

## Revolutionizing Plastic Waste Management: Fuel Production from Discarded Plastics

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### ABSTRACT

The startling acceleration in the amount of pollution caused by plastic rubbish has created a significant ecological issue on a scale that encompasses the entire planet. This study presents a comprehensive analysis of the process of reverse engineering, which is utilized in the conversion of unwanted plastic waste into beneficial fuel products. Pyrolysis and catalytic conversion are two examples of modern technologies for thermally degrading waste plastic, and both of these processes result in the production of fuels generated from hydrocarbons as well as other valuable byproducts. This study aims to increase the generation of fuel in terms of both quantity and quality. To accomplish this, it will investigate ways in which operational parameters, catalysts, and feedstock sources can be adjusted. In addition, the economic and environmental effects of the novel method are analyzed, with a particular focus on lowering the amount of pollution caused by plastic and increasing the production of renewable energy. The findings of the study emphasize the practicability and potential of changing plastic trash into viable fuels. This is a sustainable resolution to global energy and environmental challenges, and the findings also highlight the promise of this solution. We want to emphasize how important it is to conduct continual research and development in this field in order to support the extension of these processes for general acceptance and to contribute in the construction of a future that is environmentally conscientious and sustainable. To summarize, the findings of this study indicate the possibility of employing waste plastic in the production of valuable fuel commodities. This would both address environmental concerns and provide a solution that is both practical and effective to the problem of waste plastic. This is a great resource for policymakers, scientists, and businesses that are looking for long-term answers to the problems of managing plastic trash and producing energy.

**Keywords:** Pyrolysis; Plastic; Catalyst; Source; Fuel.

### 1. Introduction

Plastics are used in a wide variety of ways, and their ubiquitous presence in modern life necessitates that these uses be considered together. In the decade of the 1950s, the total amount of plastic that was consumed on a global scale was five million tonnes per year. At this time, the total amount of polymeric materials produced around the globe amounts to 311 million tonnes. As a consequence of this, the amount of polymeric materials that are manufactured today has increased by a factor of nearly 62 in comparison to the levels that were seen sixty years ago.

Plastic is used in the manufacturing of a diverse assortment of products, including mobile phones, containers, constructions, and cars, among other things. In order to manufacture plastics, it is necessary to make use of raw materials that are obtained from petroleum, which is a resource that is harmful to the environment [1]. Approximately 8% of the global production of crude oil is allocated to the manufacturing of plastics, wherein oil serves as a fundamental constituent and a source of energy. The issue of environmental contamination caused by plastic waste is a significant concern, necessitating the exploration of novel strategies for its mitigation.

The objective of this study is to enhance the efficiency of pyrolysis and catalytic conversion methodologies in order to facilitate the recycling of plastic waste into fuels that possess tangible utility. This investigation encompasses a comprehensive analysis of various processes, such as the careful evaluation of plastic feedstock selection, the precise modification of reaction conditions, and the utilisation of catalysts. Polyethylene, polypropylene, and polystyrene are among the plastic polymers currently under investigation for their potential application in the synthesis of premium liquid fuels, gases, and solid waste management. The distinct socioeconomic circumstances

present in these areas, marked by widespread poverty and environmental inequity, intensify the gravity of the existing issue of plastic waste [2]. The lack of comprehensive integrated solid waste management systems is also a contributing factor in this regard.

According to Villupuram (year), it was estimated that in 2010, coastal nations disposed of approximately 4.8-12.7 million metric tonnes (MT) of plastic waste into the ocean. The estimate presented in this study is grounded on research conducted in 2010. According to a recent study [3], the recycling rate of Kampala's annual waste plastics production, which amounts to over 62,050 tonnes, is merely 2%. This limited percentage is allocated towards the production of new items such as bags, cones, and fencing poles.

However, it is noteworthy that Kampala produces approximately 62,050 metric tonnes of plastic waste on an annual basis. According to certain estimates, the annual quantity of plastic waste present in soil is approximately 3,000 metric tonnes. Polyethylene terephthalate (PET), low-density polyethylene (LDPE), high-density polyethylene (HDPE), polypropylene (PP), polystyrene (PS), and polyvinyl chloride (PVC) are identified as the prevailing categories of plastic waste [4].

Polystyrene (PS) is another common type of plastic garbage. Furthermore, this investigation examines the environmental impacts and economic feasibility of implementing this approach, with a specific focus on its capacity to address the issue of plastic pollution and concurrently offer renewable energy resources [5]. This study emphasises the importance of regarding waste plastics as a valuable resource rather than perceiving them solely as an environmental burden, as is commonly depicted. The temperature range between 400 and 500 degrees Celsius is frequently considered to be the optimal range for the occurrence of the breakdown process. Pyrolysis, a well-established technique, is employed for the conversion of waste plastic into diverse states such as liquid, gas, wax, and char [6]. The temperature exerts a significant influence on the relative proportion of each product in relation to the overall total.

Additional factors that warrant consideration encompass the specific type of plastic under examination, the presence or absence of a catalyst, the type of reactor employed, and the rate of heat delivery [7]. The catalytic impact is a crucial factor in the pyrolysis of waste plastic and the subsequent alteration of pyrolytic pathways. Both of these processes are commonly known as pyrolysis. There has been a proposal that plastic-based diesel, commonly referred to as PBD, could serve as a viable substitute for conventional energy sources, owing to its comparable physicochemical properties [8].

## 2. Materials and Methods

### 2.1. Types of plastic suitable for pyrolysis conversion

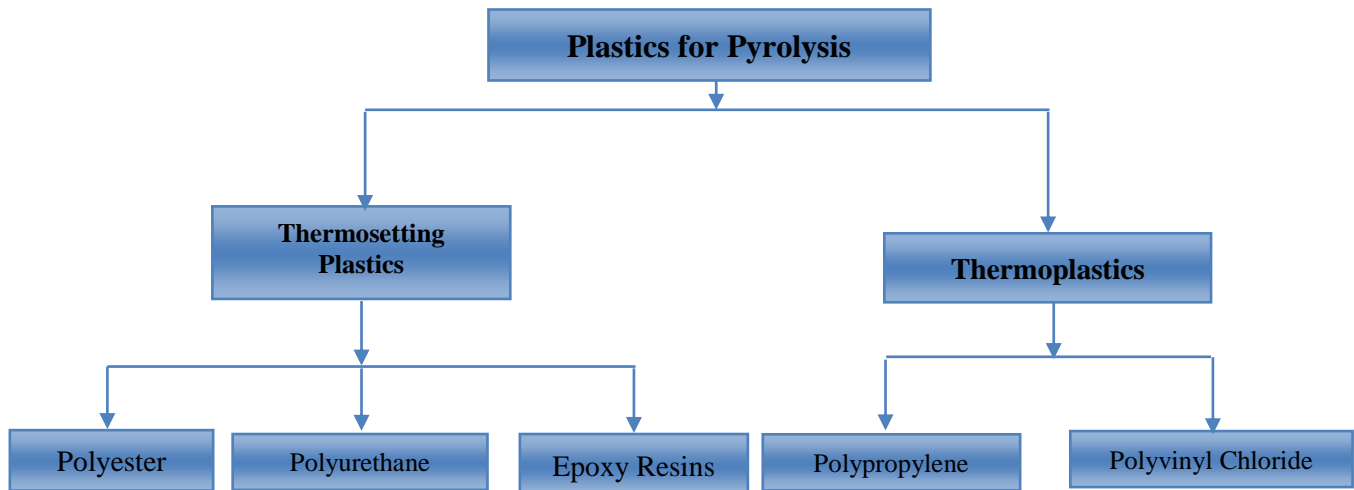
It is essential to keep in mind that not all plastics are created equal in terms of their potential for conversion into useful fuel products through the process of reverse engineering. This fact is especially important to keep in mind. The suitability of a plastic for this application is dependent on a number of factors, including its ability to withstand high temperatures, its chemical make-up, and other properties. Plastics of the following categories are typically regarded as being more appropriate for conversion [9]: Table 1 provides an illustration of the diverse array of polymers that are utilized in the pyrolysis conversion process.

**Table 1.** Types of plastic suitable for pyrolysis conversion

<b>Types of Plastics</b>	<b>Conversion Range (%)</b>	<b>Energy Content (%)</b>	<b>Calorific value. (%)</b>
<b>Polyolefins</b>	70	73	72
<b>Polystyrene (PS)</b>	75	78	77
<b>Polyethylene Terephthalate (PET)</b>	84	87	86
<b>Polyvinyl Chloride (PVC)</b>	75	78	77
<b>Mixed Plastics</b>	78	81	80
<b>Non-recyclable Plastics</b>	80	83	82
<b>Low-Density Plastics</b>	82	85	84
<b>Thermosetting Plastics</b>	85	88	87
<b>Waste Plastics from Agriculture</b>	78	81	80
<b>Polyvinyl chloride</b>	58	61	60

Polyethylene (PE) and polypropylene (PP) are two examples of polyolefins that see extensive use and have attractive qualities for conversion into fuel-based commodities. Both of these polyolefins are referred to by their respective abbreviations. Despite having a very uncomplicated chemical structure, the molecules in question store a significant amount of potential energy. Polystyrene is a type of plastic that, through pyrolysis or other processes, can be transformed into useful components for fuel. The numerous classifications of plastic are shown in Figure 1. Through recycling procedures such as depolymerization, plastic bottles and food storage containers made from polyethylene terephthalate (PET) can be converted into usable forms of energy. Pyrolysis has been found to be a viable method for converting PVC into gasoline; however, there is a risk that the process will result in the production of byproducts that contain chlorine and must be managed with extreme caution. Many diverse plastic waste streams are composed of a wide array of polymers that originate from a variety of different sources [10]. Using mechanical and chemical sorting processes, mixed polymers can be sorted into more homogenous feedstocks, making it much simpler to convert them into other forms of the material. Plastics that are difficult to recycle using normal methods, such as multilayer packaging or plastics that have been polluted with pollutants, have the potential to be transformed into fuel-based commodities, which appears to be an exciting possibility. Low-density polymers such as LDPE (low-density polyethylene) and LLDPE (linear low-density polyethylene) could be feasible alternatives due to the high calorific value of these polymers. Certain thermosetting plastics, such as phenolic resins and epoxy resins, can be pyrolyzed at high temperatures to yield useful fuel components. This is the case with some thermosetting plastics. Because recycling agricultural plastics such as mulch film and irrigation tubing presents significant challenges, these materials must instead be transformed into products that may be used as fuel [11]. One example of a synthetic thermoplastic polymer is polyvinyl chloride (PVC), which is manufactured

from vinyl chloride monomers. The substance at issue is extremely malleable, making it suitable for use in a wide number of applications across many different industries, including construction, plumbing, electrical insulation, and many more. PVC, or polyvinyl chloride, is a versatile material that can be used for a wide variety of applications due to its many advantageous characteristics, including as its long lifespan, excellent resistance to chemicals, and low cost to manufacture.



**Figure 1.** Types of Plastics Used for Pyrolysis

## 2.2. The origin of plastic refuse

The research involved the collection of plastic waste from the Villupuram Landfill site. The landfill site in Villupuram, located in the eastern region of Tamil Nadu, is widely regarded as the largest and most efficiently operated facility of its kind. The 8-hectare parcel of land is situated approximately 12 kilometers away from the central area of Villupuram city. The landfill serves as the main waste disposal site for the approximate population of 1.5 million individuals residing in the area. The plastic waste at the Villupuram landfill is segregated into three distinct kinds, namely polyethylene (PE), polypropylene (PP), and polystyrene (PS). The preparation procedures encompassed the activities of sorting, washing, and shredding. In order to mitigate pollution, the implementation of these pre-treatment measures was undertaken.

## 2.3. High-density polyethylene (HDPE), polypropylene (PP), and polystyrene (PS) undergo pyrolysis in order to generate valuable fuels

### 2.3.1. Temperature curve during the pyrolysis of plastic waste

The University of Kentucky's Appropriate Technology and Sustainability (UKATS) research group designed and built the processor used in the pyrolysis process. It was crucial to use an appropriate technology, also known as an Assistive Technology (AT), to aid in the creation of the UKATS processor. The rocket stove is made out of mild steel, and its combustion chamber is 38 cm in diameter and 88 cm in height. The mild steel that the reactor is made out of allows for the following dimensions and characteristics to be achieved: a total height of 42.5 centimetres, a conical section height of 15 centimetres, and a conical section angle of 27 degrees [12]. The remaining plastic proceeded through a process of thermal breakdown and disintegration as the temperature in the room rose during

the beginning stages of the pyrolysis process. The distillation pipes were used to transport the gases that were created into the condenser that was cooled by water. The temperatures of the continuous reactor's outer wall and interior were measured using two thermocouples, which were numbered 1 and 2, respectively. These temperatures were denoted as T1 and T2, respectively. Measurements of the temperature were obtained at five-minute intervals during the process. The process was considered finished after the production of the product was halted. By taking use of the fact that oil has a lower density than water, we were able to gather liquid fuel over water [13]. This was possible because oil is less dense than water.

### 2.3.2. The thermal and catalytic pyrolysis of high-density polyethylene (HDPE), polypropylene (PP), and polystyrene (PS)

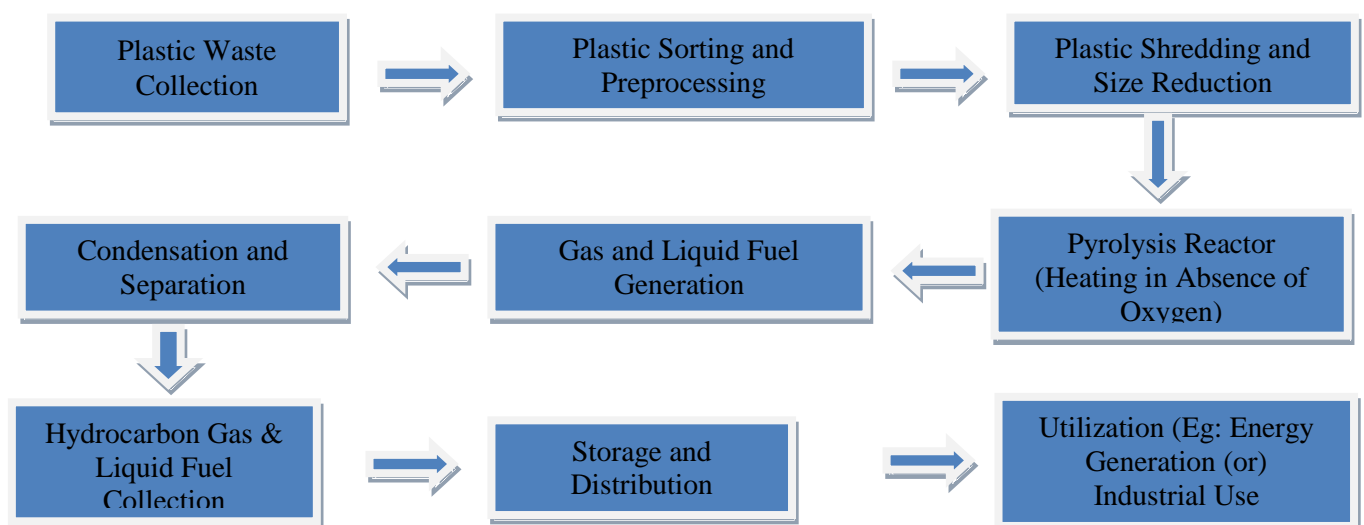
Thermal and catalytic pyrolysis are two different processes used to break down plastics like HDPE (high-density polyethylene), PP (polypropylene), and PS (polystyrene) into their constituent hydrocarbons or other valuable products.

#### A. Thermal Pyrolysis

Thermal pyrolysis involves subjecting polymers to elevated temperatures ranging from 300°C to 800°C in anaerobic conditions, whereby oxygen is absent. High-density polyethylene (HDPE), polypropylene (PP), and polystyrene (PS) experience degradation and decomposition processes, resulting in the formation of smaller molecules, when exposed to elevated temperatures[14]. The primary outcome of this process is the production of a combination of hydrocarbons, which include gases, liquids commonly referred to as pyrolysis oil, and solid remnants known as char. The products have the potential to undergo additional processing or refinement in order to acquire fuels, chemicals, or other materials of significant value.

#### B. Catalytic Pyrolysis

Through the utilization of a catalyst and the application of heat energy, a process known as catalytic pyrolysis can be carried out to hasten the degradation of polymeric materials.



**Figure 2.** Pyrolysis Experiment Format

The catalyst, which can take the form of a solid or a mixture of a number of different substances, brings the minimum temperature necessary for pyrolysis down while simultaneously increasing the degree of specificity in the products. Catalytic pyrolysis is often carried out at temperatures ranging from 300 to 600 degrees Celsius, in contrast to thermal pyrolysis, which is typically carried out at lower temperatures. This method provides the opportunity to boost the yield of the products that are wanted by the customization of the catalyst composition to fulfill certain requirements, such as the production of fuel-grade hydrocarbons or specialized compounds [15]. The composition of the products that are generated by thermal and catalytic pyrolysis can be affected by a number of characteristics, including temperature, residence time, the kind of catalyst employed, and the type of plastic feedstock that is utilized (HDPE, PP, or PS). The properties of the end products that are wanted and the degree to which the process as a whole can be optimized both have a role in determining which method, thermal or catalytic pyrolysis, should be utilized. The data are graphically represented in Figure 2.

### **C. Methods: Pyrolytic Liquid Fuel**

The term "pyrolytic liquid fuel" refers to fuel that is created in the form of a liquid through the process of pyrolysis. In this process, organic compounds are broken down by the use of heat even while oxygen is not present. During the aforementioned process, which is normally carried out at high temperatures, the feedstock is broken down into a wide variety of distinct flammable components. These components can take the form of gases, liquids, or solids. Pyrolytic liquid fuels, which are the liquid result of the pyrolysis process, have the potential to be an important and sustainable source of renewable energy. The majority of the pyrolytic liquid fuel is composed of the organic molecules that were derived from the feedstock. The chemical composition of the end product could be different depending on the kind of feedstock that was pyrolyzed throughout the manufacturing process [16]. A few examples of typical feedstocks include biomass (which might include things like waste products from crops and algae), polymers, and waste materials.

Because of their exceptionally high energy density, pyrolytic liquid fuels are an excellent option for use not only as a source of power but also of heat. Although the energy content can change based on the feedstock and the conditions of the pyrolysis, in general, it is comparable to the energy content of traditional liquid fuels such as diesel or gasoline. Pyrolytic liquid fuels are frequently considered to be more ecologically sustainable than fossil fuels due to the fact that they have the ability to leave a smaller carbon footprint and that they are derived from renewable sources. The type of feedstock that is used and the degree of pyrolysis efficiency both play a role in determining the effects that are had on the environment.

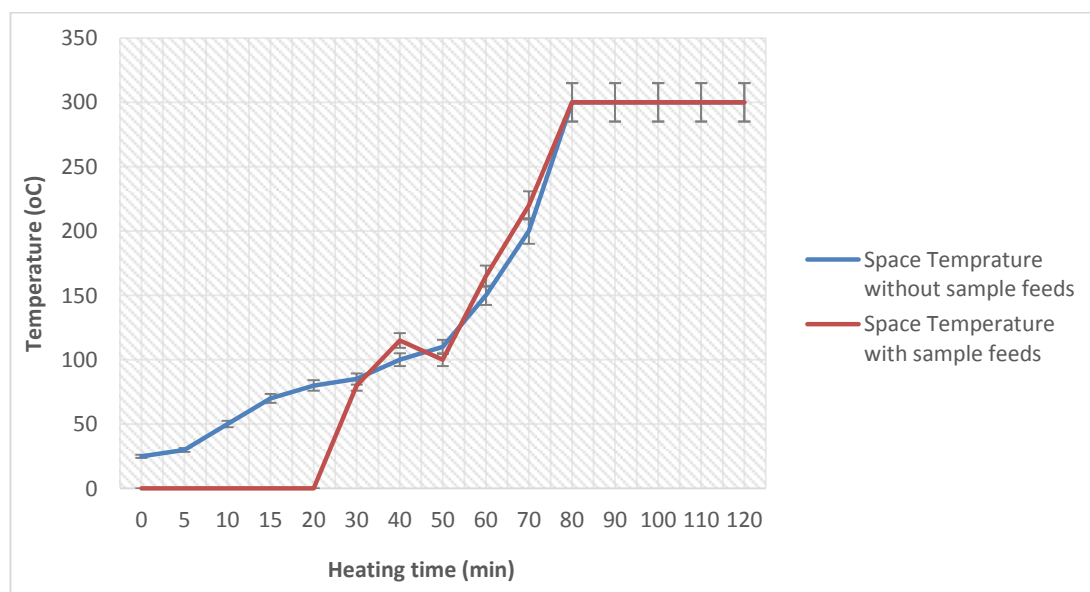
The viscosity of pyrolytic liquid fuels can change depending on a variety of circumstances, including the feedstock that is utilized and the conditions under which the fuels are produced. In order to satisfy the requirements of specialist applications such as diesel engines, it may be necessary to make adjustments or to incorporate other fuel sources. Blends of pyrolytic liquid fuel often contain a large number of different chemical components, the most common of which are hydrocarbons, oxygenated molecules such as alcohols, ketones, and acids, and a wide variety of other chemical components [17]. Both the features and the performance of the fuel are susceptible to change if there is a change in the specific chemical composition of the fuel. The procedures for storing and managing

pyrolytic liquid fuels are, for the most part, equivalent to those used for normal liquid fuels. On the other hand, the chemical make-up of a substance can have an effect on how stable it is during storage and how it must be handled. One of the most significant benefits of pyrolytic liquid fuels is their potential to be manufactured utilizing renewable feedstocks such as biomass in the production process. Because of this property, it is possible that we will be able to lower the amount of fossil fuels that we use, hence reducing the negative influence that these fuels have on the environment. Pyrolytic liquid fuels can be used to heat industrial facilities and as a chemical feedstock in the manufacturing of a wide variety of chemicals and minerals[18]. In addition to being a viable replacement for diesel or gasoline in internal combustion engines, pyrolytic liquid fuels can also be utilized in internal combustion engines. Pyrolytic liquid fuels face a number of significant obstacles, the most significant of which are monetary expense, the availability of feedstock, and the progression of technological knowledge. The economics of the manufacturing of fuel can be negatively impacted by the costs associated with several inputs, including feedstock, energy, and infrastructure. Scientists are currently attempting to improve the efficiency of pyrolytic liquid fuels, optimize their feedstock selection, and increase the properties of these fuels in order to make them more competitive with traditional fossil fuels.

### 3. Results and Discussion

#### 3.1. Temperature Profile

Following a duration of 35 minutes, an increased rate of thermal energy transfer occurred, leading to the attainment of temperatures of 136.5°C and 119.0°C for the wall and space of the pyrolysis reactor, respectively. The material underwent pyrolysis for a duration of 70 minutes until the observation of the maximum temperature gradient, which measured 100°C. During the time interval spanning from the 35th to the 40th minute, there was a rapid vaporization process seen for a duration of roughly five minutes, specifically involving the High-Density Polyethylene (HDPE) material. The wall temperature reached a steady state of 350°C, while the temperature inside the reactor touched 283°C. This concept is visually depicted in Figure 3.



**Figure 3.** Temperature profile of pyrolysis reactor with and without sample feed

In the experimental procedure, a heating rate of 15 °C/min was selected. A noticeable disparity was observed between the conditions of an empty pyrolysis reactor and a sample feed undergoing continual and early heating. This discrepancy suggests a temporal lag in the temperature rise within the heating zone of the pyrolysis reactor. The discrepancy in findings between this investigation and those recorded by Gao can be attributed to the disparity in the sample feed quantities considered, with this study utilizing a larger amount of 1000.0 g compared to Gao's 10.0 g.

### 3.2. HDPE, PP, and PS undergo catalytic and thermal pyrolysis

The study aimed to explore the impact of a silica alumina catalyst on the degradation temperature observed during the pyrolysis process of high-density polyethylene (HDPE), polypropylene (PP), and polystyrene (PS). The P-values were calculated for the different catalyst and polymer types.

High-density polyethylene (HDPE) exhibited the most significant thermal deterioration at around 450°C, whereas polypropylene (PP) and polystyrene (PS) experienced degradation at lower temperatures of 350°C and 300°C, respectively. Thermal pyrolysis necessitates a greater amount of energy compared to situations where catalysts are utilized. A catalyst that facilitates the conversion of raw materials. The observed temperature shifts were found to be the greatest when the ratio of 1:10 was applied, with HDPE exhibiting a movement of 100°C, PP showing a change of 80°C, and PS displaying a shift of 70°C. The reduced reactivity seen at a temperature of 50°C for HDPE can be attributed to a catalyst to feedstock ratio of 1:20.

### 3.3. Output Tabulation

The quantity of fuel derived from plastic waste exhibits variability contingent upon many aspects, including the plastic type, the employed pyrolysis technique, and the precise operational parameters of the pyrolysis procedure. The energy content of different types of plastics exhibits variability, while the yield of fuel products can be influenced by the efficiency of the pyrolysis process.

**Table 2.** The Output Efficiency of Various Plastics

Type of the plastic waste	Weight of plastic waste	Amount of fuel produced
PET	50 kg	37.50 (lit)
HPDE	50 kg	40.00 (lit)
LDPE	50 kg	35.00 (lit)
PP	50 kg	32.50 (lit)

Among all other plastics waste, HDPE produces high amount of fuel on pyrolysis. Moreover, the amount of fuel produced is directly impacted by the mass of the plastic waste during the processing stage. Table 2 presents a concise depiction that provides a comprehensive overview of the correlation between the categorization of plastic waste, its associated weight, and the potential amount of fuel produced.



### 3.4. Continuous VS Batch Pyrolysis

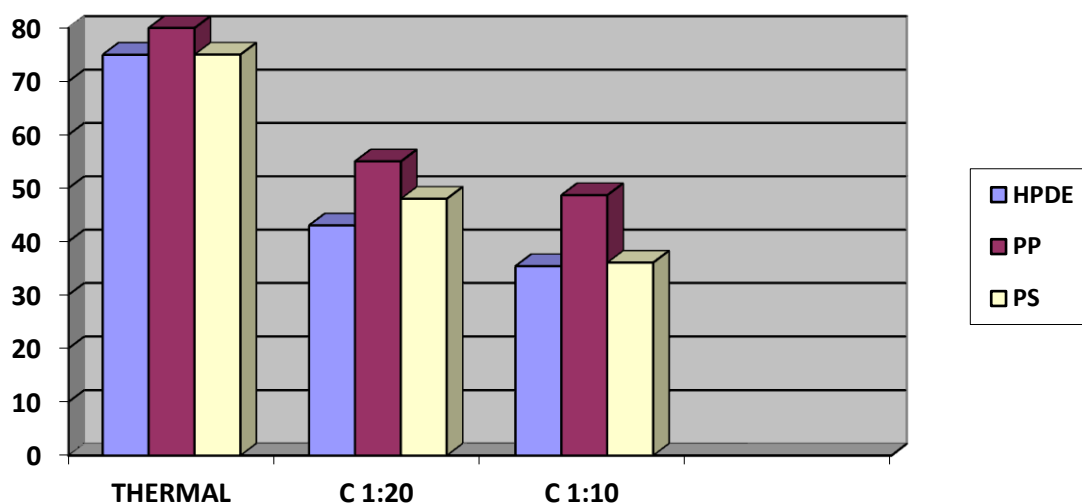
Continuous and batch pyrolysis are distinct methodologies employed for the conversion of plastic waste into fuel via a thermochemical process. Continual pyrolysis is a process characterized by the uninterrupted introduction of plastic waste into a reactor, resulting in a continual production of various products. The increased throughput and efficiency of the system render it well-suited for implementation in large-scale operations. Small-scale applications may not be suitable for the constant supply of feedstock. The batch pyrolysis process involves the thermal decomposition of plastic waste in separate batches conducted within a reactor. The lower initial expenditure of this product renders it more attainable for smaller-scale companies. Table 3 presents a comparative analysis of continuous pyrolysis versus batch pyrolysis, highlighting their distinctions across multiple dimensions.

**Table 3.** Continuous VS Batch Pyrolysis

Sl. No.	Aspect	Continuous Pyrolysis	Batch Pyrolysis
1	Operating Mode	Continuous	Batch
2	Process Efficiency	Higher	Lower
3	Product Yield	Consistent	Variable
4	Scalability	Easier	Limited
5	Residence Time Control	Precise	Limited control
6	Energy Efficiency	Generally higher	Variable
7	Product Quality	More consistent	May vary
8	Space and Equipment	Compact	Bulkier
9	Investment Costs	Higher	Lower (per batch)
10	Suitable for Large Volumes	Yes	Less practical
11	Applicability	Industrial Scale	Small-scale/lab use

### 3.5. How the silica-alumina catalyst affects the amount of product parts that are made.

The impact of polymer type and catalyst, including catalyst ratios, on the production of liquid fractions can be deduced. The P-values corresponding to the catalyst and polymer types were determined to be 0.0002 and 0.0405, respectively. In the context of thermal pyrolysis, it is customary for the liquid fraction to constitute between 60 and 82.6 weight percent of the total yield. The observed phenomenon can be attributed to the saturation of the sample feed, as illustrated in Figure 4, accompanied by a progressive utilisation of catalysts.



**Figure 4.** Effect of catalyst on the yield of liquid Percentage (%) liquid

Throughout the course of the experiment, a substantial disparity in temperature was observed between the internal region and the boundary of the reactor. During the time span of 35 to 40 minutes in the HDPE cracking process within a continuous reactor, a rapid vaporization phenomenon was observed. This event transpired during the course of the operation. The duration of vaporization during this period was estimated to be approximately five minutes. The quantities of liquid oils in high-density polyethylene (HDPE), polypropylene (PP), and polystyrene (PS) were observed to decrease as the ratio of catalyst to polymer was increased to 1:10 or higher. The investigation determined that the most effective temperatures for achieving the highest possible conversion rates of HDPE, PP, and PS were 300 degrees Celsius, 270 degrees Celsius, and 250 degrees Celsius, respectively. The implementation of a silica-alumina catalyst has enabled the streamlining of the process for generating gaseous fractions. The production of the gaseous fraction experienced a substantial rise, transitioning from a weight percentage range of 17.2 to 20 to a range of 40 to 60.

#### 4. Conclusion

The combination of heat and catalytic processes in reverse polymerization stands out as a potentially useful strategy for the management of plastic waste. The thermal pyrolysis method produced the highest temperature throughout the degradation process, but it also produced the most amount of liquid oil relative to the amount of sample that was used. The technique of thermal pyrolysis was applied to high-density polyethylene (HDPE), polypropylene (PP), and polystyrene (PS), with the temperatures of degradation being 450 degrees Celsius, 350 degrees Celsius, and 300 degrees Celsius, respectively. The boiling point ranges for HDPE and PP liquid oils are 119 and 364 degrees Celsius, respectively; the densities of HDPE and PP liquid oils are 0.796 and 0.786 g/cm<sup>3</sup>, respectively; the kinematic viscosities are 2.373 and 2.115 mm<sup>2</sup>/s and 1.89 and 1.86 mPas; and the cetane indices are 46 and 63. In particular, PS oil needs to go through additional refining steps before it can be utilized in diesel engines. In addition, before to fully deploying the technology in cities that are growing, it is required to conduct an in-depth analysis of its economic viability, environmental effects, and societal acceptance. This must be done before the technology can be fully implemented.

## Declarations

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This study has not received any funds from any organization.

### Competing Interests Statement

The authors have declared no competing interests.

### Consent for Publication

The authors declare that they consented to the publication of this study.

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