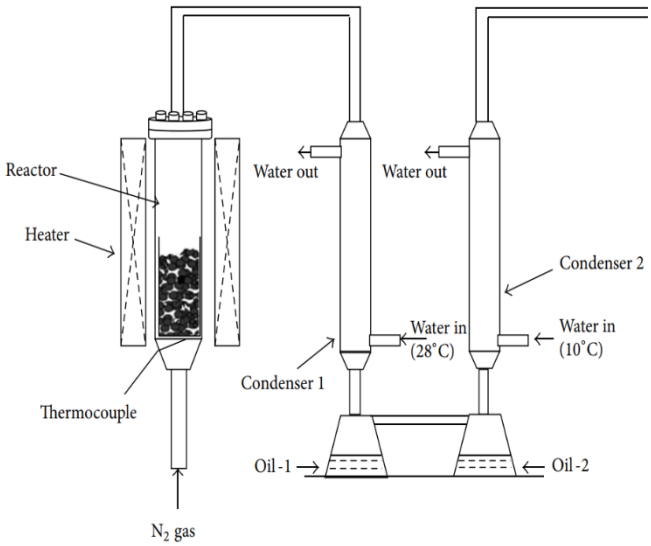

Fig. 1 Experimental Setup

3. Results and Discussion

3.1. Fuel products

The pyrolysis process resulted in the production of three distinct fuel products, and the quantities of each product were influenced by the various types of plastic decay initially introduced into the thermolysis reactor. The fuel byproducts included condensable liquids, Non condensable gases (NCG), and other residual materials. Among these, condensable liquid had the highest yield, ranging between 50% and 90%. The remaining products comprised char and wax, accounting for approximately 1% to 21%, while non-condensable gases constituted less than 0.8 % of the total output.

The conversion rate of plastic to fuel witnessed a significant boost with an extended residence time (min), leading to higher yields of fuel products. Specifically, when employing a feed weight of 12 kg and a residence time of 338 min, the thermolysis of LDPE resulted in the largest oil production at 9.44 kg. Conversely, PET exhibited the lowest oil production at 6.89 kg, along with 3.1 kg of char and 0.6 kg of non-condensable gas (NCG)

3.2. Condensate oils

When various types of plastic decay undergo pyrolysis, a considerable the amount of condensate liquids is generated, with a substantial portion remaining as bottom liquids in the hydrolysis reactor. This lesson focuses on the condensable liquid with the highest yield, referred to as condensate oil, as it holds potential for the production of cost-effective alternative fuels. The condensate oil yield (%) was determined using Eq. (1), revealing an increase in output with higher feed composition. LDPE exhibited the maximum yield for condensate oil at 95%, followed by PP (90%), HDPE (80%), mixed-PW (79%), and PET (71%). It is noteworthy to highlight that a combination of PE (and HD and LD), PET, and PP was subjected to pyrolysis to produce the mixed-PW condensate oil.

$$Yield\ (\%) = \frac{Weight\ of\ oil}{Weight\ of\ plastic\ wastes\ input}\ x\ 100\% \quad (1)$$

3.3. FTIR Characterization

The condensate oils were subjected to Fourier-Transform Infrared (FTIR) spectroscopy to identify the existence of organic and inorganic functional groups. Additionally, the analysis included the determination of aliphatic and aromatic carbon and hydrogen content. By amplifying the primary absorption regions in an IR spectra, it becomes feasible to identify diverse functional groups within the oils. Consequently, Figures 2(a)-(c) showcase the enlarged infrared spectra of the condensate oils within distinct frequency ranges. The primary functional groups identified in the analysis were alkenes and alkanes.

Fig. 2. The FTIR spectra of the condensate oils were examined across specific frequency intervals: (a) 876 – 918 cm−1, (b) 1354 – 1472 cm−1, and (c) 2802 – 2982 cm−1.

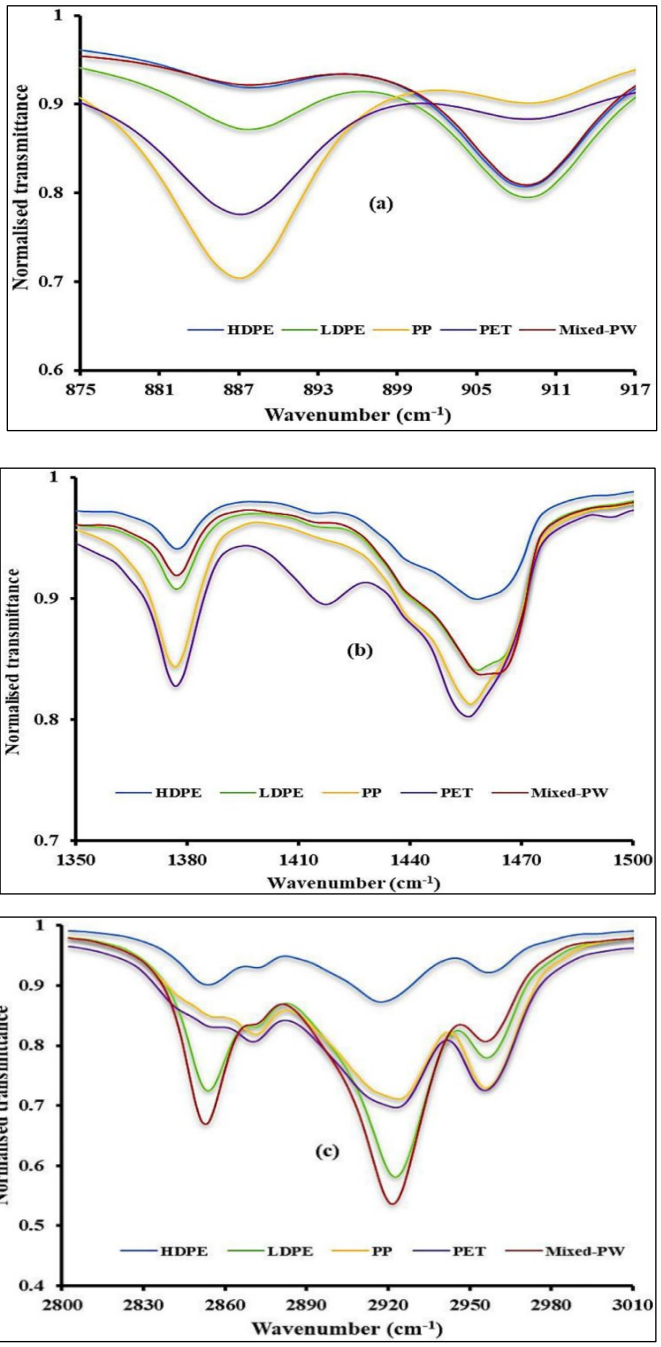

Figure 2(a) illustrates a contrast of spectra representing different condensate oils within the 882 ± 6 cm−1 range. This range corresponds to the C-H bending of the vinylidene functional groups. Within the condensate oils, PP displayed the most pronounced band, succeeded by LDPE, HDPE, PET, and mixed-PW condensate oils.

Likewise, the band at 908 ± 6 cm−1 showed a similar trend. in Fig. 2(a) indicates that the majority of alkenes in plastic fuels consist of vinyl functional groups. The HDPE, mixed-PW condensate oils and LDPE, exhibited a more conspicuous band in comparison to PP and PET, indicating a higher concentration of vinyl functional groups in these oils.

As illustrated in Figure 2(b), the frequency intervals encompassing the 1373 cm-1 and 1464 cm-1 bands indicate the existence of alkane functional groups. These bands signify asymmetrical and symmetrical -CH3 deformations, characteristic of alkane functional groups, and are frequently linked to diesel fuel according to existing literature. The intensified intensities of these bands in PET and PP materials can be attributed to the higher presence of methyl groups in the plastic sources from which they were derived.

In Figure 2(c), the vibrational stretching of the (C - CH3) alkane functional groups is evident, particularly in specific bands located at 2851 cm-1, 2921 cm-1, and 2962 cm-1. In comparison to the mixed PW condensate oil, which displayed heightened vibrational stretching at 2851 ± 6 cm-1 and 2921 ± 6 cm-1, PET and PP, closely trailed by HDPE and, LDPE exhibited a more pronounced band at 2961 ± 6 cm-1.

3.4 Mass Spectrometry - Gas Chromatography (MS - GC) Studies

To supplement the results obtained from FTIR analysis, the identification of chemical components in the condensate oils was conducted using MS-GS. Tables 1-3 offer an overview and detailed description of the identified chemical components in the condensate oils. Predominantly, these components consist of alkanes, alkenes, and aromatic compounds.

Table. 1 Mass Spectrometry - Gas Chromatography (MS - GC)analysis unveiled the chemical constituents found in the condensate oils originating from HDPE.

Name of compound	Molecular weight	Percentage area
2, 4- Dimethyl-1-heptene	125.96	65.7
Undecane	157.71	43
Dodecane	171.33	38.5
Tridecane	185.37	37
Tetradecane	199.39	40.6
Pentadecane	213.42	35.1
Hexadecane	227.41	38.3
Heneicosane	298.57	35.1

Table. 2 Mass Spectrometry - Gas Chromatography (MS - GC) was utilized to identify the chemical components present in the condensate oils derived from PET.

Name of compound	Molecular weight	Percentage area
2,4-Dimethyl-1-heptene	125.96	55.1
Cyclopentane, 1,2,3,4,5-pentamethyl	139.26	42.8
Undecane	156.31	38.1
Dodecane	170.33	32.7
Tridecane	184.37	26.3
Biphenyl	154.21	66.2

Table. 3 The chemical constituents found in the condensate oils obtained from PP were identified using Mass Spectrometry - Gas Chromatography (MS - GC) analysis.

Name of compound	Molecular weight	Percentage area
2,4-Dimethyl-1-heptene	125.96	64.4
Cyclopentane, 1,2,3,4,5-pentamethyl	139.26	39.1
Undecane	156.31	35.4
Dodecane	170.33	40.3
Tridecane	184.37	36.3

4. Conclusions

Effort are taken towards sorting plastic garbage so that it may be recycled into various alternative fuels, which could help lessen our overreliance on fossil fuels. As a result, the current study uses pyrolysis to transform mixed-plastic and separated plastic trash into alternative fuel products. Pyrolysis occurs in the absence of oxygen and at high temperatures of around 300oC, hence a reactor to generate the necessary temperature for the process was developed. Waste plastics will be depolymerized to produce various value-added fuels for instance diesel, kerosene and petrol, lubricating oil .The conversion of plastic decay into gasoline benefits both the environment and the economy. The conversion of plastics to fuel will now transform the difficulties into an opportunity to create income from trash. A significant amount of oil was produced during the pyrolysis process, leaving relatively little gas or other components behind. According to analyses conducted using both Gas Chromatography-Mass Spectrometry (GC-MS) and Fourier-transform infrared spectroscopy (FTIR) techniques, the condensate oils were predominantly composed of aromatic and aliphatic compounds.

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