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Value Addition of Plastic Waste to Fuel

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ABSTRACT

The accumulation of plastic waste has risen tremendously in the last few decades and is posing a significant threat to the environment. To reduce its negative impact various methods of developing biodegradable plastics are underway but there have not been many conclusive steps for the existing problem. The conversion of plastic waste into valuable fuels offers a compelling solution that simultaneously tackles the pressing issues of plastic waste accumulation and the scarcity of traditional fuel sources. The process described here is Pyrolysis. Plastic Pyrolysis is the thermal degradation of plastic waste at different temperatures (300 – 900 °C), in the absence of oxygen. The valuable products obtained from this technique are fuel oil, syn gas, and a solid residue of carbon black. As the calorific value of the fuel oil produced is similar to that of conventional fuels, it can be used as a great alternative. The fuel oil produced needs to be refined before it can be used as a fuel for domestic purposes, vehicles and industries. Plastic pyrolysis is a promising technology for the conversion of plastic waste into needed fuels but further research is required in this field to optimize the process and increase its efficiency.

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Introduction
Plastic Waste: A Global Problem

Global synthetic plastic production stands at 400 million tons, and over half of that amount ends up in landfills or is recycled. There are more than 15 million tons of plastic poured into seas and oceans every year, most of which come from various sources. This marine waste can be divided into one-third dumped overboard, and two-thirds from land-based sources including litter left on beaches, runoff from rivers and drains, the quantity of discarded items in urban areas. The latter comes from industrial spills, carelessly operated landfill sites, coastal bins and anything flushed down the toilet. Main culprits are single-use plastics including drink bottles, plastic bags, cotton bud sticks, sanitary products and wet wipes. However, even if plastic waste is incinerated, it does so at considerable environmental cost. In this case, America alone emitted no less than 5.9 million metric tons of carbon dioxide in 2015 from the combustion of plastic which is slated to reach 49 million metric tons by 2030 and an astounding 91 million metric tons by 2050. The result is the diffusion of many pollutants, harming communities near incinerators. Compared to incineration, landfilling has a lower climate impact. But available landfills are nearly at capacity, with waste accumulation posing a serious challenge. The soil and water are polluted, and wildlife suffers. Western countries, including the U.S., used to have their contaminated trash dumped in China so as to offload the problem of handling wastes. But in 2018 China stopped taking the West's dirtied-up recycling[1]. One potential alternative solution is to accept that waste plastic can be a suitable fuel, with properties similar to diesel. This opens up the prospect of replacing diesel with waste plastic fuel, which would offer a more sustainable option for handling plastics [2].

Plastic and Its Classification

Plastic is a high molecular weight material developed by Alexander Parkes in 1862 (commonly known as polymers) [3]. A simple unit is repeated to form a polymer, or molecule. For example, the structure of polystyrene can be illustrated as in Figure 1 or Figure 2.

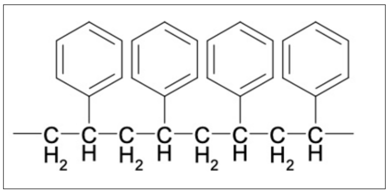

Figure1: Common Expression of Polystyrene

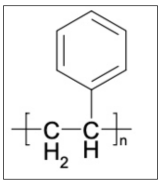

Figure 2: Simplified Expression of Polystyrene

The repeating unit of the polymer is in the brackets with a subscript, n, to represent the number of the unit in this polymer molecule [4].

Owing to its wide application in everyday life, plastic can be divided into several different kinds according to one or another mode of categorization. These include classification by chemical structure; synthetic process: density and other properties. To encourage the recycling of plastic garbage, Society of Plastic Industry (SPI) came up with a resin identification code system. This system categorizes plastics into seven groups based on their chemical structure and applications:

1. PET (Polyethylene Terephthalate)
2. HDPE (High Density Polyethylene)
3. PVC (Polyvinyl Chloride)
4. LDPE (Low Density Polyethylene)
5. PP (Polypropylene)
6. PS (Polystyrene)
7. Other

Seven different types of plastics are named on various plastic products; this helps consumers and recyclers to sort out the waste plastic in an effective manner.

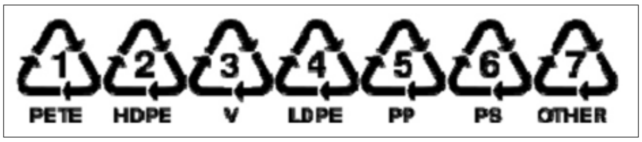

Figure 3: 7 types of plastics

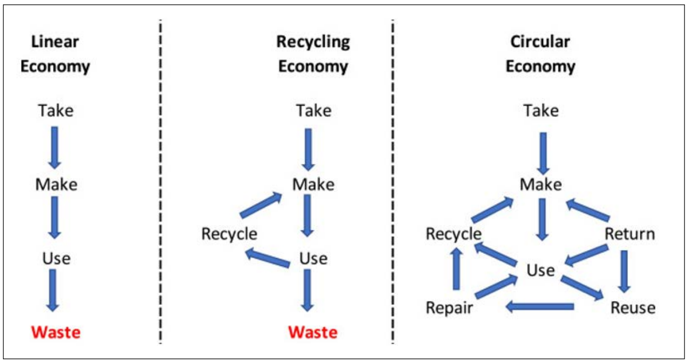

Figure 4: Schematic Representation of The Economies

With the ever-growing consumption of fossil energy and fuels, in the near term we face real threats of future energies shortages as well as environmental challenges. Nevertheless, practical answers are available through the use of renewable energy sources and the transformation of wastes into energy and fuels.

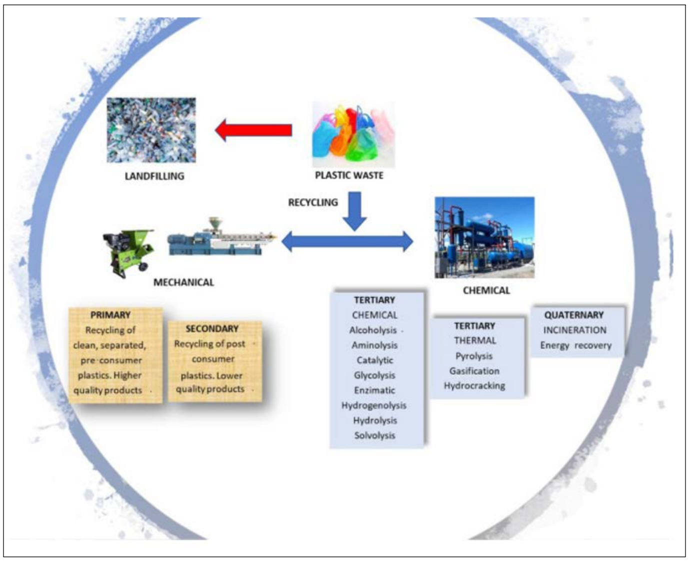

Figure 5: Plastic Recycling Techniques

Waste plastic pyrolysis emerges as a profitable way to deal with the plastics crisis, while also producing high-quality liquid fuel that is similar in quality to petroleum fuels. Thermal decomposition of waste plastic in the absence of oxygen, by means known as pyrolysis, produces valuable liquid fuels [5]. This process provides not only an environment friendly answer to the plastic waste problem, but also supplies another source of energy.

Therefore, the processed liquid fuel obtained from pyrolysis has properties similar to various kinds of commonly used petroleum fuels, making for a convenient and idea friendly substitute. In other words, not only does the adoption of pyrolysis technology resolve problems caused by rapidly accumulating piles of plastic waste, it is also consistent with contemporary trends toward energy conservation.

However, adopting this approach can both ease environmental concerns and open up a fresh channel for providing the world's energy needs in an environmentally friendly and resource-efficient way.

Literature Review

In order to fully grasp the latest technologies for plastic-to-fuel, a review of the relevant literature was undertaken to see what methods were currently in use around the world. The findings are summarized as follows: Through this process crude oil can be refined and distilled into products such as petrol, diesel and kerosene. This technique works for converting all types of waste plastic into various grades of fuel, including jet-grade fuel. A review of several literature sources suggests that different pyrolysis processes have been successfully used for turning plastic waste into useable fuel.

Chanashetty and Patil conducted a study on deriving fuel from waste plastic, employing a pyrolysis process that utilized a condenser and reactor [6]. They found this approach to be well-suited for addressing large-scale plastic pollution in seas and aiding fuel storage through the production of diesel, kerosene, and lubricant oil. The investigation encompassed various forms of waste plastic, including rigid film, sheet plastic, and expanded foam materials.

In a separate investigation, Karad and Havalammanavar explored the conversion of waste plastic into fuel, petrol, diesel, and kerosene through pyrolysis within a temperature range of 350 – 500 °C [7]. The study included diverse plastic sources such as bags, food wrap, vegetable oil bottles, automotive parts, garment bags, carpets, and refrigerated containers. They concluded that this eco-friendly approach contributes to the Swachh Bharat initiative and has the potential to save one million species of oceanic life, fostering a green future.

Arunkumar and Nataraj delved into transforming waste plastic into fuel oil using bentonite as a catalyst, employing a pyrolysis strategy with a condenser and reactor [8]. Their study yielded outputs of petrol, diesel, and fuel oil from inputs like PET bottles, shopping bags, and plastic packages. The conclusion highlighted the potential for a perfect and environmentally friendly future, emphasizing fuel efficiency and the control of hazardous elements like nitrogen, halogen, and sulphur.

Mathur et al [9]. investigated the extraction of pyrolysis oil from various types of waste plastic, using the pyrolysis process. The study indicated that for grade 5 types of plastic materials, 1.65 litres of oil could be obtained from 1.5 kg of plastic.

Experiments with waste plastics by Verma etal [10]. attributed an examination to performances of CI Motor with diesel blending. The study used materials such as condenser, oil collector, furnace reactor, load controller, gas analyser, fuel meter, dynamometer and computer. The final summary noted that mixing plastic oil with diesel saved 40% without any loss of power and with lower exhaust emissions.

Bezergini et al [11]. studied the production of substitute diesel from plastic garbage through a pyrolysis plant. Its products were diesel fuel, heavy oils and naphtha, and its inputs were bags, bottles and liquid containers. The results of this study show that this method provides an attractive substitute diesel fuel with about 70 – 85 % lower production costs.

Available Methods

Pyrolysis

Pyrolysis is the thermal cracking of carbon chains in polymer molecules. It decomposes large molecular weight polymer carbon chains into smaller molecular weight molecules, and produces gas oil as well as water and other matters. In principle, post-consumed plastics were treated using methods such as landfills or incineration. But landfilling entails drawbacks, including little or no available space and the long lifespan of plastics. Insufficient burning creates toxic by-products, taking a heavy toll on human life. Alternate processes such as gasification and bioconversion are mostly limited to organic [12].

HDPE, LDPE, PP, and PS are hydrocarbons. They have some corresponding similarities with the hydrocarbon fuels used in daily life such as liquefied petroleum gas (LPG), petrol and diesel. Plastics, like the oil from which they're derived, have calorific values that fall within a range similar to LPG, petrol and diesel (see table 1 below).

Table 1: Comparison of Energy Density of Plastics and Other Fuels [13].

Material	Calorific value (MJ/kg)
Polyethylene	46.3
Polypropylene	46.4
Polystyrene	41.4
Polyvinyl chloride	18.0
Coal	24.3
Liquefied petroleum gas	46.1
Petrol	44.0
Kerosene	43.4
Diesel	43.0
Light fuel oil	41.9
Heavy fuel oil	41.1

Many operationalist commercial plastic pyrolysis plants can process different kinds of post-consumer plastics. But they still require a hydrochloride scrubber, especially for PVC cracking. If this approach is adopted, it is preferable to avoid the chloride in the fuel product. It is not for small-scale production.

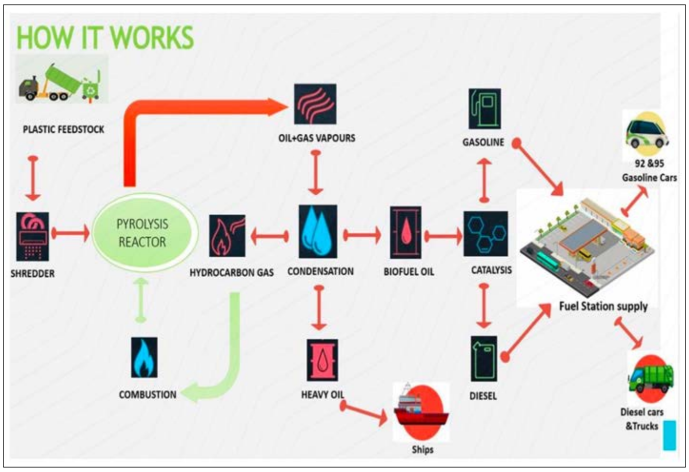

Figure 6: The Pyrolysis Process

Over the past decade, extensive research has been undertaken to comprehend and optimize the pyrolysis of waste plastic, with a focus on investigating the impacts of different types of plastics. Notable contributions to this field include studies by Kaminsky, Scheirs, and their colleagues, who examined the effects of reaction conditions on pyrolysis products [14]. Williams delved into the products resulting from the pyrolysis of various individual and mixed plastics, while Aguado et al [15]. explored the influence of catalysts on pyrolysis reactions. The majority of these studies employed lab-scale pyrolysis reactors, predominantly of the batch or semi-batch type rather than continuous. Most research efforts concentrated on assessing the impact of operational parameters such as temperature, heating rate, and catalysts on product yield. However, there is a limited number of studies in the literature that investigate the intricate cracking process of pyrolysis products during the pyrolysis, which is considered complex. Moreover, the final products are highly intricate, comprising over a hundred components in the hydrocarbon products, including paraffin, olefin, and their isomers.

The PONA system, an abbreviation for paraffin, olefin, naphthene, and aromatic compounds, is commonly used to describe these petroleum hydrocarbons [16]. Paraffins are saturated hydrocarbons with straight or branched carbon chains, also known as "alkanes." Olefins share a similar chain structure with paraffins but have one or more multiple bonds between carbon atoms in their chains. Naphthene's are saturated hydrocarbons like paraffins, but their chains form a ring in their structure. Aromatics include a benzene ring in their structure. Another method to describe hydrocarbons is based on the carbon numbers in their molecular structure, particularly applied to petroleum fuels.

The complex pyrolysis products can be categorized as petroleum gases, petrol, kerosene, diesel, and wax. These fuels contain hydrocarbon groups with varying carbon chain lengths. Additionally, alternative ways to describe hydrocarbons include boiling range, the phase of products at room temperature, and more.

The Pyrolysis reaction can be carried out with or without the presence of catalyst. Accordingly, the reaction will be thermal and catalytic pyrolysis. Below is the flow diagram of the process where a catalyst is added to increase the rate and efficiency of the reaction.

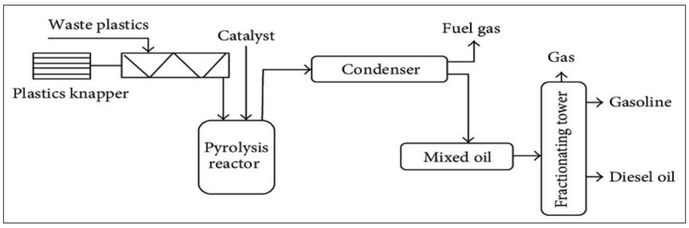

Figure 7: Thermal Pyrolysis of Plastic Waste

In many of today's equipment configurations, catalysts are used in these facilities to improve the quality of pyrolysis products [17]. Yet these configurations with equipment settings and catalysts have their shortcomings, such as a longer material resistance time; direct contact between plastics and catalysts resulting in unintended chemical reactions that are not captured on the roll; rapid heat transfer rate required by differentiation reaction (and pollution); costly investment of large quantities of high-quality catalysts.

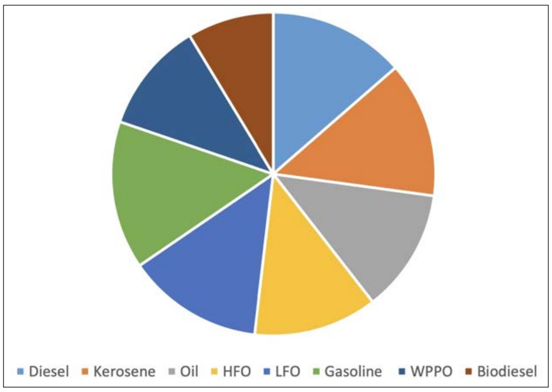

Figure 8: Similarity of Plastic Waste Product Oil to Other Fuels

Hydrothermal Liquefaction

The hydrothermal liquefaction (HTL) process involves the dissolution (recrystallization) of materials that are typically not soluble under normal conditions, facilitated by aqueous solvents at elevated temperatures and pressures in a heterogeneous process [18]. Due to advancements in the process and a deeper understanding, hydrothermal liquefaction has emerged as a leading technology for recycling various types of plastic residues and biomass, contributing to both resource recovery and energy production [19]. This process allows for the decomposition of discarded polymers into gas, liquid fuel, or a new raw material. Water is a fundamental component of the HTL process, primarily chosen for its remarkable changes in properties under specific temperature and pressure conditions. The elevated pressure in supercritical conditions enhances the rate of collision in the free radical reactions with low molecular weight. The altered properties of water confer several key roles in the process:

1. A good solvent for organic compounds.
2. A favourable homogeneous reaction medium.
3. A basic (or acidic) catalyst.

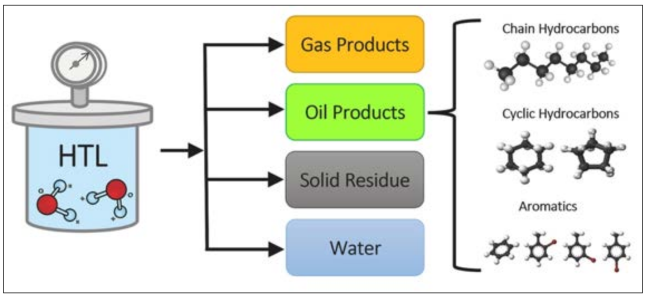

Figure 9: HTL Process of Plastic Waste

As a result of these characteristics, the hydrothermal liquefaction (HTL) process holds the potential for the recycling of mixed plastic waste, facilitating sustainable production of crude oil, fuel, or raw materials. The HTL process can be conducted at either subcritical or supercritical conditions, depending on the targeted polymer or polymer mixture.

Gasification

In the process of gasification, plastic waste undergoes a reaction with a gasifying agent, such as steam, oxygen, or air, at elevated temperatures ranging from 500 °C to 1300 °C. This reaction yields synthesis gas, or syngas, as the primary product. The significance of this study lies in its emphasis on the gasification of plastic waste, as the produced syngas holds the potential for generating various products and serving as fuel for fuel cells to generate electricity. Limited experimental studies have been conducted on the gasification of plastic waste.

illustrates the schematic representation of the plastic waste gasification process. The plastic waste considered here is polyethylene (PE) and polypropylene (PP). In practical applications, the plastic waste can be directly introduced into the gasifier, where it undergoes a reaction with steam as the gasifying agent. Plastic waste is a non – conventional component, it must undergo decomposition into its constituent elements before engaging in the reaction.

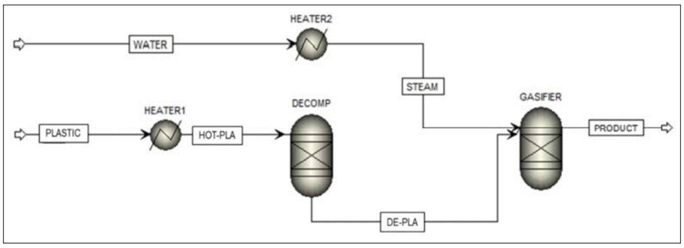

Figure 10: Gasification of Plastic Waste

The process involves two main stages: the decomposition of plastic waste (DECOMP) and the reaction of plastic waste with steam (GASIFIER). As depicted in Figure 10, the plastic waste (PLASTIC) undergoes initial heating in the heater (HEATER 1) before being fed into the decomposition unit (DECOMP). Subsequently, the DE-PLA stream is directed to the gasifier (GASIFIER) in tandem with steam (STEAM), while water (WATER) is preheated using heater (HEATER 2). Upon completion of the chemical reactions within the gasifier, the resulting gas product (PRODUCT) is generated.

Results and Conclusions

Plastics pose a significant menace to both contemporary society and the environment. Annually, over 14 million tons of plastics find their way into the oceans, resulting in the demise of marine life. While awareness of this threat has prompted advancements in the production of biodegradable plastics, there still remains a lack of efforts to rectify the damage already caused. This review underscores the significance of recycling plastic waste, particularly in developing countries, as a strategic approach to reduce unnecessary energy consumption and subsequently lower the production costs. The conversion of waste plastic into high – value fuel serves as a viable alternative energy source. The adoption of this practice not only diminishes the volume of plastic waste in the environment but also mitigates associated environmental impacts, such as excessive heating and greenhouse effects. In this context, among all the other processes discussed in this review, pyrolysis emerges as a promising solution. It offers an efficient, clean, and highly effective method for addressing the debris left behind over the past several decades. By adopting such innovative techniques, there is hope for not only preventing further ecological harm but also remediating the existing damage caused by plastic pollution. Recognized for its effectiveness, cleanliness, and remarkable success, pyrolysis not only addresses the issue of plastic waste but also offers an economically advantageous source of energy. This dual benefit positions pyrolysis as a valuable and sustainable solution for the disposal of plastic waste while contributing to the generation of affordable energy resources.

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