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Extraction of Fuel from Plastic Waste

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Abstract

Plastic undoubtedly is one of the greatest inventions and perhaps was a game changer to make our life easier with its innumerable products. Excessive use of plastic has generated tonnes of plastic waste material and recycling of such waste has not been adopted in an efficient manner in India. Therefore we need to continuously create new technologies to get rid of discarded plastic into any form of recycled products for the use of mankind.
The increasing global production of plastic waste and the growing demand for energy have led to a critical need for innovative waste management solutions. Therefore, there is a need to create a process in order to get rid of the problems associated with recycling that can ensure hundred percent conversion of waste into a desired mix of fuels without leaving any scope for secondary pollution.

Plastics are primarily created from energy, typically natural gases or oil. The hydrocarbons that make up plastics are embodied in the material itself, essentially making plastics a form of stored energy, which can be turned into a fuel source. In the pyrolysis process plastics are heated in an oxygen-free environment, melted and vaporized into gases, which are then cooled and condensed into a variety of useful products. Depending on the specific technology, products can include synthetic crude or refined fuels for various applications.
This paper explores the concept of converting plastic waste into fuel as a viable and sustainable approach. It examines the technologies involved in plastic-to-fuel conversion, their environmental implications, economic feasibility and potential benefits in addressing both the plastic waste crisis and energy demand.
Key Words: Plastic. fuel, pyrolysis, gas, plastic waste, process, oil

I Introduction

Plastic waste has become a significant environmental concern because of inefficient disposable methods. This study delves into the concept of plastic-to-fuel conversion, which offers a promising way to address waste management issues while simultaneously contributing to energy generation.

In India, 80% of total plastic consumption is discarded as waste and official statistics say the country generates 25,940 tonnes of waste daily. At least 40% of this remains uncollected. Since 1950, global plastic production has increased dramatically from 2 million tonnes to 380 million tonnes in 2015 [1]. India alone generated around 3.4 million metric tonnes of plastic in 2022 out of which only 30% is recycled. Seventy nine percent of the plastic generated worldwide enters our land, water and environment as waste; part of it also enters our bodies through the food chain.

Its sheer convenience, lightweight and durability has made this man-made material ubiquitous in every sphere of human existence. During the last 70 years, 8.3 billion of plastics have been produced worldwide.

The Central Pollution Control Board (CPCB) has conducted a study in 60 major cities in India. It reported that these cities generate in total 4,059 tonnes of plastic waste which is about one-sixth of the total plastic waste [2]. Major cities like Delhi, Kolkata, Mumbai and Bengaluru together generate more than half of the total contribution out of these sixty cities.

1.1 Role of Plastic in Water Pollution

The pollution in the ocean is mostly from plastic and it has a terrible impact on marine species. As a result, it can hurt the economy and food supply for communities that rely on fishing and aquaculture. Plastic can hurt tiny organisms like plankton, which bigger aquatic animals rely on as food. These small organisms are poisoned from ingesting plastic, the whole marine ecosystem gets infected through this spread of toxins [3]. The toxins work their way up the food chain and can even be present in the fish consumed by a human being. These tiny invisible microplastics cause damage not only to the ocean, but also contaminates groundwater sources. Plastic toxins in dumps and litter seeps into the groundwater and pollutes the entire water distribution system.

1.2 Role of Plastic in Land Pollution

Wind plays a pivotal role in spreading plastic waste and litter on a vast scale of landscape.The plastic constituents get entangled on trees and fences because of wind and the entire land infrastructure gets polluted and plastic landfills are now seen everywhere. Animals and bird species in turn get affected by these hazardous toxins after consuming plant feeds. The animal digestive system gets suffocated and clogged [4]. Almost 200 different species of animals are known to ingest plastic debris.

1.3 Role of Plastic in Air Pollution

When plastic is burned in the open air, it releases large amounts of poisonous gases, which pollute the air. If the toxins are inhaled for a long period of time, it can lead to respiratory disorders [5]. As the world's population increases, land becomes more valuable, and it will soon become difficult to find separate places to put garbage. Over time, landfills and dumps will take up more land, invading animals' habitats and coming even closer to groundwater sources.

In addition to harming plants, animals, and people, it costs millions of dollars every year to clean up areas exposed to plastic toxins. Many regions have seen a decrease in tourism because of the amount of pollution in their environment, which can have a serious impact on local economies.

1.4 Need of the Hour

There is a dire need to expand our range of options for keeping this plastic waste out of landfills. One potential approach is "plastic to energy", which unlocks the chemical energy stored in waste plastic and uses it to create fuel. Plastic is manufactured from refined crude oil and conversion of plastic into fuel is a reversible process. The most sustainable option is to recycle the plastic and recover fuel from it.

The fuel obtained from the pyrolysis process is used for burners of boilers, furnaces, hot water, hot air generators, thermic fluid heaters, hot mix plants, other industries and also in electricity generators and diesel pumps (mixed with 50 percent diesel).

II Material and Methodology

Basic process of conversion of plastic into oil

2.1. Identification of type of plastic

There are a variety of different plastic materials and compounds where each possesses unique properties. Most plastic products or their component parts are marked with a plastic identification code symbol specifying the type, allowing ease of identification for recycling purposes.

#1 PETE (Polyethylene terephthalate)

There are many polyesters but the commonest type encountered in the home is PETE or Polyethylene terephthalate PETE is spun into a synthetic fiber which is used to produce textiles. Polyester fiber is also mixed with natural fibers such as cotton to improve durability. They are mainly used in clothing, usually called terylene and in the manufacture of plastic bottles.

#2 Polyethylene HD

High density polyethylene has a high strength to weight ratio and also a high resistance to solvents, acids and other chemicals. They are widely used in plastic bags, food storage containers, beverage bottles, etc.

#3 Poly Vinyl Chloride (PVC)

Poly Vinyl Chloride is more commonly known as PVC or 'vinyl'. It comes in two forms: rigid or flexible. The rigid form is used for structural work e.g door and window frames. The flexible form is widely used as electrical insulation, upholstery coverings and inflatable products like beach balls and footballs.

#4 Low Density Polyethylene (LDPE)

Low Density Polyethylene is a soft flexible plastic widely used for making clear plastic bags and sheeting. It has a higher resilience than HDPE, which means that it can be stretched or deformed more without cracking or ripping. It is mainly used for plastic bags, clear flexible plastic sheeting e.g. for polytunnels and soft flexible snap on lids.

#5 Polypropylene

Polypropylene is a tough, flexible plastic, so it can be repeatedly deformed or strained without cracking. PP also has good resistance to acids and solvents. Polypropylene is able to withstand higher temperatures than HDPE and so is used for applications where a product must be sterilized or heated, e,g. kettles and dishwasher proof kitchenware. A disadvantage of PP is that it degrades when exposed to heat and UV present in sunlight, so additives must be used if products are required to be long lasting in sunshine.

#6 Polystyrene

Polystyrene is a stiff and rigid polymer, which can be made clear, it is ideal for applications such as casings for CDs, display boxes, kitchen appliances, TVs, radios, torches and other electrical gadgets.

#7 Other Plastics

These include all the remaining plastics like acrylic, nylon and polycarbonates They are used in cups, water bottles, water gallons, metal food can liners, ketchup containers, and dental sealants.

2.2. Shredding

After the segregation of waste plastic, it is cleaned if possible. Then it is shredded to speed up the reaction and to ensure that the reaction is complete.

2.3. Anaerobic Heating (Pyrolysis)

The shredded material must be heated in a controlled manner in an oxygen-free reactor. One of the most crucial factors in this operation is maintaining the right temperature (430^{0}C for plastic) and the rate of heating, which influences the quality and the quantity of the final product.

2.4. Condensation

The gas that comes out from the reactor must be condensed by passing it through a condensation tube or by directly bubbling it in water.

2.5. Distillation

This mixture of oil purified through a fractional distillation process can be used as furnace oil.

2.6. Designing of a Pyrolysis unit

Various parameters that influence the yield of oil are melting point, density, quality, moisture content, temperature of reactor, rate of heating, size of the reactor, feed rate, uniform temperature and types of condensers used.

The apparatus should be designed to operate at high temperatures and atmospheric pressure. The heart of the experimental apparatus is a vertical tubular reactor. A feeder is attached to the reactor‘s upper end; which enables controlled amounts of plastic pellets to be added before or during operation. At the bottom of the reactor a furnace is attached for heating the reactor. Biomass and charcoal with a blower is used as a heating source to heat the reactor. Due to increasing reactor temperature the plastic starts to evaporate, these vapors leave the reactor and pass into a condenser maintained at atmospheric temperature. The cyclone separator is provided at the end of the condenser to separate the gaseous and plastic liquid fuel compounds. The gas is reused to heat the pyrolysis unit and another end of the cyclone separator is connected to a flask in which the liquid hydrocarbon product is collected. Temperatures and pressure are monitored continuously by using thermocouples and pressure gauge.

2.7. Thermal pyrolysis process of various types of plastics and its output:

2.7.1. Polyethylene Terephthalate (PET)

Pyrolysis of PET to produce liquid oil using a fixed-bed reactor at 500°C and maintaining the rate of heating at 10°C/min. Nitrogen gas is used as the sweeping gas. The gaseous product obtained is 76.9 wt % and the liquid oil obtained is 23.1wt% [6]. The pyrolysis oil has an acidic characteristic which is unfavorable to use directly in locomotives due to its corrosiveness which deteriorates the fuel quality. Benzoic acid is a general sublime but this needs serious attention for industrial scale.

2.7.2. High-density polyethylene (HDPE)

Pyrolysis of HDPE was done in a steel reactor at a temperature range of 300–400°C: The fluidizing medium used is nitrogen. 80.88 wt% of liquid is obtained and the total conversion happens to be at 350°C. 33.05 wt% solid residues are obtained at 300°C which are found to be large. If thermal pyrolysis is conducted at a higher temperature of 400 – 550°C then the highest liquid yield and gaseous product (79.08 wt% and 24.75 wt% respectively) is obtained at a temperature of 550°C. Also dark brownish oil was obtained from pyrolysis of HDPE plastics at 550°C. The liquid oil yield obtained was 84.7 wt% and gaseous product was found to be 16.3 wt% [7]. This result shows that higher liquid oil yield is possible from HDPE at higher temperature. However, too high temperature would reduce the liquid oil yield and would increase the gaseous product yield as the process may go beyond the maximum thermal degradation point of HDPE. So it can be concluded that at a temperature above 550°C, the liquid was cracked to a gaseous state.

2.7.3. Polyvinyl chloride (PVC)

PVC is exceptional from other thermoplastics such as polyethylene, polystyrene and polypropylene and it is manufactured from a mixture of chlorine (57%) and carbon (43%) . Due to the chlorine content, PVC has high fire resistance, and is suitable for electrical insulation. The work done on the PVC pyrolysis is very less due to the hydrogen chloride (HCl) fumes that are released when heated at high temperatures. Pyrolysis of PVC in a batch reactor at temperature range of 220 then 58.2 wt% of HCl was also obtained from the experiment.

2.7.4. Low-density polyethylene (LDPE)

LDPE has lower tensile strength and hardness. If we conduct pyrolysis for a duration of 20 minutes and nitrogen gas was used as a fluidizing medium, the liquid yield obtained was 95 wt% with low gas yield and negligible amount of char [7]. 93.1 wt% of liquid oil was obtained when the same experiment was conducted in a batch reactor at a temperature of 550°C. From the pyrolysis 75.6 wt% of liquid oil was obtained in a batch reactor at 400°C and 74.7 wt% of liquid oil when using the same type of reactor at a temperature of 450°C. Pyrolysis of LDPE at a temperature of 425°C in a pressurized batch reactor (0.8– 4.3 MPa). The liquid oil yield obtained was 89.5%, gas obtained was 10 wt% and char was 0.5 wt%.

2.7.5. Polypropylene (PP)

PP has high chemical as well as heat resistance properties. It is a saturated polymer having a linear hydrocarbon chain. It does not melt below 60°C. PP has high hardness and rigidity which makes it preferable for the plastic industry. The process of pyrolysis of PP by altering the parameters to optimize the liquid oil yield. Pyrolysis of PP was done at 250 – 400°C temperature. From the experiments it was found that 69.82 wt% of liquid oil was achieved at a temperature of 300°C. Pyrolysis of PP results in reduction in liquid yield with increasing temperature.

2.7.6. Polystyrene

PS is synthesized from the liquid petrochemical and is a polymer of styrene monomers. It has compounds of long hydrocarbon chains with phenyl groups attached to every carbon atom. It is a colorless compound, but can be colored with suitable colorants. Pyrolysis of PS in a pressurized autoclave reactor for one hour at a temperature of 300°C-500°C. The heating rate used was 10°C/min. and the pressure applied was in the range of 0.31MPa-1.6MPa. From the pyrolysis, the oil yield obtained was around 97.0 wt% at a temperature of 425°C [8]. The plastic category PS found to give maximum liquid yield whereas PET category, the least. Pyrolysis process is not advisable for the PVC category as it produces HCl fumes which are highly toxic. But pyrolysis is a reliable and sustainable method to find a solution for the problem of plastic waste accumulation in the country which is increasing tremendously day by day.

2.8. Plastic Pyrolysis

Pyrolysis is a thermochemical decomposition of organic material at elevated temperatures in the

absence of oxygen (or any halogen). It involves the simultaneous change of chemical composition and physical phase, and is irreversible. The word is coined from the Greek-derived elements pyro "fire" and lysis "separating".

Pyrolysis differs from other high-temperature processes like combustion and hydrolysis in that it usually does not involve reactions with oxygen, water, or any other reagents. In practice, it is not possible to achieve a completely oxygen-free atmosphere. Because some oxygen is present in any pyrolysis system, a small amount of oxidation occurs. Bio-oil is produced via pyrolysis, a process in which biomass is rapidly heated to 450–500°C in an oxygen-free environment and then quenched, yielding a mix of liquid fuel (pyrolysis oil), gases, and solid char. Variations in the pyrolysis method, biomass characteristics, and reaction specifications will produce varying percentages of these three products. Several technologies and methodologies can be used for pyrolysis, including circulating fluid beds, entrained flow reactors, multiple hearth reactors, or vortex reactors. The process can be performed with or without a catalyst or reductant. The original biomass feedstock and processing conditions affect the chemical properties of the pyrolysis oil, but it typically contains a significant amount of water (15%– 30% by weight), has a higher density than conventional fuel oils, and exhibits a lower pH (2). 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. Bio-oil can be hydro-treated to remove the oxygen and produce a liquid feedstock resembling crude oil (in terms of its carbon/hydrogen ratio), which can be further hydro-treated and cracked to create renewable hydrocarbon fuels and chemicals [9] hydro-treating stabilizes the bio-oil, preventing molecule-to-molecule and molecule-to-surface reactions and eventually produces a finished blend-stock for fuels. Bio-oil can be deoxygenated from its high initial oxygen content of 35-45 percent by weight (wt%) on a dry basis all the way down to 0.2 wt%.

2.9. Use of catalyst

Catalyst speeds up a chemical reaction but remains unchanged towards the end of the process.
Catalysts are widely used in industries and research to optimize product distribution and
increase the product selectivity. Hence, catalytic degradation also yields products of great commercial interest such as automotive fuel (diesel and gasoline) and C2–C4 olefins, which have a huge demand in the petrochemical industry [10]. When a catalyst is used, the activation energy of the process is lowered down, thus speeding up the rate of reaction. The use of catalysts helps in saving energy and upgrading the products.

2.9.1 Types of catalysts

There are two types of catalyst which are homogeneous (only one phase involved) and heterogeneous (involves more than one phase). Homogeneous catalysts used for polyolefin pyrolysis are the classical Lewis acids such as $AlCl_3$ [11] and heterogeneous is commonly used as the fluid product mixture can be easily separated from the solid catalyst and they are more economical. Heterogeneous catalysts can be classified as nanocrystalline zeolites, conventional acid solid, mesostructured catalyst, metal supported on carbon and basic oxides [12]. Some examples of nanocrystalline zeolites are HZSM-5, HUSY, Hb and HMOR which are extensively used in the research of plastic pyrolysis. Besides, the non-zeolites catalysts such as silica–alumina, MCM-41 and silicalite have also received much attention in current research. Hence, the three types of catalysts that are widely used in plastic pyrolysis which are zeolites, FCC and silica–alumina catalysts The presence of catalyst reduced the liquid fraction and increased the gaseous fraction. Theoretically, the catalyst can enhance the cracking reaction of the pyrolysis gas. Long chain hydrocarbons have been cracked into lighter hydrocarbon gases. Pyrolysis over natural zeolite catalyst produced higher liquid product compared with Y zeolite catalyst. This is due to different activity between natural zeolite and Y zeolite.

2.10. Purification Setup

In this method an equal proportion of plastic fuel and water is taken and shaken well in a container and allowed to settle for 5-7 hours. Now water along with some crystals is collected at the bottom and pure plastic fuel is collected at the top of the container. In the meantime the pH value of plastic oil is checked with a pH meter, if it is acidic in nature it is washed several times with water to make it neutral.

III Fuel Production in Various Countries

Countries like Japan, Germany and the United States have already implemented the plastic to fuel conversion process with much success. These three have also been successful in creating business models out of the conversion process. China is importing enormous amounts of plastic wastes to use in oil refineries. An oil refinery in Hunan province had succeeded in processing 30,000 tonnes of plastic waste into 20,000 tonnes of gasoline and diesel oil that satisfied the provincial standards.

IV **Indian Scenario**

India generates 5.6 million metric tons of plastic waste annually, with Delhi generating the most of any municipality at 689.5 metric tons every day, according to a report from the Central Pollution Control Board (CPCB) [13] . About 60 percent of the total (9,205 metric tons per day) is recycled. Though India still has a long way to go in terms of adopting plastic to fuel as a business model, breakthroughs are being made to convert plastic to usable fuel.

With over 15,000 tonnes of plastic waste generated daily in India, there is a potential for implementing thousands of 'waste to wealth' projects across the country. The Tamil Nadu Pollution Control Board has recommended that the state government set up polymer energy plants to produce crude oil from plastic waste at the Kodungaiyur and Perungudi dumping yards.

The Bangalore Municipal Corporation has implemented a similar project. This idea came from the experience of a private company called MK Aromatics which has been producing crude oil from plastic waste at its plant in Alathur, which used about 10 tonnes of plastic per day to produce 10,000 litres of crude oil. A plant of 10-tonne capacity costs Rs 10 crore.

However, one major problem for the civic authorities is segregation of garbage. Despite repeated attempts at implementing source segregation by distributing colour-coded waste bins to households, source segregation remains a difficult task.

V Experimental Study: We conducted an experiment for conversion of plastic into fuel in the National Physical Laboratory, Delhi under the guidance of Dr. S.K. Dhawan, an emeritus scientist.

Virgin HDPE plastic was shredded into fine pieces and pyrolysis was done in the nitrogen atmosphere to produce anaerobic condition. Aluminum oxide or Zeolite was used as a catalyst in the process, which was followed by the process of condensation. The experimental yield in the laboratory was about 2ml when 4 gm of virgin HDPE was used. The small yield could be explained due to the limitations of the experimental setups in the laboratory.

VI Indian Institute of Petroleum (IIP) Dehradun

Similar experimental set up on industrial scale is available at Dehradun based Indian Institute of Petroleum (IIP), a constituent laboratory of the Council of Scientific and Industrial Research (CSIR) and this was inaugurated by Mr. Harshvardhan, Union Minister of Science and Technology in 2019 [14]. They developed a unique process of converting plastic waste like polyethylene and polypropylene, both together accounting for 60 percent of plastic waste into either gasoline or diesel. The technology is capable of converting one kg of plastic to 750 ml of automotive grade gasoline. Due to nearly nil presence of sulphur in the produced fuel, IIP's plastic converted fuel is pure and meets the Euro-III standards. IIP also started using a vehicle which would be able to run for at least two kilometres more per litre. The technology was developed by IIP after nearly a decade of research in hope of commercialising it for industrial usage.

About 60 to 70% of all plastics are either PET or PP. Only these two types of virgin plastics are used for oil production. Virgin plastics have no impurities in them. Gati foundation provides the required plastic to IIP, Dehradun for conversion into fuel. The plastic collected is compressed and brought on trucks to the center. Blower machines are used to remove dust from them. After this process the plastic is cut into small pieces. Using this method the shredded plastic is cleaned as only PP and PET plastic float on the surface and rest sink. The centrifuge machine is used to remove water from the clean shredded plastic. Using a solar dryer the plastic is completely dried. It is then agglomerated to form lumps of high density to make it ready for the final process of pyrolysis.

The lumps of plastic are heated in the absence of oxygen. All plastics are polymers mostly containing carbon and hydrogen and a few other elements like chlorine, nitrogen etc. When this long chain of polymers breaks at certain points, or when lower molecular weight fractions are formed, this is the reverse of polymerization. If such breaking of a long polymeric chain or scission of bonds occurs randomly, it is called random depolymerization. Here the polymer degrades to lower molecular fragments.

In the process of conversion of waste plastic into fuels, random polymerization is carried out in a specially designed reactor in the absence of oxygen and in the presence of certain catalysts. The maximum reaction temperature is 350-500°C. A process called purging of nitrogen is done to completely remove oxygen.

Catalyst crackers are designed in such a way that the vapour formed during the pyrolysis from the reactor must have maximum surface contact with the catalyst. The catalyst used breaks the hydrocarbon molecules in a random way to produce a mixture of smaller hydrocarbons.

The hot vapours coming out of catalyst crackers are condensed to give products.Researchers from the Indian Institute of Petroleum, Dehradun have invented a technology that can convert plastic waste into high-grade petrol, diesel or aromatics. This new fuel will cost Rs.30 to Rs.40 per litre and India will soon become one of the very few countries in the world to convert plastic waste into high-grade petrol and diesel.

This technology, developed by researchers at the Indian Institute of Petroleum (IIP), Dehradun, has catapulted India into the league of Germany, Japan and the US, the only other countries to have access to this green technology at present.

The need is to create a smartly tailored process design that can ensure 100 per cent conversion of waste into a desired mix of fuels without leaving any scope for secondary pollution

Output consists of about 70 per cent liquid fuel, 20 per cent coke and 10 per cent petroleum gases on completion of the depolymerisation process.

Depolymerization (or depolymerisation) is the process of converting a polymer into a monomer or a mixture of monomers. all polymers depolymerize at high temperatures, a process driven by an increase in entropy.

VII Conclusion

The paper focuses on a comprehensive classification of distinct plastic types, highlighting their unique properties and characteristics. It delves into the intricate process of pyrolysis, an innovative thermal degradation technique employed to transform these plastics into valuable fuels. The study meticulously examines the yield of fuel derived from a diverse array of plastic sources, shedding light on the efficiency and potential of this conversion method. The benefits presented by plastic to fuel (PTF) technologies are two-fold: transforming non recycled polymers (segregated plastic waste) and generating energy. By investigating the correlation between plastic composition, pyrolysis conditions and fuel output, the paper contributes vital insights into sustainable waste management and energy production.

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