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Harnessing the Power of Plastic Waste: A Sustainable Approach to Fuel Production

Anant Sidhappa Kurhade[1]*, Pallavi Vishnu Kharat[2], Sukhadip Mhankali Chougule[3], Milind Manikrao Darade[4], Madhuri Mohanrao Karad[5], Govindarajan Murali[6], Girish Anant Charwad[7], Shital Yashwant Waware[1] and Rahul Shivaji Yadav[8]

[1]Department of Mechanical Engineering, Dr. D. Y. Patil Institute of Technology, Sant Tukaram Nagar, Pimpri, Pune - 411018, Maharashtra, India; a.kurhade@gmail.com
[2]Civil Engineering Department, Ajeenkya D. Y. Patil School of Engineering, via Lohegaon, Charoli Budruk, Pune - 412105, Maharashtra, India
[3]Department of Mechanical Engineering, Pimpri Chinchwad College of Engineering and Research, Ravet, Pune - 412101, Maharashtra, India
[4]Civil Engineering Department, Anantrao Pawar College of Engineering and Research, Parvati, Pune - 411009, Maharashtra, India
[5]Department of Electronics and Telecommunication Engineering, Dr D. Y. Patil Institute of Technology, Pimpri, Pune - 411018, Maharashtra, India
[6]Department of Mechanical Engineering, Koneru Lakshmaiah Education Foundation Green Fields, Vaddeswaram, Guntur (Dt) - 522502, Andhra Pradesh, India
[7]Department of Applied Art, Bharati Vidyapeeth's College of Fine Arts, Pune - 411043, Maharashtra, India
[8]Department of Mechanical Engineering, Marathwada Mitramandal's College of Engineering, Karvenagar - 411052, Maharashtra, India

Abstract

The rapid pace of economic growth has placed immense strain on our planet's resources. Our current reliance on fossil fuels, such as oil, gas, and coal, is unsustainable and poses significant environmental risks. Fortunately, a multitude of renewable energy alternatives, including biomass, hydropower, and wind energy, offer promising solutions. In addition to energy production, effective waste management is crucial. The surge in industrial and consumer activity has led to a dramatic increase in waste generation, particularly plastic waste. The widespread use of plastics, due to their versatility and affordability, has resulted in a global plastic crisis. In 2019 alone, a staggering 299 million tons of plastic were produced worldwide, a significant increase from previous years. Despite recycling efforts, a substantial amount of plastic waste ends up in landfills and oceans, causing severe environmental damage. It is estimated that between 10 and 20 million tons of plastic pollute our oceans annually, leading to the accumulation of over 5 trillion plastic particles. Our project aims to address this pressing issue by developing a sustainable solution to convert plastic waste into valuable biofuel. Through a process known as pyrolysis, we can extract oil and diesel from unsorted and dirty plastic, producing a product called Plastic Pyrolyzed Oil (PPO). This biofuel can be sold at competitive prices, making it a viable alternative to traditional fossil fuels. Both plastics and petroleum-derived fuels are primarily composed of hydrocarbons, making them chemically similar. By harnessing the power of pyrolysis, we can break

**Author for correspondence*

down plastic waste into its constituent components and convert it into a clean-burning fuel. This process offers several advantages over traditional waste disposal methods, such as incineration. Pyrolysis is non-toxic and environmentally friendly, requiring minimal pre-treatment and producing valuable by-products.

***Major Findings:** 1. Plastic pollution crisis: The excessive production and improper disposal of plastic waste pose a significant threat to the environment, particularly marine ecosystems. 2. Dependence on fossil fuels: The continued reliance on fossil fuels contributes to climate change and air pollution. 3. Potential of plastic-derived fuels: Converting plastic waste into fuel through processes like pyrolysis offers a sustainable solution to both waste management and energy production.*

Keywords: *Biofuel, Circular Economy, Environmental Impact, Plastic Pollution, Pyrolysis, Renewable Energy, Sustainable Energy, Waste Management*

1.0 Introduction

The relentless pursuit of economic growth has exerted immense pressure on our planet's resources. Our heavy reliance on fossil fuels, such as oil, gas, and coal, has not only fueled industrialization but also exacerbated environmental issues like climate change and air pollution. While renewable energy sources like solar, wind, and hydropower offer promising alternatives, the challenge of waste management, particularly plastic waste, remains a pressing concern. The ubiquitous presence of plastic in modern society, driven by its versatility and affordability, has led to a global plastic crisis. The staggering amount of plastic waste generated annually is overwhelming, with a significant portion ending up in landfills and oceans. This plastic pollution poses serious threats to marine ecosystems, wildlife, and human health. To address this critical issue, our project aims to develop a sustainable solution by converting plastic waste into valuable biofuel. Through a process known as pyrolysis, we can transform discarded plastic into clean-burning fuels like diesel and gasoline. This innovative approach not only reduces plastic waste but also provides a sustainable alternative to fossil fuels. By harnessing the power of pyrolysis, we can contribute to a cleaner and more sustainable future. Plastics, celebrated for their lightweight, durability, energy efficiency, rapid production, and versatile design, have become deeply ingrained in our modern lifestyle. Their widespread use spans various industries and households. However, their non-biodegradable nature, primarily attributed to their polymeric structure composed of carbon, hydrogen, and sometimes elements like chlorine and nitrogen, presents a significant environmental challenge. Plastic waste constitutes a substantial portion of municipal solid waste. These materials, whether derived from chemically modified natural substances or synthesized from inorganic and organic raw materials, are categorized into three main types based on their physical properties: thermosets, elastomers, and thermoplastics. Each type exhibits unique thermal behaviour due to its distinct molecular structure.

Our project aims to address the plastic waste crisis by transforming it into a valuable resource. Through a process known as pyrolysis, we can convert waste plastic into diesel fuel. In this process, shredded plastic is heated in an oxygen-free chamber to approximately 400 degrees Celsius. As the plastic melts, the released gases are recycled to power the machine. The resulting liquid fuel undergoes refinement to produce diesel fuel. This process not only reduces the volume of plastic waste but also minimizes air pollution, offering a sustainable solution to a pressing environmental issue.

2.0 Literature Review

Daniyan I. A. *et al.* highlighted that recycling activities not only benefit the environment and economy but also serve as an excellent source of self-employment. These activities have the potential to reduce unemployment in developing countries[1]. Ajay Jayswal *et al.* emphasized the necessity of incorporating an effective agitation mechanism in the pyrolysis reactor to ensure uniform heating of plastics. Without it, plastics at the bottom may char while those above remain unpyrolysed. Maintaining an appropriate heating rate is crucial to achieving a good yield of pyrolysis oil, as a lower heating rate results in reduced oil output. For example, pyrolysis of 10 kg of waste LDPE has yielded 2.236 kg of char and 6.63 litres of pyrolysis oil, consuming 3.169 kg of LPG gas[2]. Fabio A. Cruz Sanchez *et al.* conducted a systematic literature review

to analyze advancements in plastic recycling for additive manufacturing. They proposed a framework comprising six key stages (recovery, preparation, compounding, feedstock, printing, and quality) to map the global value chain of distributed recycling through additive manufacturing[3]. Shafferina Dayana *et al.* investigated pyrolysis, a process involving the thermal degradation of long-chain polymer molecules into smaller, simpler molecules under heat and pressure, without oxygen. This process requires high heat over a short duration and yields three primary products—oil, gas, and char—that hold significant industrial value, particularly for production and refineries[4].

Dezhen Chen reviewed the state-of-the-art in Municipal Solid Waste (MSW) pyrolysis, focusing on technologies, reactors, products, and environmental impacts. The review examines the effects of key operating +parameters such as final temperature, heating rate, and residence time on pyrolysis behavior and outputs. Additionally, it evaluates the pyrolysis technologies and reactors used in research and large-scale applications[5]. Kemal Ozkan introduced a novel classification scheme for plastic waste based on recycling labels. This scheme demonstrates high accuracy and real-time applicability, achieving approximately 90% recognition accuracy for classifying plastic bottle types. Furthermore, it delivers around 96% accuracy in separating Polyethylene Terephthalate (PET) from non-PET plastics and 92% accuracy in categorizing non-PET plastics into High-Density Polyethylene (HDPE) or Polypropylene (PP)[6]. This research delves into thermal management techniques for electronic devices, particularly in challenging conditions. The studies cover a range of topics, such as: Optimizing electronic component temperature control: This includes exploring the impact of substrate thermal conductivity on component temperature, utilizing Phase Change Materials (PCM) for cooling smartphone circuits, employing Computational Fluid Dynamics (CFD) for Integrated Circuit (IC) chip thermal management, and utilizing AI-based strategies for efficient IC chip placement[7-13].

Enhancing heat transfer in heat exchangers: This involves investigating methods like jet impingement, twisted tape inserts, and nanofluids to improve heat transfer efficiency in tubular heat exchangers[14-22]. Thermal management of electronic devices in harsh environments: This research examines the thermal performance of electronic components on different substrate materials and the influence of heat transfer on symmetric and asymmetric IC chips mounted on Switch-Mode Power Supply (SMPS) boards, both with and without PCM[23-31].

The aim of this research is to develop a sustainable and environmentally friendly solution to convert plastic waste into valuable biofuel, thereby reducing reliance on fossil fuels and mitigating plastic pollution.

3.0 Methodology

The process of converting plastic waste into diesel fuel is relatively straightforward, akin to the production of alcohol. When plastic waste is heated in an oxygen-free environment, it melts without burning. As the melted plastic continues to heat, it vaporizes. These vapours are then channelled through a cooling pipe, where they condense into a liquid state. Shorter hydrocarbon chains in the vapour remain as gas. To capture any remaining liquid fuel, the outlet of the cooling pipe is submerged in a water-filled bubbler. The water absorbs the final traces of liquid fuel, leaving only gas, which is then burned. If the cooling process is effective, no fuel should accumulate in the bubbler. However, if the cooling is insufficient,

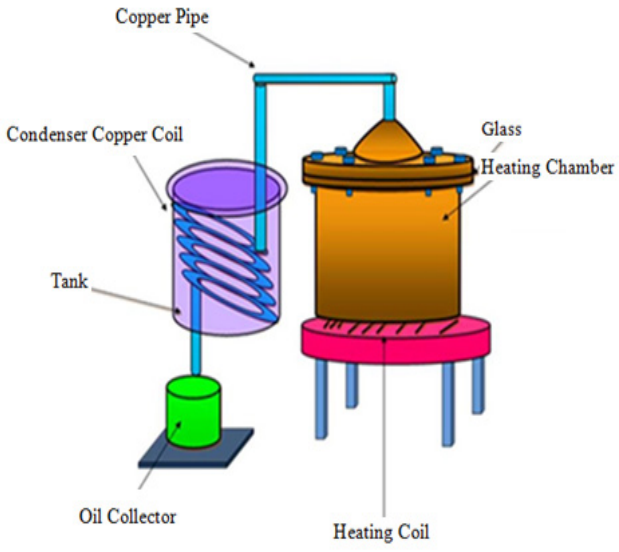


Figure 1. Reactor setup.

the liquid fuel will float on the water's surface and can be easily extracted. A steel reservoir is positioned at the bottom of the cooling tube to collect the condensed liquid fuel that collects all the liquid, and it has a release valve on the bottom so that the liquid fuel can be poured out. Here are some pictures to better understand the design as shown in Figure 1.

4.0 Working

This device operates on single-phase electricity and utilizes nichrome coils as heating elements, consuming a total of 1 kilowatt of power. Three solid-state relays, one for each phase, control the activation and deactivation of the coils. A digital thermostat, equipped with a temperature sensor positioned just below the lid, monitors and regulates the vapour temperature.

To initiate the process, the plastic waste, shredded into small pieces, is slowly heated to approximately 310 degrees Celsius. At this temperature, the plastic undergoes thermal decomposition, yielding various products, including diesel fuel. The device has a capacity of 5 litres and can accommodate around 1 kilogram of shredded plastic. The entire process typically takes about 2 hours, but with minor design modifications, the duration can be significantly reduced.

5.0 Design Calculations

5.1 Stress Calculations

- **Tangential Stress (σt):** $\sigma t = (Pi * Di) / (2 * t)$
- **Longitudinal Stress (σl):** $\sigma l = (Pi * Di) / (4 * t)$

5.2 Material Selection and Safety Factor

- Material: C45 (mild steel)
- Factor of Safety (FoS): 2
- Allowable stresses:
  - $\sigma t = \sigma b = 540\ N/mm^2 / 2 = 270\ N/mm^2$
  - $\sigma s = 0.5 * \sigma t = 135\ N/mm^2$

5.3 Design of Heating Chamber

- **Shell Thickness:**
  - Based on thin cylinder theory with modifications: $t = (Pi * Di) / (2 * \sigma t * \eta t)$ $t \approx 0.27$ mm
  - A 3mm thick pipe is sufficient for safety.

5.4 Design of Condenser

- **Heat Transfer:**
  - $Q = U * A * \Delta T$
  - $\Delta T = ((T1 - T_{atm}) - (T_2 - T_{atm})) / \ln((T_1 - T_{atm}) / (T_2 - T_{atm}))$
- **Tube Length:**
  - $A_contact = \pi * D_tube * L_tube$
  - $L_tube \approx 1500$ mm
  - Number of turns ≈ 3.1

5.5 Design of Frame Leg

- **Bending Moment:**
  - $M = WL/4$
- **Section Modulus:**
  - $Z = B^3/6 - b^4/(6B)$
- **Bending Stress:**
  - $\sigma = M/Z$
  - The design is safe as the induced bending stress is less than the allowable stress.

Calculations are made using the above formulas.

6.0 CAD Drawing

The entire model was designed using SolidWorks with the help of actual calculations as shown in Figures 2 and 3.



Figure 2. Isometric front view.

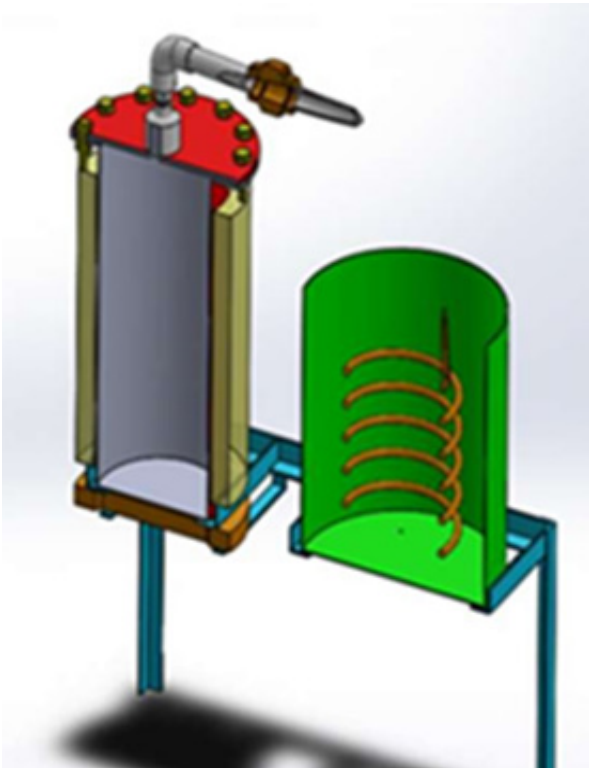


Figure 3. Cut section view.

7.0 Conclusion

The process of converting waste plastic into thermo fuel is an innovative and eco-friendly approach that addresses both environmental concerns and fuel production. This method efficiently transforms discarded plastic into valuable fuel products, contributing to sustainable waste management and energy solutions. Approximately 700 grams of fuel can be extracted from every kilogram of raw plastic material. Through distillation, this fuel can be separated into specific components like petrol, diesel, kerosene, naphtha, carbon, and other useful by-products.

One of the primary advantages of this project is that it offers a viable alternative to conventional fossil fuels. This alternative fuel source can help reduce our reliance on depleting natural resources while simultaneously addressing the escalating issue of plastic waste.

8.0 Advantages

1. **Alternative fuel source**: The process provides a sustainable and renewable alternative to traditional fuels, which can help address energy shortages.
2. **Effective plastic waste disposal:** By using waste plastic as a raw material, this project contributes to reducing the accumulation of plastic waste in the environment.
3. **Utilization of by-products**: The carbon residue obtained during the process can be effectively used for refilling cartridges, adding economic value to the by-products.
4. **Minimal process loss:** The thermo-fuel production method ensures high efficiency with very little material lost during processing, making it a highly viable industrial solution.

This project not only offers economic and environmental benefits but also has the potential to support industries by supplying a steady source of alternative fuel. It can play a crucial role in reducing plastic pollution, lowering greenhouse gas emissions, and contributing to a circular economy. Furthermore, widespread implementation of such projects could foster technological innovation and create new employment opportunities in waste management and energy sectors.

In conclusion, the production of thermo fuel from waste plastics stands as a promising pillar for both environmental conservation and fuel generation, paving the way for a cleaner, more sustainable future.

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