

A Futuristics Pyrolysis Technique: Conversion of Waste Plastic Polybags Into Fuel

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Abstract

Plastics are high molecular weight materials composed of repeating polymer units and can be classified based on factors like chemical composition, structure, stiffness, application types, and processing methods. A key environmental issue with plastics is their non-biodegradability, causing them to persist in the environment. Pre-consumer plastic waste includes manufacturing defects, rejected items, and excess materials produced during virgin plastic manufacturing. In India, around 15,342 tons of plastic waste are collected daily, highlighting the urgency of the problem. Recycling remains a common but largely ineffective method due to the challenges of cleaning and segregating plastics. Globally, over 100 million tons of plastic are produced annually, with plastic waste filling landfills and acting as carbon sinks, trapping CO₂. Disposal methods like incineration and gasification are criticized for releasing toxic gases and being costly. Pyrolysis stands out as a promising solution, involving the thermal decomposition of plastics into fuel-range hydrocarbons like petrol, diesel, and kerosene. The process involves catalytic cracking at high temperatures, where the resulting gases are condensed to produce liquid fuels. The efficiency of this method depends on the type of plastic used, with some yielding better fuel conversion rates. Compared to traditional disposal methods, pyrolysis offers significant environmental advantages by reducing plastic waste and conserving petroleum resources. As this technology advances, it holds the potential to become a pivotal solution for managing the global plastic waste crisis.

Keywords: PVC, PET, HDPE, LDPE, PP, OD, CFD

INTRODUCTION

Plastic has become one of the most essential materials in modern life due to its lightweight nature, durability, energy efficiency, and flexibility, making it a highly versatile and widely used substance. Its widespread availability and cost-effectiveness further enhance its appeal, making it a preferred choice across multiple industries. These factors allow businesses to access the material easily and at a lower expense, which can be crucial for maintaining competitive pricing while meeting production demands. As a result, its use has expanded across diverse sectors, contributing to its broad adoption and continued

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relevance in various applications. The plastic industry has a vast scope, with applications spanning across automotive, construction, electronics, healthcare, textiles, and many other sectors. The Plast India Foundation reports that the industry has grown at a remarkable rate of approximately 10% annually by volume, reaching 8.33 million metric tons per year. This growth underscores the increasing reliance on plastics and highlights their importance in supporting global economic development and technological advancement. As such, plastic plays a crucial role in shaping the modern world, driving innovation, and meeting the demands of various industries [1]. The management of plastic

waste has become one of the most pressing global challenges due to its non-degradable nature. Plastics, which can take centuries or even millennia to decompose, persistently accumulate in landfills, oceans, and ecosystems, causing severe environmental damage. This accumulation leads to pollution, disrupts wildlife habitats, and contributes to long-term ecological degradation. As plastic waste continues to build up, addressing this issue has become crucial for safeguarding the environment and promoting sustainability. This persistent waste not only pollutes land and water but also poses risks to wildlife, as many animals mistake plastic for food, leading to ingestion and potential harm or death. The sheer volume of plastic waste produced daily, combined with its resistance to natural degradation, makes it an ongoing issue that seems to grow with time. In response, various regions around the world have designated specific areas for the collection and disposal of plastic waste, and efforts to increase recycling have been steadily improving. Recycling programs, however, face challenges in terms of efficiency, as plastics often need to be sorted and cleaned before they can be processed into new products. Despite these challenges, the recycling of plastics has gained momentum, as it helps conserve resources, reduces the environmental impact, and contributes to the creation of a more sustainable circular economy. Governments, industries, and communities are increasingly focusing on improving plastic waste management systems, although more work is needed to address the widespread issue comprehensively [2].

Plastic, revolutionized various industries due to its versatile and durable properties. Plastics are polymers, composed of long chains of repeating molecular units that result in their high molecular weight. These polymers are usually created through a process known as polymerization, in which small monomer molecules chemically bond to form larger, more intricate structures. Over time, plastics have become integral in daily life due to their lightweight, flexible, and cost-effective nature [3].

The process of pyrolysis is a promising method for managing plastic waste and converting it into useful energy. Pyrolysis involves heating plastic waste to temperatures ranging from 350 to 900°C in an oxygen-deficient environment, which prevents combustion. During this process, the plastic breaks down into smaller molecules, producing valuable by-products such as fuel, oil, and gas, making it an effective energy regeneration technique. This process helps to reduce plastic waste while generating usable energy, offering an environmentally friendly alternative to traditional plastic disposal methods [4].

Plastics are broadly classified into two categories: thermoplastics and thermosetting plastics (Figure 1).

Thermoplastics can be repeatedly heated and molded without undergoing any chemical change, allowing them to be reprocessed and recycled multiple times. Common examples include polyethylene, polypropylene, and PVC [5]. On the other hand, thermosetting plastics undergo a chemical change when heated, making them hard and rigid, and they cannot be remolded once set. Both types have distinct properties and applications, but the growing demand for efficient plastic waste management solutions emphasizes the importance of understanding their characteristics and developing sustainable recycling or disposal methods [6]. The plastic industry classifies plastics based on their chemical structure and intended applications, with each type offering unique properties suited for specific uses. PET (Polyethylene Terephthalate) is widely used in beverage bottles, food containers, and textile fibers due to its strength, transparency, and moisture resistance. HDPE (High-Density Polyethylene) is prized for its high strength-to-density ratio, making it ideal for milk jugs, detergent bottles, and piping systems. PVC (Polyvinyl Chloride) is highly versatile, finding applications in plumbing pipes, flooring, and medical equipment, and is one of the most commonly produced synthetic plastics. LDPE (Low-Density Polyethylene), known for its flexibility, is used in products like plastic bags, shrink wrap, and containers, offering more pliability compared to HDPE. Polypropylene (PP) is a durable plastic with a high melting point, suitable for heat-resistant containers and automotive parts. Meanwhile, Polystyrene (PS) is commonly found in disposable cutlery, CD cases, and packaging materials; however, its brittleness and environmental impact due to its non-biodegradable nature pose significant challenges [7]. Despite the

widespread use of plastic, only less than 5% of plastic produced is recycled, a statistic that highlights the challenges in managing plastic waste. The global production of plastics is expected to continue growing, with projections suggesting a rise of approximately 3.8% annually until 2030. Over the past 60 years, plastic production has soared, contributing to the accumulation of over 6.3 billion tonnes of plastic waste.

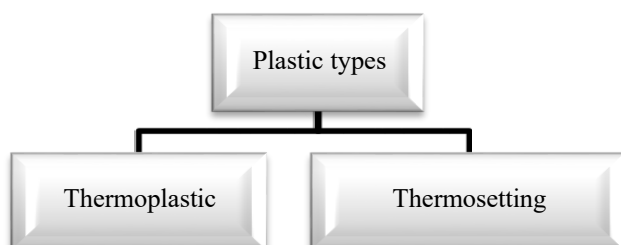


Figure 1. Types of plastics.

One promising solution to this mounting plastic waste is the conversion of plastic into fuel. This process has the potential to significantly decrease waste volume while simultaneously addressing pollution, contributing to a cleaner and more sustainable environment. Moreover, cleaner methods of plastic-to-fuel conversion are being developed, aiming to reduce harmful by-products, such as sulfur content, and to create valuable by-products like heavy diesel, which could be used in industrial applications. These advancements in plastic recycling and waste management are critical steps towards addressing the environmental impact of plastic while also creating a more sustainable circular economy.

Plastics play a vital role across various industries due to their versatility, cost-effectiveness, and the unique properties of each type that cater to specific applications. *PET (Polyethylene Terephthalate)* is extensively used for water and soft drink bottles, food jars, and other packaging needs, thanks to its strength, transparency, and heat resistance, making it ideal for food and beverage storage. *PVC (Polyvinyl Chloride)* is a cornerstone in construction, plumbing, and electrical industries, commonly used in cables, pipes, and building materials due to its durability, flexibility, and resistance to moisture and chemicals. *HDPE (High-Density Polyethylene)* stands out for its strength and rigidity, making it perfect for shampoo bottles, consumer goods packaging, and other applications requiring chemical resistance and low moisture absorption. On the other hand, *LDPE (Low-Density Polyethylene)* is prized for its flexibility and lightweight properties, making it ideal for grocery bags, shrink wraps, and other thin, easily moldable products. *Polypropylene (PP)*, known for its toughness and resistance to chemical solvents, bases, and acids, is widely used in chips packaging, medicine bottles, and bottle caps, particularly in the food and pharmaceutical industries. *Polystyrene (PS)*, a lightweight and inexpensive plastic, is commonly found in disposable cutlery, food packaging, and foam products, though it has raised environmental concerns due to its non-biodegradable nature. Finally, *Polycarbonate (PC)* is a highly durable plastic used in demanding applications such as electronic components, defense gadgets, and food packaging, appreciated for its strength, optical clarity, and heat resistance. Together, these plastics demonstrate the incredible adaptability and importance of polymer materials in modern life, despite the challenges posed by their environmental impact.

Table 1 illustrates the wide range of uses that plastics serve across different sectors, from food packaging and electronics to construction and healthcare. Each plastic type is chosen based on its unique set of characteristics, such as flexibility, rigidity, chemical resistance, or transparency, ensuring its effectiveness in the specific application. However, while these plastics provide numerous benefits in various industries, the environmental challenges posed by plastic waste have led to a growing focus on developing sustainable alternatives and improving recycling efforts [8].

Table 1. Applications of plastic in for different uses.

S.N.	Plastic	Uses
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1	PET (Polyethylene Terephthalate)	Water and soft drink bottle, food jar
2	PVC (Polyvinyl Chloride)	Cables, pipes
3	HDPE (High Density Polyethylene)	Shampoo bottles, packings
4	LDPE (Low Density Polyethylene)	Grocery bags
5	PP(Polypropylene)	Chips packs, bottle caps, medicine bottles
6	PS(Polystyrene)	Food packing, cutlery, packing foam
7	PC(Polycarbonate)	Food packings, electronic goods, defense gadgets

Plastics are indispensable materials in modern society due to their diverse and valuable properties, making them highly versatile and desirable for a wide range of applications across various industries. These unique characteristics include:

1. *Less Brittle and Transparent:* Unlike many other materials that are prone to breakage, plastics are less brittle, meaning they are more resistant to cracking or shattering. This property not only improves their durability but also allows plastics to be made highly transparent and smooth. This makes them ideal for applications such as packaging, where the visual appeal and clarity of the material are essential, particularly in food and beverage packaging, where consumers expect to see the contents clearly.
2. *Lightweight with Good Strength and Rigidity:* One of the standout advantages of plastics is their lightweight nature, which makes them easy to handle, transport, and use in a variety of applications. Despite their lightness, many types of plastics possess impressive strength and rigidity. This combination allows them to be used in demanding applications where materials need to maintain structural integrity under stress, such as in automotive parts, construction materials, and consumer goods like furniture and household appliances.
3. *Good Toughness:* Plastics are known for their toughness, meaning they can absorb significant amounts of energy and withstand impacts without cracking or breaking. This makes plastics especially valuable in industries like automotive and packaging, where durability is paramount. The ability to resist damage from rough handling or external forces ensures that products such as car bumpers, protective packaging, and safety equipment maintain their functionality over time.
4. *Resistance to Corrosion and Chemicals:* One of the key properties of plastics is their resistance to corrosion and the action of chemicals. Plastics do not rust or degrade easily when exposed to moisture or harsh chemicals, making them ideal for use in a variety of environments, from outdoor applications like plumbing and piping to medical and food packaging, where hygiene and protection from contaminants are critical. This resistance enhances the durability of plastic products, ensuring they remain reliable even in harsh or challenging conditions, thus extending their lifespan.
5. *High Dielectric Strength for Electrical Insulation:* Many plastics have high dielectric strength, meaning they can effectively insulate against electrical currents. This property is essential in the production of electrical components, wiring, and insulating materials used in a wide array of electrical and electronic devices. Plastics with high dielectric strength play a crucial role in ensuring safety by minimizing the risk of short circuits and other electrical hazards, effectively preventing potential electrical accidents.
6. *Ease of Mass Production:* One of the most significant advantages of plastics is their ability to be mass-produced efficiently and cost-effectively. Plastics can be manufactured at a high rate, making them suitable for mass-market products like packaging, containers, and disposable goods. This scalability, combined with the relatively low cost of production, allows plastics to be used in large volumes and ensures they remain accessible to consumers worldwide.
7. *Low Moisture Absorption:* Plastics generally have low moisture absorption, meaning they do not easily absorb water or other liquids. This is particularly useful in applications where materials need to maintain their properties in humid or wet environments, such as food packaging, medical devices, and outdoor equipment. This characteristic also helps to preserve the integrity of plastic

products and prevents them from weakening or deteriorating when exposed to moisture.

8. *Ease of Molding into Desired Shapes:* Plastics can be easily molded into almost any shape, making them incredibly versatile in manufacturing. This ability to take on intricate or complex forms allows for the production of highly specialized products, from everyday household items to sophisticated components used in industries like automotive and electronics. The flexibility in design and manufacturing helps meet the needs of a wide range of sectors, creating everything from simple containers to highly customized, intricate parts [9].

In combination, these properties explain why plastics are integral to a variety of industries, from packaging and electronics to construction, healthcare, and automotive sectors. Plastics are indispensable in the modern world due to their versatility, ease of use, and cost-effectiveness. However, their widespread use also brings substantial environmental challenges. The durability and resistance to degradation that make plastics so valuable also contribute to the escalating issue of plastic waste. As plastics remain in the environment for centuries, their accumulation in landfills, oceans, and other ecosystems leads to significant environmental and ecological risks, threatening wildlife and disrupting natural habitats.

Consequently, the focus on developing sustainable alternatives, improving recycling processes, and reducing plastic consumption is more crucial than ever in addressing the long-term impact of plastic waste on the planet.

The *experimental procedure* section typically describes the step-by-step methods and techniques used to carry out an experiment or research project. This includes all the specific actions, materials, and equipment that were used, as well as how data was collected and analysed. The purpose of this section is to provide clear, reproducible instructions so that others can replicate the experiment or research to verify results or build upon the work.

The experimental procedure begins by outlining the objective, which defines the goal or hypothesis and sets the stage for the investigation. Following this, a list of materials and equipment is provided, detailing all necessary items such as laboratory instruments, plastics, reagents, catalysts, measurement tools, and safety gear. The step-by-step procedure then offers a clear, logical sequence of actions to carry out the experiment, including instructions for material preparation, experimental execution, and specific conditions like temperature, timing, or environmental factors. Detailed guidance on sample manipulation is also included. In the data collection section, the procedure specifies how to gather data, what measurements to take, and which instruments to use, such as thermometers, scales, or analytical tools. It also outlines how to document results, including units and timekeeping protocols. The safety protocols section ensures the protection of researchers by recommending personal protective equipment (PPE), safe chemical handling practices, and steps for managing potential hazards. In cases where analysis is required, the analysis methods section describes how the data will be interpreted, using statistical techniques, graphical methods, or specialized software. Finally, some experimental procedures may include a section on expected outcomes, providing an overview of what results the researcher aims to observe or achieve during the experiment.

By elaborating on these steps, the experimental procedure provides a structured, transparent account of how the experiment was performed, ensuring that others can understand the methodology, replicate the process if need, and assess the validity of the results (Figure 2).

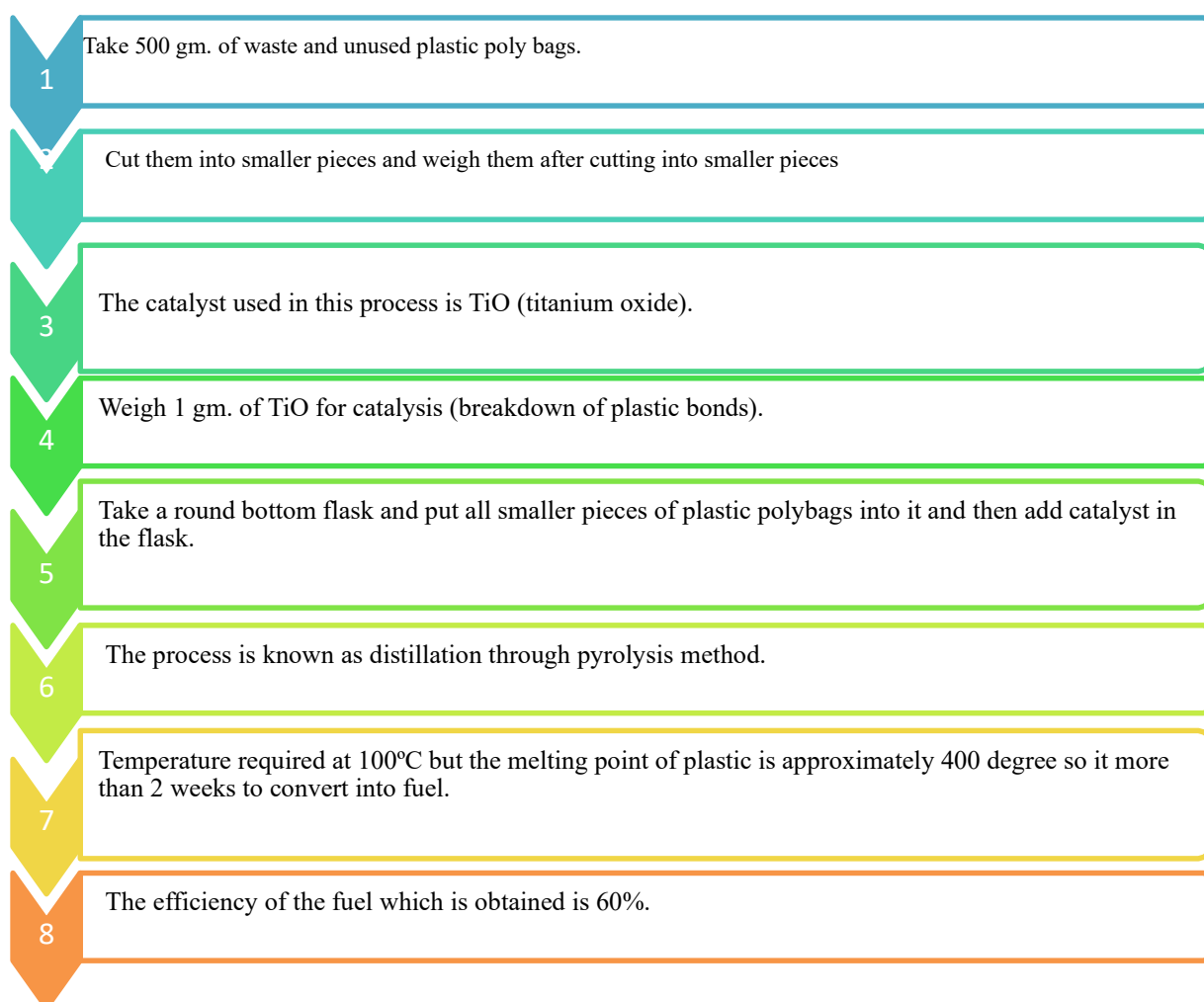


Figure 2. Flow Chart of the procedure methodology.

The methodology for pyrolysis of plastic bags involves a systematic process designed to convert plastic waste into valuable products through controlled heating. Pyrolysis is a chemical process that breaks down plastics in the absence of air and moisture, preventing combustion while allowing the material to decompose into smaller molecules such as liquids, gases, and solid residues. The plastic bags, which are composed of long chains of monomers, undergo thermal degradation at temperatures typically ranging from 350–400°C, breaking these chains into smaller, more manageable molecules. These monomers or smaller units can then be processed into useful products like fuel, chemicals, or even recycled plastic components. To enhance the efficiency of this process, catalysts are often employed to accelerate the reaction rate without being consumed, ensuring higher yield and quality of the final products. The reaction conditions, including temperature, pressure, and reaction time, must be carefully controlled to optimize the breakdown of plastic and achieve the desired outcomes. One of the key challenges addressed by this methodology is the environmental impact of plastic bags, which are non-biodegradable and pose serious ecological threats through accumulation in landfills, oceans, and urban areas. Pyrolysis offers a sustainable solution by converting waste plastic bags into useful resources like fuel, thus reducing waste and providing an eco-friendly alternative for plastic waste recycling.

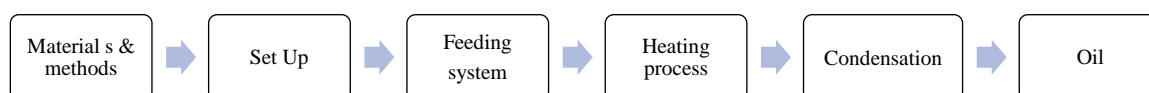


Figure 3. Overview of the Methodology.

This section would typically include a diagram or flowchart that illustrates the pyrolysis process, showing the steps involved from heating the plastic in a controlled environment to the breakdown of polymers into smaller molecules, followed by the collection of the resulting products. Figures 3 and 5 acts as a visual representation that aids in understanding the methodology and outlining the steps involved in the process. It provides a clear, graphical overview of the various stages, such as the breakdown of plastic, the role of catalysts, and the conditions under which the pyrolysis reaction occurs. By illustrating the process flow, the figures helps to simplify complex concepts and enhance comprehension of how plastic waste is converted into valuable products.

In conclusion, the methodology highlights the controlled process of pyrolysis to convert waste plastic into valuable products, addressing the global issue of plastic waste and providing a sustainable solution to reduce environmental impact.

Problem with Plastic Bags

Plastic bags, while commonly used and convenient, present significant environmental and human health issues. Their widespread use has become a major concern due to the long-lasting negative impact they have on the environment and human well-being [10].

Environmental Issues

The environment plays a crucial role in sustaining all living organisms, as we are all interconnected with the surroundings. Unfortunately, plastic bags are hazardous to the environment in numerous ways. One of the most alarming issues is that plastic bags, though used for a very short period, take hundreds of years to decompose in landfills. This long degradation process leads to the accumulation of non-biodegradable plastic waste, which harms ecosystems and wildlife.

In addition to their environmental persistence, plastic bags also contribute to the emission of greenhouse gases, which intensify the effects of climate change. When plastic waste is improperly disposed of or incinerated, it releases harmful gases such as carbon dioxide (CO₂) and methane (CH₄) into the atmosphere, worsening global warming and its associated impacts on ecosystems and weather patterns.

The production and disposal of plastic bags involve the release of carbon dioxide and other harmful gases that trap heat in the Earth's atmosphere, leading to global warming. While plastic bags can be recycled or reprocessed, the overall process still has a negative impact on the environment, and recycling efforts are often limited by contamination and inefficiency in waste management systems.

Burning plastic bags as a method of disposal is another major environmental concern. When plastic is burned, it releases toxic fumes and pollutants, such as carbon monoxide, dioxins, and hydrochloric acid, into the air. These harmful emissions contribute significantly to air pollution, posing serious health risks to humans and animals and further deteriorating air quality. The combustion of plastic also exacerbates environmental degradation by introducing hazardous chemicals into the atmosphere.

These emissions not only disrupt the natural balance of the environment but also pose significant risks to human and animal health. The harmful effects of plastic combustion can harm the air quality, leading to an imbalance in the ecosystem, which is detrimental to plants, animals, and other living organisms [11].

Human Health

The disposal and handling of plastic bags can also have severe health implications.

Burning plastic bags releases toxic chemicals, including dioxins and furans, into the atmosphere. These harmful substances pose serious health risks when inhaled or absorbed by the body. Immediate effects of exposure to these hazardous fumes can include headaches, dizziness, and even

unconsciousness. Over time, prolonged exposure to the fumes can lead to more severe long-term health problems, such as respiratory issues, weakened immune function, and an increased risk of certain cancers. The environmental and human health implications of burning plastic bags make it a dangerous practice with lasting consequences. These can include respiratory problems such as asthma, coughing, and throat swelling, as well as liver dysfunction and other systemic health disorders. Furthermore, the chemicals released by burning plastic bags can cause digestive issues, including diarrhea, vomiting, stomach ache, and food poisoning.

In addition, plastic bag-related chemicals have been associated with hormonal disruptions, leading to a range of reproductive health issues, such as infertility, birth defects, and hormonal imbalances. Studies have also shown that exposure to these harmful substances can reduce sperm count in males and increase the risk of cancer in both men and women. On a more immediate level, they can also cause skin diseases, rashes, allergies, and eye irritation, potentially leading to vision problems. The cumulative health impact of burning or improperly managing plastic bags is a significant concern for public health.

In conclusion, while plastic bags are widely used due to their convenience, their environmental and health impacts are considerable. They contribute to long-term environmental damage, including the destruction of ecosystems, the emission of greenhouse gases, and air pollution. Furthermore, the harmful effects of burning plastic and prolonged exposure to its chemicals pose serious health risks, ranging from respiratory problems to reproductive issues and even cancer. Addressing the problem of plastic bag waste requires more sustainable solutions, such as improved recycling systems, better waste management practices, and the development of biodegradable alternatives [12].

Marine Issues

Plastic pollution is causing devastating harm to marine life, with millions of tons of plastic waste entering the oceans each year. Marine animals, including fish, sea turtles, and seabirds, often mistake plastic for food, leading to ingestion that can cause injury, malnutrition, or death. The physical presence of plastic in the ocean also disrupts ecosystems, damaging coral reefs and habitats. Additionally, chemicals in plastics can leach into the water, further contaminating the marine environment and harming the creatures that rely on it. The widespread and growing issue of plastic pollution is endangering biodiversity and threatening the health of ocean ecosystems.

It is estimated that nearly 7,000 species, including fish, seabirds, and marine mammals, have been killed due to plastic waste, with some species even becoming extinct. Approximately 267 species worldwide are affected by plastic pollution, causing significant disruption to marine ecosystems. Among the affected species, sea turtles, seabirds, and marine mammals are the most commonly impacted, with varying percentages of species within each group suffering from the consequences of plastic ingestion and entanglement.

The death of marine mammals, for example, is often the result of various factors associated with plastic pollution, including ingestion of plastic materials, starvation due to blockages in their digestive systems, suffocation, infections, drowning, and entanglement in plastic debris. Studies have shown that approximately 48% of marine species have plastic within their bodies, and the plastic contamination has been found at depths of up to 2,000 meters in the ocean. This widespread contamination of the marine environment further exacerbates the vulnerability of these species and threatens their survival as shown in Table 2 [13].

Table 2. Affected Species Percentage in Marine Environment.

Species	Affected Count	Percentage
Sea Turtles	98	37%
Sea Birds	84	31%
Marine Mammals	44	16%

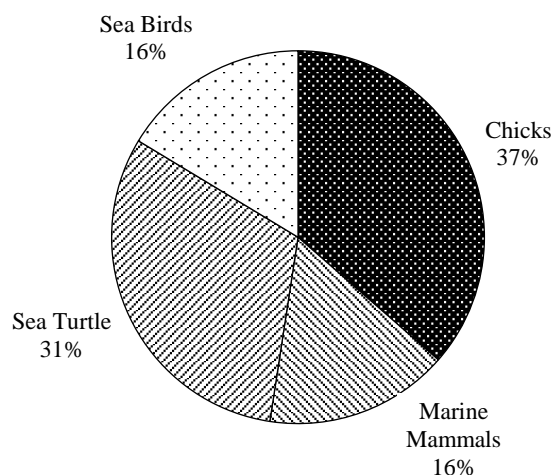


Figure 4. Graphical Representation of species

As illustrated in **Figure 4**, the percentage of affected species in the marine ecosystem reveals a staggering impact, with sea turtles and sea birds being particularly vulnerable. For instance, 37% of sea turtles and 44% of marine mammals have been impacted by plastic pollution. The situation is critical, as many marine species frequently mistake plastic for food, resulting in severe health issues and, in many cases, death. This tragic outcome underscores the urgent need for global action to reduce plastic waste and prevent further damage to marine life. The continued accumulation of plastic in the oceans not only threatens the survival of countless species but also disrupts entire ecosystems. To safeguard marine biodiversity and ensure the health of oceanic ecosystems, concerted global efforts are essential to address plastic pollution at its source and find sustainable solutions.

Measures such as improved waste management, stricter regulations on plastic production, and the development of alternative materials are crucial to mitigating the long-term damage to marine ecosystems and ensuring the survival of these vulnerable species [14].

Advantages of Plastic Bags

Plastic bags offer several benefits that make them a popular choice across industries and among consumers. Some of the key advantages of plastic bags include:

Plastic bags offer a range of advantages that make them a popular choice for both manufacturers and consumers. They are cost-effective, being cheaper than paper bags, which makes them an economical option for retailers and customers alike. This affordability, combined with their convenience and ease of use, makes plastic bags widely preferred in everyday shopping and packaging. They are durable and capable of holding heavier items without tearing, making them more reliable for carrying goods. In addition to their durability, plastic bags are reusable and washable, allowing for multiple uses and reducing the need for frequent replacements, unlike paper bags. Furthermore, many plastic bags are biodegradable, especially those made from plant-based materials, which reduces their long-term environmental impact compared to traditional plastic. Their portability is another benefit, as they are lightweight, foldable, and can easily fit into a purse or pocket for future use.

Plastic bags are also energy-efficient to produce, requiring less energy than paper bags, which adds to their appeal from an environmental standpoint. They are quicker to use—easy to open, pack, and double up—making them a fast and practical choice for both consumers and retailers. The lightweight nature of plastic bags also contributes to their ease of transport and storage. Moreover, they generate significantly less solid waste than paper bags, helping to reduce the volume of materials in landfills. Plastic bags' strength further enhances their functionality, as they are less likely to break under the weight of their contents. They are also effective at preserving products, particularly perishable items,

by providing a protective seal from environmental elements. Finally, plastic bags have universal use across various industries, from food packaging to manufacturing, demonstrating their versatility and adaptability in both large and small-scale operations. These characteristics make plastic bags an integral part of modern-day packaging and transportation, contributing to their widespread use [15].

Disadvantages of Plastic Bags

Despite their many advantages, plastic bags pose substantial environmental and health risks that cannot be overlooked. One of the most critical issues is their adverse effect on marine life. Plastic bags can be mistaken for food by marine animals such as fish, seabirds, and marine mammals, leading to ingestion or entanglement, which can cause injury or death. This disrupts marine ecosystems and threatens biodiversity. Additionally, the low recycling rates of plastic bags exacerbate the problem, with a significant portion entering the waste stream and contributing to pollution. Their non-biodegradable nature means that plastic bags persist in the environment for hundreds of years, further intensifying pollution both on land and in water. As they accumulate in the environment, they become a major source of pollution and a growing concern for wildlife, particularly when animals mistake plastic for food or become entangled, leading to blockages, poisoning, or suffocation.

Another major environmental impact is the toxic emissions produced when plastic bags are burned, releasing harmful substances like dioxins and furans into the atmosphere, which can pose serious risks to human health and the environment. Additionally, plastic bags often contain hazardous additives, such as plasticizers and stabilizers, which can leach into the environment and further damage ecosystems. Recycling plastic bags also presents challenges, as the process requires significant water consumption, contributing to water wastage. Improper disposal of plastic bags in landfills or through illegal dumping leads to soil pollution, as plastic takes centuries to decompose, contaminating the ground and affecting plant and animal life.

Beyond environmental concerns, plastic bags create clutter and storage issues, as they often accumulate in homes and workplaces, taking up space and contributing to household waste. The overall threat to wildlife remains one of the most pressing issues, as plastic bags continue to endanger a wide range of species, further disrupting ecosystems. These environmental and health drawbacks emphasize the urgent need for better management strategies, enhanced recycling systems, and the development of sustainable alternatives to mitigate the negative impacts of plastic bags on the environment [16].

RESULT & DISCUSSION

The results obtained from the experiments conducted on plastic waste via pyrolysis are presented below. Various properties of the plastic waste were tested using different instruments, and the measured values are summarized in Table 3. These properties provide insights into the efficiency of the pyrolysis process in converting plastic waste into fuel oil.

Table 3. Physical Parameter of Oil.

Property	Value	Instrument Used
Ash Content (%)	0.988	Muffle Furnace
Kinematic Viscosity	2.123	Viscosity Meter
Flash Point (°C)	41	Flash Point Tester
Fire Point (°C)	44	Flash Point Tester
Specific Gravity	0.805	Hydrometer

Discussion

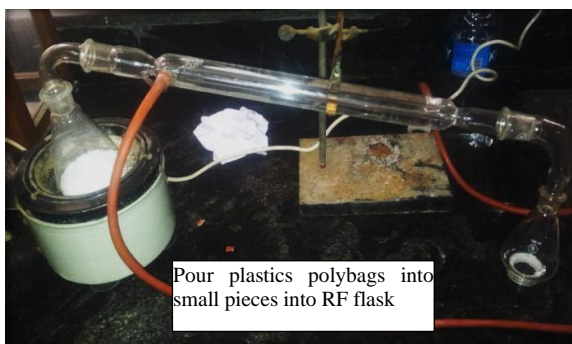
- *Ash Content:* The ash content of 0.988% indicates that the plastic waste converted via pyrolysis produces a relatively low amount of non-combustible residue. This is a favourable result, as it suggests that the pyrolysis process is effective in breaking down plastics without leaving behind a significant amount of waste.

- *Kinematic Viscosity:* The kinematic viscosity of 2.123 measured using the viscosity meter is an important parameter for assessing the flow behaviour of the resulting fuel oil. This value suggests that the fuel oil produced through pyrolysis has a moderate viscosity, which is typically suitable for use in engines or as an alternative energy source.
- *Flash and Fire Points:* The flash point of 41°C and the fire point of 44°C indicate the temperature range at which the produced fuel oil can ignite or catch fire. These values are relatively low, indicating that the fuel oil produced through pyrolysis is flammable and can be used as an energy source. However, the low flash and fire points also emphasize the need for careful handling and storage to prevent accidents.
- *Specific Gravity:* The specific gravity of 0.805 is an important property for assessing the density of the fuel oil. This value is slightly less than water (which has a specific gravity of 1), suggesting that the fuel oil is lighter than water, which is typical for hydrocarbon-based oils produced via pyrolysis (Table 4).

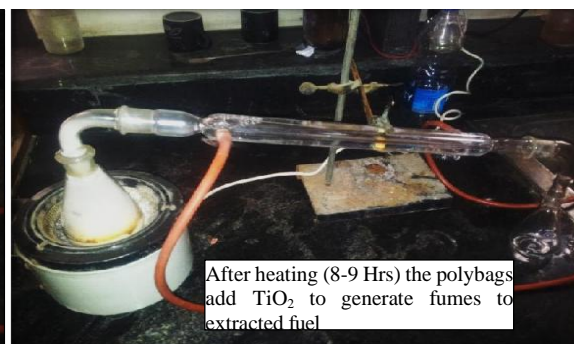


Heating mental with round bottom flask & condenser

Pour plastics polybags into small pieces into RF flask



Pour plastics polybags into small pieces into RF flask



After heating (8-9 Hrs) the polybags add TiO₂ to generate fumes to extracted fuel



Figure 5. Formation of Oil.

Table 4. Properties of plastic waste by Pyrolysis process into fuel oil.

S.N.	Properties	Value	Instruments
1	Density (kg/m ²)	848	Hydrometer
2	Ash content (%)	0.988	Muffle furnace
3	Kinematic viscosity	2.123	Viscosity meter
4	Flash point(C)	41	Flash point tester
5	Fire point(C)	44	
6	Specific gravity	0.805	hydrometer

CONCLUSION

The results from the pyrolysis process indicate that plastic waste can be effectively converted into fuel oil with desirable properties such as low ash content, moderate viscosity, and a low flash and fire point. These findings suggest that pyrolysis could be a viable method for both waste management and alternative energy production. However, additional research is necessary to enhance the efficiency and safety of the process for industrial applications. By exploring new methods, refining existing techniques, and addressing potential risks, these studies can help optimize the process, making it more reliable and scalable for widespread use. This will not only improve its performance but also ensure that it meets the standards required for large-scale industrial implementation, while minimizing any associated hazards.

Recommendations

Based on the results and findings of the pyrolysis process for converting plastic waste into fuel oil, the following recommendations are proposed to improve the process and expand its potential applications:

1. *Further Research on Pyrolysis of Different Plastic Types:* Further research should be conducted on the pyrolysis of different types of plastics such as PET (Polyethylene Terephthalate), HDPE (High-Density Polyethylene), and others. By exploring the pyrolysis of various plastics, we can better understand their behavior during the process and optimize it for different plastic waste materials. Additionally, using locally available technology and materials for pyrolysis can help make the process more cost-effective and accessible, especially in developing regions.
2. *Use of Stainless Steel Instead of Mild Steel:* It is recommended to use stainless steel in place of mild steel for the construction of the pyrolysis reactor. Stainless steel has higher resistance to rusting and corrosion, which would increase the durability and longevity of the reactor. Additionally, stainless steel has better heat conductivity properties, which can improve the efficiency of the pyrolysis process by ensuring better heat transfer during the breakdown of plastics.
3. *Recirculation of Excess Gas to the Furnace Region:* Recirculating excess gases back into the furnace region can help conserve fuel and enhance the overall energy efficiency of the pyrolysis process. Excess gases are often generated that the condenser cannot condense, but these gases remain flammable and can be used as an alternative heating source. This would reduce fuel consumption and increase the sustainability of the process.
4. *Use of CFD Simulation for Accurate Analysis:* Computational Fluid Dynamics (CFD) simulations can be utilized to provide a more precise and detailed analysis of the pyrolysis process. By modeling the flow, heat transfer, and chemical reactions involved, CFD simulations allow for a deeper understanding of the process dynamics. This can help identify optimal conditions, improve efficiency, and predict potential issues, ultimately leading to enhanced performance and safety in industrial-scale pyrolysis operations.
5. CFD simulations can help model heat transfer, fluid flow, and other key parameters in the reactor, providing a deeper understanding of the pyrolysis reactions and helping to optimize reactor design and operating conditions for better yield and efficiency.
6. *Incorporation of a Stirring Mechanism in the Pyrolysis Reactor:* Incorporating a stirring mechanism into the pyrolysis reactor can improve the heat distribution and ensure uniform processing of the plastic waste. This would potentially increase the yield of pyrolysis oil and reduce the formation of unwanted by products. Stirring mechanisms can play a crucial role in enhancing

reaction rates and improving overall process efficiency in pyrolysis. By ensuring better mixing of the materials, stirring promotes uniform heat distribution and increases the contact between the plastic feedstock and the necessary catalysts, if used. This enhanced mixing accelerates the breakdown of polymer chains, leading to faster decomposition and higher yields of desired products. Additionally, consistent agitation can help prevent the formation of hot spots and ensure that the process operates smoothly, making it more efficient and effective at larger scales.

7. *Blending Pyrolysis Oil with Diesel*: The properties of pyrolysis oil, such as density and viscosity, could be improved by blending it with diesel. This could make the pyrolysis oil more suitable for use in existing diesel engines, improving its practical applications. Further studies should be conducted to determine the optimal blending ratios and their effects on engine performance, efficiency, and emissions.

By implementing these recommendations, the pyrolysis process for plastic waste could be further optimized, leading to improved efficiency, sustainability, and scalability, thereby contributing to more effective waste management and alternative fuel production.

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