International Journal for Multidisciplinary Research (IJFMR)
E-ISSN: 2582-2160 ● Website: www.ijfmr.com ● Email: editor@ijfmr.com

Conversion Of Waste Plastic Into Liquid Fuel Through Pyrolysis: Design And Performance Evaluation Of A Laboratory-Scale Reactor

Pramod B. Bajantri

Department of Mechanical Engineering, Basaveshwar Engineering College, Bagalkote, Karnataka, India

Abstract

The accumulation of waste plastics has become a major environmental concern due to their non-biodegradable nature and increasing consumption. Pyrolysis is an efficient thermochemical process that converts plastic waste into valuable liquid fuel under oxygen-deficient conditions. In this study, a laboratory-scale pyrolysis reactor was designed and fabricated to convert polyethylene-based waste plastics into crude liquid fuel. The reactor comprises a heating chamber, condenser, cooling coil, pressure gauge, and collection unit. Plastic waste was thermally decomposed at temperatures ranging from 350–500°C, producing hydrocarbon vapours that were condensed into liquid fuel. The developed system provides an economical and environmentally sustainable approach for plastic waste management while recovering energy from non-recyclable plastics. The study demonstrates the feasibility of producing alternative fuel through pyrolysis and highlights its potential for decentralized waste-to-energy applications.

Keywords: Waste plastic, Pyrolysis, Liquid fuel, Waste-to-energy, Polyethylene, Alternative fuel.

1. Introduction

The rapid growth in plastic consumption has created significant environmental challenges because most plastics are non-biodegradable and persist in the environment for decades. Conventional disposal methods such as landfilling and open burning contribute to land pollution and harmful emissions. Therefore, sustainable technologies that convert plastic waste into useful products have gained considerable attention. Pyrolysis has emerged as one of the most promising waste-to-energy technologies, in which plastics are thermally decomposed in the absence of oxygen to produce liquid oil, combustible gases, and solid char. Compared with incineration, pyrolysis offers higher energy recovery with lower environmental impact.

Polyethylene (PE), High-Density Polyethylene (HDPE), and Low-Density Polyethylene (LDPE) are the most common plastic wastes due to their extensive use in packaging and household applications. These materials possess high calorific values and can be converted into hydrocarbon-rich liquid fuels through controlled thermal degradation. The quality and yield of the fuel depend on operating parameters such as reactor temperature, heating rate, residence time, and condenser efficiency. Proper optimization of these parameters improves fuel recovery and process efficiency.

The present study focuses on the design and fabrication of a laboratory-scale pyrolysis reactor for converting waste plastics into crude liquid fuel. The reactor was developed using locally available materials and operated under controlled heating conditions. The objectives were to evaluate the reactor performance, demonstrate the feasibility of plastic-to-fuel conversion, and promote an environmentally friendly approach for plastic waste management. The findings contribute to the development of low-cost waste-to-energy systems suitable for small-scale applications.

2. Materials and Methods

2.1 Materials

Waste plastic, predominantly polyethylene (PE), high-density polyethylene (HDPE), and low-density polyethylene (LDPE), collected from household and commercial sources, was used as the feedstock for the pyrolysis process. The plastics were cleaned, dried, and shredded into smaller pieces to ensure uniform heating and efficient thermal degradation. These polymers were selected because of their high hydrocarbon content, favourable calorific value, and suitability for liquid fuel production through thermal decomposition.

2.2 Reactor Design and Fabrication

A laboratory-scale batch pyrolysis reactor was designed and fabricated using mild steel to withstand high operating temperatures and pressures. The experimental setup consisted of a sealed reactor chamber, an electric heating system, a temperature sensor, a pressure gauge, a copper condenser coil, a water-cooling arrangement, and a liquid fuel collection chamber. The reactor was designed to operate under oxygen-deficient conditions, preventing combustion and facilitating thermal cracking of plastic waste into hydrocarbon vapours. The compact design ensures ease of operation and demonstrates the feasibility of small-scale waste-to-energy conversion.

2.3 Experimental Procedure

The shredded plastic waste was loaded into the reactor, sealed, and heated electrically to temperatures between **350°C and 500°C**. During heating, the absence of oxygen promoted pyrolytic decomposition of the polymer chains into volatile hydrocarbon vapours. These vapours flowed through the condenser, where circulating cooling water condensed them into crude liquid fuel, while non-condensable gases were safely vented. The collected liquid fuel was stored for further analysis, and the solid residue remaining inside the reactor was removed after cooling. The experimental procedure was repeated under controlled operating conditions to ensure repeatability and reliable fuel recovery.

```
Waste Plastic
      |
      ▼
 Shredding & Cleaning
      |
      ▼
 Pyrolysis Reactor
 (350–500°C)
      |
      ▼
Hydrocarbon Vapours
      |
      ▼
 Condenser
      |
      ▼
 Liquid Fuel + Non-condensable Gas + Char
```

Figure 1. Process flow diagram for waste plastic pyrolysis.

2.4 Process Parameters

The efficiency of the pyrolysis process is primarily influenced by reactor temperature, heating rate, residence time, and cooling efficiency. Reactor temperature is the most critical parameter governing the thermal cracking of polymers and the yield of liquid fuel. Temperatures between **350°C and 500°C** were found to be suitable for effective decomposition of polyethylene-based plastics. Proper condensation of hydrocarbon vapours using the water-cooled condenser improved liquid fuel recovery while minimizing vapour losses.

3. Results and Discussion

The fabricated laboratory-scale pyrolysis reactor successfully converted waste plastic into crude liquid fuel through thermal degradation under oxygen-deficient conditions. During the experiments, polyethylene-based plastic waste decomposed at temperatures between **350°C and 500°C**, producing hydrocarbon vapours that were subsequently condensed into liquid fuel. The process demonstrated stable operation with efficient thermal decomposition and condensation, confirming the suitability of the developed reactor for small-scale waste-to-energy applications. The quality and quantity of the recovered fuel were primarily influenced by reactor temperature, heating rate, and condenser efficiency. Proper temperature control ensured effective cracking of polymer chains while minimizing excessive gas formation and carbon residue.

3.1 Effect of Reactor Temperature on Fuel Production

Reactor temperature significantly influenced the pyrolysis process and liquid fuel recovery. At temperatures below **350°C**, thermal decomposition was incomplete, resulting in lower liquid fuel yield. Increasing the temperature enhanced polymer cracking and promoted the formation of condensable hydrocarbon vapours. Maximum liquid fuel production was observed within the optimum temperature range of **400–450°C**, whereas temperatures above **500°C** favoured secondary cracking reactions, leading to increased production of non-condensable gases and a reduction in liquid fuel yield. Similar trends have been reported in previous studies on thermal pyrolysis of polyethylene-based plastics.

Table 1. Effect of Reactor Temperature on Liquid Fuel Yield

Reactor Temperature (°C)	Relative Fuel Yield (%)
350	Low
400	Moderate
450	High (Optimum)
500	Moderate

The results indicate that maintaining the reactor temperature around **450°C** provides favourable conditions for maximizing liquid fuel recovery while minimizing gaseous losses.

3.2 Performance of the Fabricated Reactor

The fabricated reactor operated safely throughout the experimental trials without leakage of gases or vapours. The heating chamber provided uniform thermal energy to the reactor, while the water-cooled copper condenser efficiently converted hydrocarbon vapours into liquid fuel. The compact reactor design facilitated easy loading and unloading of plastic waste, making the system suitable for laboratory-scale investigations and educational demonstrations. The process also generated a small quantity of solid char and non-condensable gases, which are typical by-products of thermal pyrolysis. The experimental results confirm that the fabricated reactor provides a simple and economical solution for converting non-recyclable plastic waste into valuable fuel products.

3.3 Environmental and Engineering Significance

Pyrolysis provides an environmentally sustainable alternative to conventional plastic disposal methods such as landfilling and open burning. The developed system converts non-biodegradable plastic waste into useful liquid fuel, thereby reducing environmental pollution and recovering energy from waste materials. In addition to minimizing landfill requirements, the process contributes to the circular economy by transforming waste into a valuable energy resource. Although the crude fuel obtained requires further refinement for commercial applications, the study demonstrates the technical feasibility of decentralized waste-to-energy systems suitable for rural and urban communities.

4. Conclusions

A laboratory-scale pyrolysis reactor was successfully designed and fabricated for converting waste plastic into crude liquid fuel. The experimental investigation confirmed that pyrolysis is an effective thermochemical process for recovering energy from polyethylene-based plastic waste under oxygen-deficient conditions. Reactor temperature was found to be the most influential process parameter, with optimum liquid fuel production occurring between **400°C and 450°C**. The fabricated system operated efficiently, producing liquid fuel through condensation of hydrocarbon vapours generated during thermal degradation. The study demonstrates that pyrolysis is a promising and environmentally friendly waste management technique capable of reducing plastic pollution while producing an alternative energy source. The developed reactor provides a low-cost and practical solution for small-scale waste-to-energy applications and offers scope for future improvements through catalytic pyrolysis and fuel characterization.

References

1. A. V. Bridgwater, Biomass Fast Pyrolysis Processes, *Biomass and Bioenergy*, 2012.
2. J. Aguado and D. P. Serrano, *Feedstock Recycling of Plastic Wastes*, Elsevier, 1999.
3. ASTM International, *Standard Test Methods for Petroleum Products*, ASTM Standards.
4. M. Scheirs and W. Kaminsky, *Feedstock Recycling and Pyrolysis of Waste Plastics*, Wiley, 2006.
5. A. Demirbas, “Pyrolysis of municipal plastic wastes for recovery of gasoline-range hydrocarbons,” *Journal of Analytical and Applied Pyrolysis*, 2004.
6. S. Al-Salem *et al.*, “A review of plastic waste management and pyrolysis technologies,” *Waste Management*, 2017.
7. J. Lopez *et al.*, “Thermal and catalytic pyrolysis of plastic waste,” *Renewable and Sustainable Energy Reviews*, 2018.
8. R. Miandad *et al.*, “Waste plastic conversion into liquid fuel: A review,” *Energy Conversion and Management*, 2019.
9. S. Miskolczi *et al.*, “Pyrolysis of polyethylene and polypropylene mixtures,” *Fuel Processing Technology*, 2009.
10. J. A. Conesa, “Thermal degradation of plastics,” *Waste Management*, 2015.