

Plastic Waste to Pyrolysis Oil Conversion

Mr.Chethan Kumar B M, Mr. Chiranjeevi B K, Mr.Darshan B R, Mr.Darshan H J,
Dr. Mohammad Rafi. H. Kerur, Proff. Somashekar B R

Dept. of Mechanical Engineering, PES College of Engineering,
Mandya - 571401

Abstract- This project presents the design and development of a Plastic Waste to Pyrolysis Conversion system — an innovative waste-to-energy solution. Plastic waste has become one of the most critical environmental challenges due to its non-biodegradable nature and widespread usage. The project focuses on converting plastic waste into pyrolysis oil through controlled thermal degradation in an oxygen-free environment. The obtained crude oil is further refined through fractional distillation and upgrading techniques to yield diesel-range fuel. Key processes include catalytic cracking and hydrotreatment to improve fuel quality. Testing of physical and chemical properties such as calorific value, viscosity, flash point, and density confirms the viability of the produced fuel as a sustainable alternative to conventional diesel.

Keywords: Pyrolysis Conversion, Plastic Waste, LDPE, Waste-to-Energy, Fractional Distillation, Biodiesel, Thermal Degradation. Environmental Sustainability.

I. INTRODUCTION

Every year, humans produce nearly 400 million tons of plastic, and much of that plastic ends up in the environment, harming marine life and other ecosystems. Since plastics are non-biodegradable in nature, it is very difficult to eliminate plastic waste from the natural environment. Since the 1950s, over 1 billion tonnes of plastic have been discarded and may persist for hundreds or even thousands of years. Expenditure incurred on the disposal of plastic waste throughout the world is around US\$ 2 billion every year.

The majority of plastic waste ends up in landfills, becoming a carbon sink where it may take up to 1,000 years to decompose, potentially leaking pollutants into soil and water. Plastic waste dumped in oceans threatens the health and safety of marine life. Uncontrolled incineration of plastic produces poly-chlorinated dibenzo-p-dioxins, a known carcinogen.

Converting waste plastic through pyrolysis offers a dual solution: effective waste management and alternative fuel generation. This project addresses both challenges by developing a small-scale pyrolysis system capable of converting waste plastics such as polyethylene (PE), polypropylene (PP), and polystyrene (PS) into liquid fuel with properties comparable to conventional diesel.

II. PROBLEM IDENTIFICATION

In today's modern world, plastics have become integral to human life due to their low cost, light weight, durability, and versatility. However, the same properties that make plastics useful also make them one of the world's most challenging environmental problems. Plastic waste accumulation has reached alarming levels globally, posing serious threats to land, water, air, and living organisms.

Every year, the world produces over 400 million tons of plastics, yet only about 9-10% of all plastic produced is recycled. Conventional disposal methods such as land-filling and incineration are neither sustainable nor environmentally friendly — land-filling causes long-term soil contamination, while incineration generates CO₂, CO, and other harmful gases contributing to greenhouse gas emissions.

Both methods fail to recover the embedded chemical energy in plastics, resulting in permanent loss of valuable resources. Meanwhile, the world faces a rising demand for energy and depletion of fossil fuel reserves, making pyrolysis-based plastic conversion an urgent and practical necessity.

III. METHODOLOGY

Collection and Sorting of Plastic Waste

The first step involves collecting waste plastics from domestic, commercial, and industrial sources. Plastics such as polyethylene (PE), polypropylene (PP), and polystyrene (PS) are most suitable for pyrolysis due to their high hydrocarbon composition. After collection, the plastic waste is sorted and cleaned to remove impurities such as metals, paper, dirt, and organic matter. Non-thermoplastic materials like PVC are avoided because they release toxic hydrogen chloride gas during heating. The cleaned plastics are shredded into small pieces (2-5 cm) to improve heat transfer and ensure uniform thermal decomposition.

Preparation of Pyrolysis Reactor

The pyrolysis reactor is the core component of the system, typically made of stainless steel or mild steel to withstand operating temperatures of 400-500 deg C. The reactor is designed to be airtight to prevent the entry of oxygen, as combustion must be avoided. A temperature control system ensures stable and uniform heating throughout the conversion cycle.

Pyrolysis Process

The prepared plastic feedstock is placed into the sealed reactor, which is then gradually heated to 400-500 deg

C. At this temperature, the long-chain polymer molecules begin to break down into smaller hydrocarbon molecules through cracking, depolymerization, and rearrangement reactions. In the absence of oxygen, plastics decompose into a mixture of hydrocarbon vapors, combustible gases, and solid char rather than burning.

Condensation and Collection of Oil

The hot hydrocarbon vapors from the reactor pass through a condenser, cooling them into liquid pyrolysis oil. This crude oil is then filtered and refined through distillation to separate fuel fractions — gasoline, diesel, and kerosene-like fuels. The diesel fraction is collected within the 250 deg C to 350 deg C temperature range. Non-condensable gases are

recycled as reactor fuel, and the solid char residue can be used as activated carbon or filler material.

Conversion of Pyrolysis Oil to Biodiesel

The obtained pyrolysis oil undergoes a series of refining steps to improve fuel quality:

- **Filtration and Settling:** Removal of char particles, water, and heavy residues from the crude oil.
- **Fractional Distillation:** Separation of the diesel fraction (250 deg C to 350 deg C) from other fuel fractions.
- **Upgradation:** Catalytic cracking or hydrotreatment to remove sulfur and improve fuel stability and combustion efficiency.
- **Transesterification:** Mixing oil with methanol and NaOH/KOH at approximately 60 deg C to produce biodiesel and glycerol as a by-product.
- **Washing and Drying:** Removal of impurities and moisture from the final fuel product.

Testing and Analysis

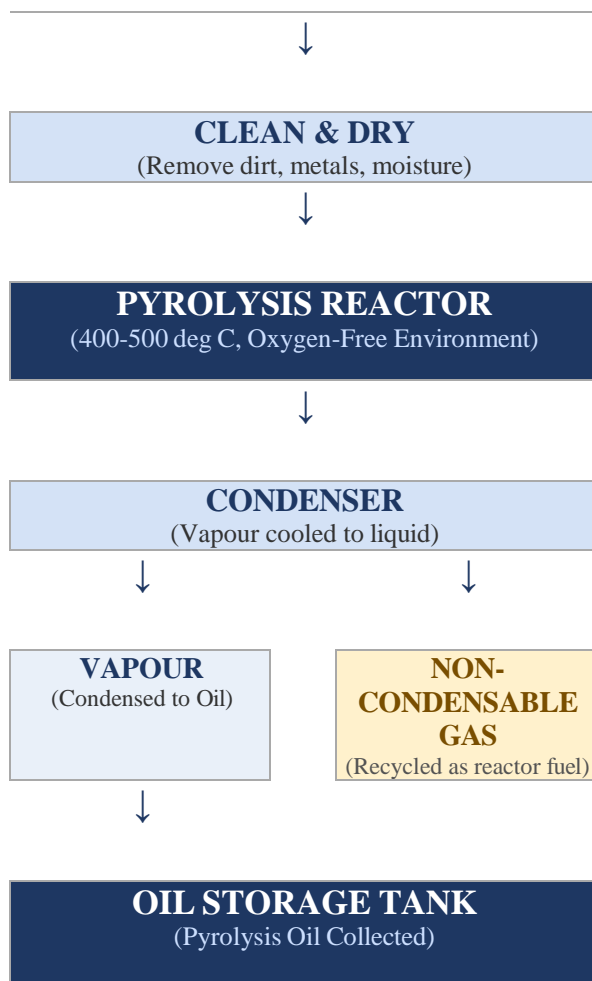
The produced fuel is analyzed for quality and suitability as an alternative fuel using the following tests:

- **Calorific value** - measures the energy content of the fuel.
- **Viscosity and density** - determines flow characteristics.
- **Flash point and fire point** - assesses safety parameters for storage and handling.
- **Sulfur content** - evaluates emission impact and environmental compliance.

PYROLYSIS PROCESS FLOW CHART

Fig. 2 - Pyrolysis Process Flow Chart (Methodology)





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III. LITERATURE REVIEW

The conversion of plastic waste via pyrolysis has been a major area of research in recent years, driven by growing environmental concerns and the search for renewable energy alternatives. Researchers across the world have investigated different thermochemical conversion techniques to extract fuel from waste plastics. This section summarizes key findings from existing literature, highlighting methodologies, process variables, catalysts used, and system performance.

Plastic waste mainly consists of polymers such as polyethylene (PE), polypropylene (PP), polystyrene (PS), polyethylene terephthalate (PET), and polyvinyl chloride (PVC). These materials are derived from petroleum hydrocarbons and contain high carbon and hydrogen content, making them ideal candidates for thermochemical conversion into fuels. Sharma and Verma (2022) reported that pyrolysis of low-density polyethylene (LDPE) at temperatures between 350 deg C and 450 deg C produced a maximum oil yield of 80-90%. The obtained oil had properties similar to diesel fuel, making it suitable for energy applications.

Kumar et al. (2022) investigated the effect of reaction temperature and heating rate on LDPE pyrolysis. Higher heating rates were found to increase oil yield and reduce char formation, confirming that optimized process parameters play a crucial role in improving both quantity and quality of pyrolysis oil. Zhang et al. (2023) demonstrated that maintaining an oxygen-free environment significantly enhances

liquid fuel yield during LDPE pyrolysis. The produced oil mainly consisted of diesel-range hydrocarbons, confirming its potential as an alternative fuel.

Ramesh and Prakash (2023) studied LDPE-derived pyrolysis oil blended with diesel in internal combustion engines. Blends of up to 20% pyrolysis oil showed acceptable engine performance and reduced emissions, demonstrating feasibility for practical deployment.

Patel et al. (2024) used zeolite catalysts in LDPE pyrolysis and observed reduced reaction temperatures and improved oil quality with a higher proportion of lighter hydrocarbons. Catalytic pyrolysis was found more efficient than purely thermal pyrolysis.

Singh et al. (2024) characterized LDPE-derived pyrolysis oil and reported a high calorific value (40-45 MJ/kg) and low sulfur content, making it comparable to conventional diesel for industrial applications.

Ahmed et al. (2025) reviewed recent advances in plastic waste pyrolysis technologies, highlighting LDPE as one of the most suitable feedstocks. Key challenges identified include scale-up of reactor designs and improvement of catalyst performance.

Qin et al. (2025-2026) provided a comprehensive analysis of plastic pyrolysis processes, concluding that oil yields can reach up to 85% under optimized conditions, with reactor design, temperature control, and catalyst selection being critical factors.

IV. LITERATURE ANALYSIS TABLE

Table No. 1 - Comparative Analysis of Plastic Waste to Pyrolysis Conversion Literature

Author & Year	Advantages	Limitations
Sharma & Verma (2022)	LDPE pyrolysis at 350-450 deg C; max oil yield 80-90%; diesel-like properties confirmed	Narrow feedstock focus; no catalytic comparison provided
Kumar et al. (2022)	Higher heating rates increase oil yield	Limited to LDPE; no engine performance

	reduce char; optimized parameters improve quality	testing
Zhang et al. (2023)	Inert atmosphere enhances liquid fuel yield; diesel-range hydrocarbons confirmed	Lab-scale only; no long-term durability data
Ramesh & Prakash (2023)	Up to 20% pyrolysis oil blends with diesel show acceptable engine performance and reduced emissions	Higher blend ratios remain untested in engines
Patel et al. (2024)	Zeolite catalysts reduce required temperature and improve lighter hydrocarbon fractions	Catalyst deactivation and regeneration costs not addressed
Singh et al. (2024)	High calorific value (40-45 MJ/kg); low sulfur content comparable to conventional diesel	No continuous or long-term operation testing
Ahmed et al. (2025)	LDPE most suitable for pyrolysis; comprehensive review of recent advances	Lack of standardized benchmarking across studies
Qin et al. (2025-2026)	Oil yield up to 85% under optimized conditions; reactor design and catalyst selection critical	Primarily theoretical; limited field validation data

V. CRITICAL ANALYSIS OF LITERATURE

A deeper evaluation of existing studies reveals several important insights beyond descriptive summaries.

1. Process Temperature and Yield Trade-offs

Most studies confirm that higher operating temperatures generally increase liquid oil yield but may also shift product distribution toward gas-phase fractions. Optimal temperature ranges of 400-500 deg C appear most effective for LDPE pyrolysis, producing maximum oil yields with acceptable fuel quality.

2. Catalyst Effectiveness

Zeolite and other catalysts significantly reduce required reaction temperatures and improve oil quality by increasing lighter hydrocarbon fractions. However, catalyst deactivation due to coke deposition remains a challenge for long-duration

operations. Regular regeneration adds to system complexity and operational cost.

3. Scalability Challenges

Most experimental studies are conducted at bench or pilot scale. Scaling up to industrial levels introduces challenges such as uniform heat distribution across larger reactor volumes, increased energy requirements, and the need for advanced process control systems.

4. Environmental Concerns

While pyrolysis avoids direct combustion emissions, the process generates non-condensable gases that must be managed carefully. PVC contamination in plastic feedstock can produce toxic chlorinated compounds, necessitating rigorous sorting procedures before processing.

5. Feedstock Variability

Real-world plastic waste is a heterogeneous mixture of various polymer types. Variations in feedstock composition significantly affect oil yield, quality, and process efficiency. Most studies focus on single polymer types such as LDPE, which limits the applicability of findings to mixed plastic waste streams.

6. Research Gap Identification

Current pyrolysis solutions do not effectively balance energy efficiency, catalyst durability, feedstock flexibility, scalability, and affordability in a unified system. This highlights the need for advanced reactor designs, improved catalyst regeneration methods, and intelligent process control strategies for real-world deployment.

Analytical Conclusion

From the critical analysis, it is evident that no existing pyrolysis system effectively balances feedstock flexibility, energy efficiency, catalyst durability, scalability, and cost simultaneously. Most solutions excel in isolated aspects while compromising others. This gap highlights the need for hybrid energy solutions, robust reactor architectures, improved catalyst protection mechanisms, and intelligent process monitoring strategies to ensure reliable and continuous plastic waste conversion under real-world conditions. Future research should focus on integrated, scalable, and cost-effective pyrolysis designs that enable continuous long-term plastic

waste processing, higher fuel quality, and reduced environmental impact.

FUTURE RESEARCH ROADMAP

- **Multi-feedstock Compatibility:** Develop pyrolysis systems capable of processing mixed plastic waste streams without pre-sorting.
- **Continuous Reactor Design:** Transition from batch to continuous-feed pyrolysis reactors to improve throughput and operational efficiency.
- **Advanced Catalyst Development:** Design catalysts with improved resistance to coking and deactivation for extended operational life.
- **Hybrid Energy Integration:** Incorporate waste heat recovery and solar energy to power the pyrolysis process, reducing external energy dependency.
- **IoT-Based Process Monitoring:** Integrate real-time sensors and IoT platforms for temperature, pressure, and yield monitoring to optimize process parameters dynamically.
- **Biodiesel Quality Improvement:** Refine transesterification and hydrotreatment protocols to meet international biodiesel standards (ASTM D6751 / EN 14214).
- **Char Valorization:** Investigate use of pyrolysis char as activated carbon, construction filler, or soil amendment to achieve zero-waste processing.
- **Pilot and Industrial Scale Testing:** Validate lab-scale findings through pilot plant operation to bridge the gap between research and commercial deployment.

VI. TEST RESULTS

The Oil and Biodiesel samples produced from the plastic waste pyrolysis conversion process were submitted for laboratory testing at the Bioenergy Research and Quality Assurance Laboratory (BRQAL), University of Agricultural Sciences, GKVK Campus, Bengaluru. The tests were conducted as per ASTM standards. The following table presents the results obtained.

The test results confirm that the pyrolysis oil (Sample 1) exhibits a kinematic viscosity of 2.542 cSt, density

of 793.7 kg/m³, pour point of 19 deg C, and flash point of 35 deg C. The biodiesel (Sample 2) shows a kinematic viscosity of 3.688 cSt, density of 801.6 kg/m³, micro carbon residue of 0.0163%, and flash point of 80.5 deg C. The higher flash point of the biodiesel (80.5 deg C compared to 35 deg C for the crude oil) indicates improved safety for storage and handling. These results validate the effectiveness of the pyrolysis and transesterification process in producing a fuel with characteristics approaching those of conventional diesel.

The literature review highlights significant progress in pyrolysis technology, with oil yields reaching up to 85-90% under optimized conditions. Catalytic pyrolysis using zeolite catalysts has shown particular promise in improving fuel quality and reducing operational temperatures. Compared to conventional land-filling and incineration, the proposed pyrolysis approach recovers the embedded chemical energy from plastics while minimizing harmful emissions.

Although challenges related to scalability, catalyst deactivation, and feedstock variability remain, the system demonstrates strong potential as a cost-effective and sustainable waste-to-energy solution. The modular architecture allows future upgrades such as continuous feeding, IoT-based monitoring, and integration with biodiesel refining processes. Overall, this project contributes a practical, eco-friendly foundation for large-scale plastic waste management and alternative fuel generation.

BIOENERGY RESEARCH AND QUALITY ASSURANCE LABORATORY
 UNIVERSITY OF AGRICULTURAL SCIENCES
 GEVVK Campus, Bengaluru - 560065
 e-mail: brqaal.vard@uasa.ac.in ☎ 080-21420022
 KARNATAKA STATE BIOENERGY DEVELOPMENT BOARD, GOVT. OF KARNATAKA

TEST REPORT

Test Report Number	UASBDRBRBQAL/REP/2026-27/01	Test Report Issue Date	13-05-2026
Sample Code Number	BRQAL-26-27-004-017	Customer person	Project Coordinator
Name & Address of the customer	Deshraj P.E.S College of Engineering, Mysuru	Customer Reference	CRF. Dtd: 08.05.2026
Name of the Sample	Oil and Biodiesel	Date of Receipt of Sample	08.05.2026
Identification of Sample		Date of Start of Test	09.05.2026
Any other information CLR Number	-	Date of Completion of Test	13.05.2026

Discipline	Chemical
Product Category	Biodiesel
Product Sub-category	-

Sample ID	Sample name	Sl No	Name of the Test	Units of Measurement	Test Method	Test Results
BRQAL-2026-27-004	Oil	1	Kinematic Viscosity@40°C	cSt	ASTM D 445	3.542
		2	Density@15°C	kg/m ³	ASTM D 7777	789.7
		3	Pour Point	°C	ASTM D 97	19.00
		4	Flash Point	°C	ASTM D 93	35.00
BRQAL-2026-27-007	Biodiesel	1	Kinematic Viscosity@40°C	cSt	ASTM D 445	3.688
		2	Density@15°C	kg/m ³	ASTM D 7777	801.4
		3	Micro Carbon Residue Test	%	ASTM D 450	0.0163
		4	Flash Point	°C	ASTM D 93	80.5

-End of Test Report-

Reviewed & Authorized By
 (Karnataka State Bioenergy Development Board)
 Analyst

VII. CONCLUSION

This project presents an integrated plastic waste to pyrolysis conversion system that addresses critical environmental and energy challenges simultaneously. By converting non-biodegradable plastic waste into usable pyrolysis oil, the system reduces landfill accumulation and provides an alternative fuel source with properties comparable to conventional diesel.

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