

# Production of Fuel from Waste Plastic

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**Abstract:** *Plastic materials have been crucial to the development of science, technology, and almost all aspects of modern progress since the mid-twentieth century. However, the increasingly unsustainable culture of plastic consumption and the accumulation of plastics in landfills, oceans, and broader ecosystems has also made negative, potentially irreversible environmental impacts. In recent decades, scientists and engineers have spent significant time and resources searching for more effective plastic waste management techniques based on thermochemical routes like pyrolysis. Indeed, plastic to fuel conversion has the potential to severely limit plastic pollution and to contribute to the circular economy, but industrial scale plastic pyrolysis has not been achieved. Therefore, this paper presents a bibliometric analysis and systematic literature review of pyrolysis-related articles in the Web of Science database published between 2001–2020. The resulting articles (n = 670) show that Spain is the most productive country in terms of total output and that there are an increasing number of researchers focused on this topic worldwide. The results also highlight the current landscape and future directions of plastic pyrolysis research based on the following hot topics: i) kinetic triplets as a vital component of plastic pyrolysis and scaling up processes, ii) catalysts syntheses and performance, iii) co-pyrolysis of plastic/biomass mixtures, and iv) reactor design and reaction parameters. In conclusion, the study offers a comprehensive overview of plastic pyrolysis progress, which will remain a major area of research for chemists and engineers in the coming decade and a powerful tool for environmental management.*

**Keywords:** Plastic pyrolysis, Waste management, Circular economy, Thermochemical conversion, Plastic-to-fuel

## I. INTRODUCTION

Waste plastic disposal and excessive use of fossil fuels have caused environment concerns in the world. Both plastics and petroleum derived fuels are hydrocarbons that contain the elements of carbon and hydrogen. The difference between them is that plastic molecules have longer carbon chains than those in LPG, petrol, and diesel fuels.

Therefore, it is possible to convert waste plastic into fuels. The main objectives of this study were to understand and optimize the processes of plastic pyrolysis for maximizing the diesel range products, and to design a continuous pyrolysis apparatus as a semi-scale commercial plant. Pyrolysis of polyethylene (PE), polypropylene (PP), and polystyrene (PS) has been investigated both theoretically and experimentally in a lab-scale pyrolysis reactor. The key factors have been investigated and identified. The cracking temperature for PE and PP in the pyrolysis is at 450 °C, but that of PS is lower, at 320 °C. High reaction temperature and heating rate can significantly promote the production of light hydrocarbons. Long residence time also favours the yield of the light hydrocarbon products. The effects of other factors like type of reactor, catalyst, pressure and reflux rate have also been investigated in the literature review.

From the literature review, the pyrolysis reaction consists of three progressive steps: initiation, propagation, and termination. Initiation reaction cracks the large polymer molecules into free radicals. The free radicals and the molecular species can be further cracked into smaller radicals and molecules during the propagation reactions.  $\beta$ -scission is the dominant reaction in the PE propagation reactions. At last, the radicals will combine together into stable molecules, which are termination reactions. There are three types of cracking of the polymers: random cracking, chain strip cracking, and end chain cracking. The major cracking on the polymer molecular backbone is random cracking. Some cracking occurs at the ends of the molecules or the free radicals, which is end chain cracking. Some polymers have reactive functional side group on their molecular backbones. The functional groups will break off the backbone, which is chain strip cracking. Chain strip

cracking is the dominant cracking reaction during polystyrene pyrolysis. The reaction kinetics was investigated in this study. The activation energy and the energy requirement for the pyrolysis are dependent on the reaction process and the distribution of the final products. Following the equations from other literatures, the theoretical energy requirement for pyrolyze 1kg PE is 1.047 MJ. The estimated calorific value of the products is about 43.3 MJ/kg. Therefore, the energy profit is very high for this process.

Despite the significant development of various technologies to handle homogeneous and relatively clean plastic waste in primary and secondary recycling, converting plastic waste into building block molecules, fuels, and energy remains a significant challenge. Part of the challenge is separating plastic waste from other solid waste components; without this step, it is not possible to process used plastic and obtain high-quality outputs. Several tertiary recycling methods and technologies have attracted attention and have the potential to be useful on the commercial stage. These include depolymerization (chemical feedstock recovery), as well as plasma arc gasification, and pyrolysis. Among the available processes for converting plastics into fuel or any other value-added product, pyrolysis has drawn the most scientific attention between early-stage and mature technologies. Recently, Solis and Silveira provided an extensive TRL assessment on eight technologies available for plastic recycling and reviews recent technological developments in pyrolysis, catalytic cracking, and gasification for TRL 8-9. Nevertheless, the full potentials of these technologies and their impact on the circular economy of plastics is still unclear and requires more full-scale projects to be subjected to critical examinations. Meanwhile, another review by Qureshi et al. argues that pyrolysis can be an effective management tool that will complement mechanical recycling. Some of the primary challenges with elevating plastic to fuel pyrolysis to the industrial scale are feedstock quality, segregation of materials, reactor operations, and stability and standardization of the end products.

Despite the abundance of scientific publications and reviews on plastic pyrolysis, we are not aware of any reviews showing the overall evolution of the state-of-the-art in recent decades and which clarify the current publication landscape of plastic waste pyrolysis research. To help fill this gap, we perform a bibliometric meta-analysis and systematic literature review of articles describing pyrolysis techniques and technologies published between 2001–2020.

## **II. SEQUENCE OF OPERATION**

### **Basic Components of Production of Fuel From Waste Plastic**

1. Reactor
2. Condenser
3. Separator

## **III. LITERATURE REVIEW**

**Prof. V. P. Thakur [2013]** Pyrolysis is an endothermic process, an environmentally attractive method for the treatment of plastic wastes. The process uses medium temperatures (300 - 700)°C and an oxygen-free environment to decompose solid plastic wastes chemically in to char, oil, and gas. Thus, producing minimal emissions of nitrogen oxide and sulphur oxide compared to incineration, the most common process in the industry. It is defined as the sum of a series of parallel and subsequent reactions that take place in the pyrolysis reactor. The products obtained with this process can be easily handled, stored, and transported which increases the applicability of this method.

**M. Elzafraney et al. [2005]** this study has incorporated use of recycled plastic aggregate in concrete material for a building to work out its performance with regards to thermal attributes and efficient energy performance in comparison with normal aggregate concrete. The plastic content concrete was prepared from refined high recycled plastics to meet various requirement of building construction like strength, workability and finish ability etc. Both buildings were subject to long- and short-term monitoring in order to determine their energy efficiencies and level of comfort. It was observed that recycled plastic concrete building having good insulation used 8% less energy in comparison of normal concrete; however saving in energy was more profound in cold climate in building with lower insulation. They recommended that efficiency of energy can further be increase if recycle plastic of high thermal capacity is used. They have suggested the use of recycle plastic aggregate concrete being economical and light weights are having high resistance to heat. The author should also incorporate the comparison of both buildings with regards to durability and strength.

**Youcef Ghernouti et al [2014]** The study presents the partial replacement of fine aggregate in concrete by using plastic fine aggregate obtained from the crushing of waste plastic bags. Plastic bags waste was heated followed by cooling of liquid



waste which was then cooled and crushed to obtain plastic sand having fines modulus of 4.7. Fine aggregate in the mix proportion of concrete was replaced with plastic bag waste sand at 10%, 20%, 30% and 40% whereas other concrete materials remain same for all four.

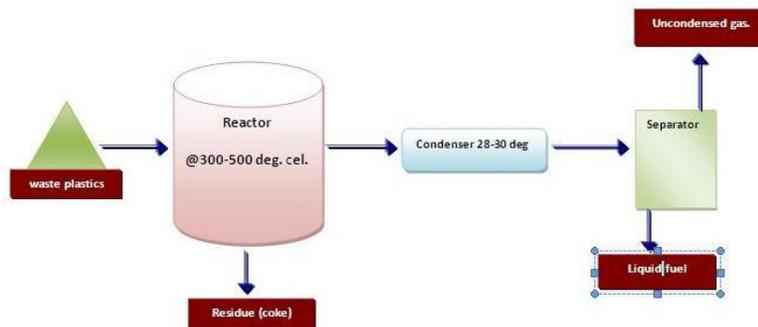
**Stella Bezergianni et al** [1] presents the two-step (i.e. Upgrading of Plastic Waste via Pyrolysis and Pyrolysis Oil Hydro-treatment) process for converting waste plastics to diesel fuel has been experimentally tested and assessed with respect to final fuel yield quality. In the first step, the plastic waste pyrolysis was produced at the semi-continuous operating pyrolysis plant shown in figure 2. This first step contains two steps; Pyrolysis Oil Quality pyrolysis (oil produced included a wide boiling-point range of molecules that cover all transportation fuel standards) and MidDistillate Fraction Quality (the main fraction is the mid-distillate fraction (170–370 °C), accounting for 68.5 wt % of the total pyrolysis oil). In the second step i.e. Pyrolysis Oil Hydrotreatment is a key refinery process that enables heteroatom removal and saturation reactions, leading to a significant improvement in the quality of the treated fuels.

**M. F. Ali et al.** [4] reported that the high yields of liquid fuels in the boiling range 100°C–480°C and gases were obtained along with a small amount of heavy oils and insoluble material such as gums and coke. The results obtained on the co-processing of polypropylene with coal and petroleum residues are very encouraging as this method appears to be quite feasible to convert plastic materials into liquefied coal products and to upgrade the petroleum residues and waste plastics.

**N. Miskolczi et al** [5] investigated the pyrolysis of real waste plastics (high-density polyethylene and polypropylene) in a pilot scale horizontal tube reactor at 520 °C temperature in the presence and absence of ZSM-5 catalyst. It was found that the yields of gases, gasoline and light oil could be increased in the presence of catalyst. They also concluded that the plastic wastes could be converted into gasoline and light oil with yields of 20–48% and 17–36% respectively depending on the used parameters.

**F. Murphy et al.** [6] from the recent literature, it is evident that the process of converting waste plastic to reusable oil is a current research topic, preparation of blends of diesel with varying proportions of waste plastic oil produced from the thermal pyrolysis and the analysis of viscosity and density of these blends is presented. The feasibility of the waste plastic oils derived from PVC plastics as an alternate fuel for transportation is also checked by conducting performance test on a single cylinder Kirlosker diesel engine equipped with electrical loading at 50% of the engine maximum load i.e., at 3.7 kW.

#### IV. EXPERIMENTAL SETUP



The washed out waste plastics are cut into small pieces to fit the reactor. Prior to the reactor feeding process the plastics samples were analyzed using Thermo gravimetric (TGA, Payris-1) analyser for onset temperature measurement, FT-IR (Spectrum 100) for functional group tracing and functional group bend energy determination, Elemental analyser (EA-2400) for carbon, hydrogen and nitrogen percentage analysis and finally Gas Chromatography and Mass Spectrometer (GC/MS) with pyroprobe for raw waste plastics compound structure determination. The mixture of waste plastics sample was placed in the reactor chamber for liquefaction process with a temperature range of 350–700°C. A total of 1000 gm of solid waste plastics were used for the reactor process. Then the reactor was covered and the screw was tightened at the end of the condenser unit. One end of a condenser unit was hooked with the reactor and the other end was hooked up with a collection container. For fuel condensation, purposed water temperature was 20°C. The collection unit top side was hooked up with a light gas cleaning device and the collection tank bottom part was hooked up with an RCI fuel purification device for fuel purification. At the end of the light gas storage system, it was hooked up with a light gas cleaning device. A temperature range of 25°C to 430°C was used for the liquefaction process.



process and process was fully closed system but without vacuum (see figure 1). There were no catalysts involved in the conversion process. The starting temperature setup was 25°C and then 25°C to increase temperature 200°C quickly for quick melting of the mixture sample. In this experiment we noticed that when the temperature was increased quickly from room temperature to 200°C some vapour started to exhaust out of the condenser unit. Again when temperature is gradually increased from 200°C to 280 °C we received liquid hydrocarbon fuel.

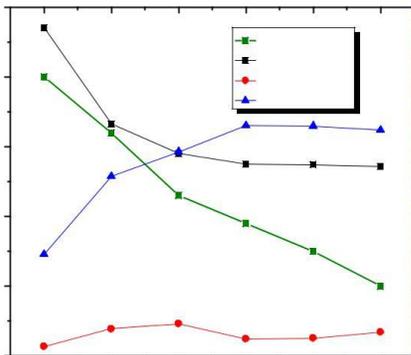
This specific temperature range was used because the melting point of the HDPE is 130°C, PP melting point is 160°C and Polystyrene's melting point is 240°C. The experiment temperature was increased every 15 minute by 10°C and until the max of 430°C. During the conversion process we notice that the entire vapours were not condensed and some portion of vapours came out as a light gas. Light gas was mixture with methane, ethane, propane and butane. An alkali filled gas cleaning system was used to decontaminate and purify the gas. The alkali solution used in the cleaning system was 0.25 (N) sodium bicarbonate solution. The light gas is collected into a Teflon bag using suction system for future usages or testing purpose. The liquid fuel was purified using a RCI purification unit and this unit has centrifugal force and micro filter technology which removes fuel sediment and water portion. We believe that the water portion may arise the atmospheric moisture. The liquid fuel yield percentage was 65 %, light gas was 30.67 % and solid black residue is 5.33%.



Figure: Experimental Setup

## V. RESULT AND ANALYSIS

Temperature (°C)	% Oil	% Char	% Gas	Reaction time (min)
450	24.64	68.5	6.85	60
500	39.8	49.9	10.3	52
550	44.55	44.2	11.25	43
600	49.6	42.1	8.3	39
650	49.5	42.05	8.45	35
700	48.75	41.65	9.6	30



## **VI. CONCLUSION**

The implementation of this project can develop so many opportunities in the city. It can be a solution to control waste plastic, develop a new technique or idea, and detect the source of diesel for the country. Bangladesh is such a country where this kind of project could be very promising and effective in the future. The use of plastic pyrolysis oil in diesel engine in the aspect of technical and economical is compared and found that oil is able to replace the diesel oil. Though the plastic pyrolysis oil offers lower engine performance, the plastic waste amount is enormous and it needed to be process to reduce the environmental problems. Moreover, the engine can be modify follow the combustion condition of plastic pyrolysis oil. The waste plastic used in the process must be PE or PP or LDPE in order to protect the contamination of chlorine in the oil.

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