Comparative Study of Pyro-Oil Yield from Individual Plastics vs. Mixed Plastic Waste

ABSTRACT

Addressing the pressing challenge of sustainable waste management amidst an alarming annual output of approximately 10 billion tons of plastic waste, this study embarks on a transformative journey. It explores the conversion of plastic waste into a promising fuel source through pyrolysis. The research meticulously examines every stage of the conversion process, commencing from the assortment of varied plastic waste origins to the eventual generation of pyro-oil. By juxtaposing the yields derived from individual plastic categories with those from mixed plastic waste, the investigation aims to pinpoint the optimal plastic ratio conducive to sustainable fuel production. The insights gleaned from this comparative evaluation are poised to revolutionize the conversion paradigm, paving the way for innovative strategies in managing and repurposing plastic waste. Moreover, they hold promise in refining separation methodologies, thereby fostering a more eco-friendly and sustainable approach to waste management and resource utilization.

Keywords: Plastic waste, Pyrolysis, Fuel source, Pyro-oil, Efficient ratio

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

NOMENCLATURE

CO_2 - Carbon dioxide

℃ - Celsius

PET - Polyethylene Terephthalate

PP - Polypropylene

LDPE - Low-density Polyethylene

HDPE - High-density Polyethylene

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF THE PROJECT WORK

Plastic pollution represents an ever-growing concern, impacting both human populations and the natural habitats of wildlife. Coastal communities alone contribute an estimated 1.1 to 8.8 million tonnes of plastic waste into the oceans annually, largely originating from post-consumer plastic packaging. Numerous studies have attempted to quantify the leakage of plastic into the environment, revealing the challenging task of pinpointing precise sources and volumes of this pervasive problem. Despite global initiatives to curb plastic waste generation, environmental losses are projected to surge. Current research forecasts an alarming trend: without substantial interventions, the ocean could witness an influx of 23 to 37 million tonnes of plastic waste annually by 2040, potentially escalating to 155 to 265 million tonnes by 2060. To counter this trend, pyrolysis emerges as a crucial process involving the thermal decomposition of materials, altering their chemical compositions. This method, commonly used in charring wood, employs heat, around 500 °C, without oxygen to convert plastics back into clean, sulfur-free oil. Though the concept of converting plastic waste into oil through pyrolysis isn't novel, it stands as a promising solution. With oil production declining and reserves depleting rapidly, the need for alternative energy sources intensifies. Pyro-oil, derived from this process, emerges as a potent substitute, especially within industrial sectors. Its high calorific value renders it a favorable alternative to conventional industrial fuels like furnace oil or industrial diesel. Pyro-oil not only serves as an energy source but also as a feedstock for refining diesel fuel through distillation. Its versatility holds value in regions facing scarcity in traditional oil resources, presenting a viable and sustainable solution amidst a landscape of high plastic pollution rates.

PLASTIC WASTE MANAGEMENT TAKING PLACE WITHIN INDIA

The Indian peninsula has been at the top of the list when it comes to waste disposal into the ocean. Among Indian states, Goa has been instrumental in converting plastic waste into fuel.Two plants in Goa’s Bicholim and Sonsoddo have been set up under the public private partnership (PPP) model with Bangalore-based M K Aromatics Ltd. Goa, which generates nearly 66 metric tons of plastic waste every day, has ample plastic waste converted to fuel. The two plants, functional since 2016, have been instrumental in converting plastic waste into fuel. The amount of Plastic disposed into the Ocean by rivers is best depicted by figure 1.

Figure 1:Plastic released into the ocean by rivers in Karnataka.

PLASTIC WASTE MANAGEMENT TAKING PLACE GLOBALLY

Around 400 million tons of plastic waste are produced by humans every year. That's roughly the weight of all humans on the planet - and plastic production is projected to be going up. From this size, 9-10 million tons end up in the ocean annually. Not only this, when we account for plastic waste that is just thrown up in the dump yard, we will have a lot of plastic that is waiting to be converted into fuel. According to the plastics value chain mapping and assessment, "Egypt generates around 20 million tons of garbage and waste annually, with plastic waste assumed to represent 6% out of the total, distributed over Cairo (60%), Alexandria (16%), the Nile Delta (19%), and other regions including Upper Egypt, Suez Canal, and Sinai (5%). Out of the 970 kilotons of plastic waste generated annually, only a range of 30% is recycled, while 5% is reused, 33% is landfilled, and 32% is left to be burned. The total amount of plastic waste represents 10% of all garbage in Egypt. The amount of plastic that is neither collected nor landfilled is 65%. Countries like Japan, Germany and the United States have already implemented the plastic to fuel conversion process with much success. These three have also been successful in creating business models out of the conversion process, resulting in the conversion model becoming a profitable business one.

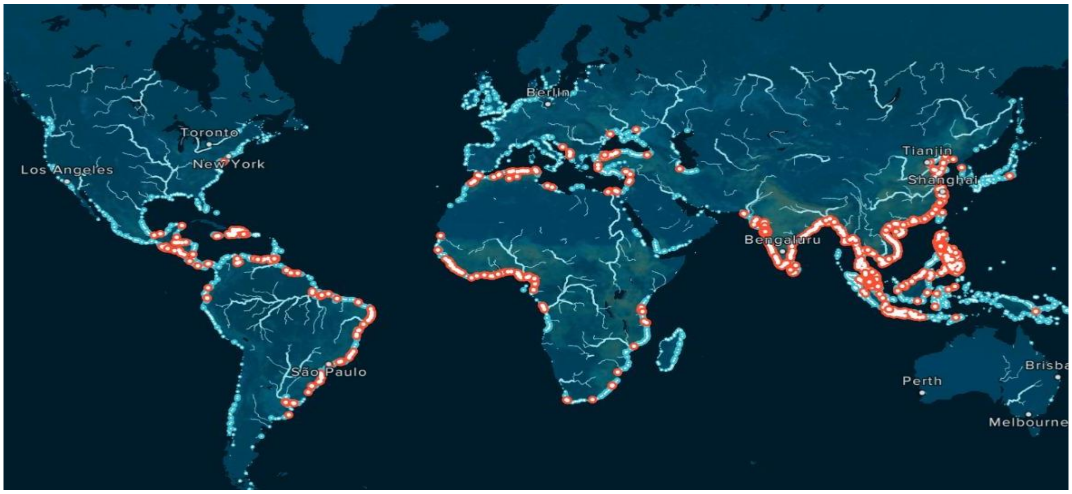

Figure 2:Major regions where plastic is released into the ocean.

1.2 SIGNIFICANCE

The significance of this project is to address the pressing issue of plastic waste management while simultaneously exploring avenues for sustainable energy production. With the world grappling with approximately 10 billion tons of plastic waste annually, there is an urgent need for innovative solutions. By comparing the pyro-oil yield between individual plastic types and mixed plastic waste, this project seeks to shed light on the most efficient methods for converting plastic waste into a valuable energy source. The project aims to contribute to finding the specific ratio at which a higher conversion yield can be obtained using mixed plastic waste. This not only holds the potential to significantly reduce the environmental impact of plastic pollution but also opens up possibilities for generating renewable energy from a previously underutilized resource.

1.3 THESIS STRUCTURE

1. Introduction: This section will provide an overview of the project's objectives, the significance of the research, and an outline of the thesis structure.
2. Literature Review: Here, a comprehensive review of existing literature on plastic waste management, pyrolysis, and conversion processes will be presented. This will serve to

contextualize the research within the broader academic landscape and identify gaps that the project aims to address.

3. Methodology: This section will detail the experimental design, including the selection of plastic samples, the pyrolysis process parameters, and the analytical techniques employed for assessing pyro-oil yield.
4. Results & Discussion: The findings of the comparative analysis between individual plastic types and mixed plastic waste will be presented in this section. Data on pyro-oil yield, efficiency, and any other relevant parameters will be discussed and interpreted. The results will be analyzed, considering their implications for plastic waste management and sustainable energy production. The strengths and limitations of the study will also be addressed, along with recommendations for future research.
5. Conclusion: The thesis will conclude with a summary of the key findings and their significance, as well as reflections on the broader implications of the research for both academia and industry.
6. References: A comprehensive list of all sources cited throughout the thesis will be provided for further reading and validation of the research.

1.4 AIM AND OBJECTIVE

Aim:

To compare yield of pyro-oil obtained from individual plastic wastes to mixed plastic wastes.

Objectives:

1. To pyrolyse individual plastic and mixed plastic waste
2. To find the viscosity, density calorific value and conversion yield of the pyro oil
3. To compare the results and find out optimum plastic waste ratio.

CHAPTER 2

LITERATURE SURVEY

2.1 LITERATURE REVIEW

1. NOVEL TRENDS IN PLASTIC WASTE MANAGEMENT [1]

As regards existing statistics, there is continual increase in plastics consumption because of its wide scope of applications, resulting in increased plastics waste. Plastics are applied in engineering, automotive, construction, medical, aerospace, electrical, robotics, and so on. The rapid growth in global economy and development has also improved the quest and reliance on these materials, resulting in its accumulation in landfills which poses danger to human and animal health, environmental pollution issues such as contamination of groundwater and sanitation challenges. Hence, an effective and sustainable route of treating these waste materials is critical to eliminating these challenges. Alongside the technical and environmental challenges of waste accumulation, there exists varying degrees of political, administrative, economic, and societal issues.

Plastic recycling includes both chemical recycling (pyrolysis) and incineration. The varying routes proposed for waste plastics recycling include primary and mechanical recycling. Primary recycling involves the in-plant waste recycling of scrap materials. Mechanical recycling involves separating plastics from its attendant contaminants and further processing via melting, shredding, or other similar procedures.

Pyrolysis is a thermochemical treatment method which can offer a panacea to these pollution challenges, in addition to recovering valuable energy, and products such as oil and gas. The pyrolysis of PSW has attained prominence, because of its numerous advantages channeled toward alleviating environmental pollution, and reducing plastic products carbon footprint through the minimization of carbon monoxide and carbon dioxide emission, in comparison to combustion and gasification.

Plastics re-utilization has some benefits including (i) fossil fuels conservation. This is because plastics production uses about 4–8% of global oil production, composed of 4% feedstock during conversion, (ii) energy reduction and MSW, and (iii) release of CO_2, NO_x, and SO_2.

To conclude this research paper talks about the growing need for plastic management in depth as well as multiple ways of plastic management. Pyrolysis is one of the best methods suggested as it helps produce oil and fuel from plastics, helping reduce plastics and making useful fuel out of it.

2. PLASTIC WASTE MANAGEMENT: A REVIEW OF PYROLYSIS TECHNOLOGY [2]

Pyrolysis is the thermal degradation of plastic waste at different temperatures (300-900°C). This degradation turns the plastics into fuels. Pyrolysis can be slow, fast or flash depending upon the heating rate with slow giving mainly solid char, fast giving liquid fuel and flash giving gases and bio-oil as main products respectively.

Table 1: Properties of liquid fuel from pyrolysis of single plastic feed

Plastic fuel	Density,40ºC (g/cm^3)	Viscous 40ºC	Flash Point(ºC)	Calorific Value(mJ/kg)	Appearance
HDPE	0.800-0.920	2.42-2.52	40-48	45.4	Light oil, Brown
LDPE	0.768-0.8020	1.65-1.801	50	39.1	Light oil, Brown
PP	0.767-0.8	2.72	31-36	40	Light oil, Yellow
PET	0.087-0.9	NA	NA	28.2	Light oil, Brown
PS	0.85-0.86	1.4 at 50ºC	28	43	Light oil, deep Brown

The advantages of using pyrolysis are its high heating value alongside its potential of being used for multiple types of feed. We also see their elemental analysis and notice the presence of sulphur and nitrogen alongside the usual suspects of carbon and hydrogen.

One of the few banes of using pyrolysis is the presence of high sulphur content in the liquid fuel, it being used in automobile industry would release sulphur dioxide in the air causing acid rain plus a low flash point which would mean high volatile compounds being present which are hard to transport.

Thus, we see what pyrolysis is, its advantages, disadvantages and seeing the properties of fuels obtained from pyrolysis of different plastics noting HDPE as one of the best sources of fuels among them.

3. PYROLYSIS OF WASTE INTO FUEL [3]

Pyrolysis is the process of thermal decomposition of plastics in an inert atmosphere and at a high temperature. In this process, the chemical composition of plastics is converted to hydrocarbon compounds and is an irreversible process. The plastics which are used in this process are mainly HDPE, PP, PE, and LDPE which are converted into fuel. The following setup was used for the process to take place.

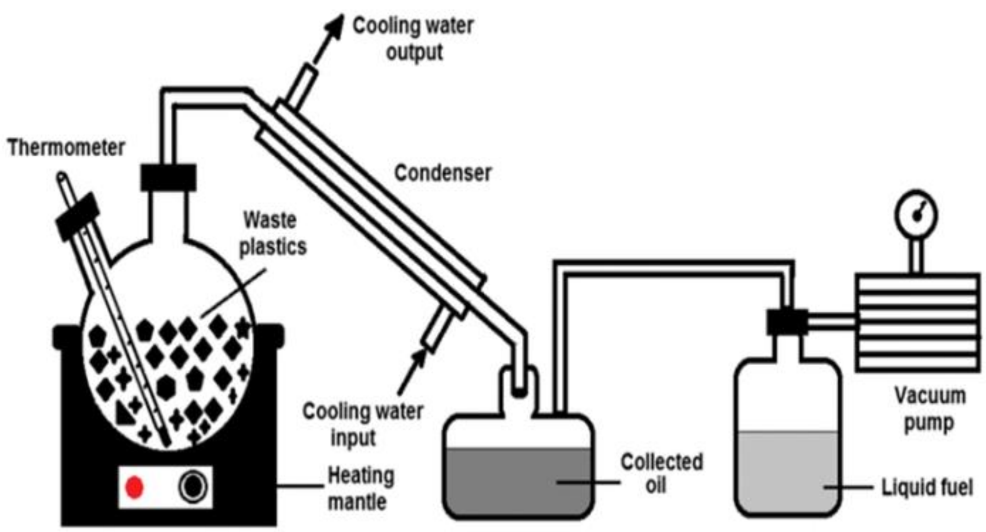

Figure 3:Pyrolysis Experimental setup

The container to be heated is kept on the fire with the test tubes or pipes connected to the container, a digital thermometer is used for measuring the temperature of the container(if needed), the test tubes are further divided for different separation and at the end of the test tube a container in which the fuel will collected is connected, a condenser(in some cases or if needed) is kept surrounded to the test tube for condensing the fuel and a pyrolizer for the process of pyrolysis. The plastic is put in the reactor and is heated at a constant temperature. The gases are evaporated and cooled in the condenser with the help of cool water. The condensed oil is collected, and fuel is obtained.

After carrying out the experiment we get to know about the physical properties of fuel waste plastic

Table 2:Physical properties of fuel derived from waste plastics.

Characteristics	Fuel
Flash point(ºC)	81
Fire Point (ºC)	90
Viscosity @(40ºC)	3.812
Density(kg/m³)	823
Calorific Value(kJ/kg)	46888

From the experiment, it can be concluded that burning 1 kg of plastic can easily yield 600 to 750 ml of diesel fuel. The characteristics of the fuel are noted and seen by turning plastic into fuel, we can reduce atmospheric CO_2 emissions by 80% and burn 1 kg of plastic in the open atmosphere to produce up to 3 kg of CO_2, thus solving both problems. The obtained waste plastic fuel has a higher efficiency than the available fuel in the market and the cost of production is 30% to 40% lower than other fuel production methods.

4. STUDY ON THE PYROLYSIS BEHAVIOR OF MIXED WASTE PLASTICS [4]

This study explores three types of waste plastics and their mixed forms to obtain thermal cracking features, products distribution, and kinetic features. TG analyzer and FTIR were used to observe the decomposition characteristics and functional groups in the volatile fractions of products. The TG furnace was 1st heated at constant rate with temperature range 30-1500ºC with mass of 10-15 mg. The products released from TG during the waste plastics pyrolysis process were blown to FTIR by capillary bundles with constant temperatures of 280ºC and 230ºC.

It was observed that the thermal decomposition of PS and PE started rapidly with both losing 90% wt with little residue and only having one step pyrolysis taking place at relatively lower temperatures, which meant PS had lower thermal stability than PE. PVC had two steps as it showed two DTG peaks. The first process mainly focused on breaking the C-Cl bond, which led to HCl formation. The second procedure mainly included molecular rearrangement, molecular cyclization, and molecular aggregation. The first peak of its TG curve went through 60 wt% weight loss, and the second peak experienced about 20 wt% weight loss.

For both PE and PS, volatile components after pyrolysis were hydrocarbons with mainly alkenes and some saturated hydrocarbons and alkynes. The products of PVC pyrolysis mainly focused on HCl and alkanes at the first stage, then alkenes and aromatic compounds at the next stage.

During the co-pyrolysis of PS with PE, the thermal decomposition of PS was restrained by PE. While for the mixtures of PS with PVC, PS had more rapid cracking rates than pure components. PS and PE both had positive effects during the co-pyrolysis process with PVC. Also from kinetic parameters, we see that all 3 pyrolysis were 1st order reactions.

To conclude, PE and PS showed similar behaviors to pyrolysis as they both decompose in one step releasing mainly alkenes with saturated hydrocarbons and alkynes, losing around 90% wt while PVC had a two-step process releasing HCL and alkanes in the first step losing 60% wt and alkenes and aromatics in the second step losing 20% wt. All 3 reactions were 1st order reactions. PS and PE restrain thermal decomposition with each other while both with PVC showed positive effects i.e., better decomposition.

5. ECONOMIC ANALYSIS OF UNCONVENTIONAL LIQUID FUEL SOURCES [5]

The main area of focus undertaken in this review article is on evaluating the potential of alternative liquid fuel sources to enter the market based on their cost structures. It discusses the historical dominance of gasoline and diesel produced from conventional oil and highlights the relatively limited success of other materials like coal, biomass, and natural gas in the fuel market, with some exceptions in certain regions. Recent interest in unconventional fuel sources has resurfaced due to increased oil prices, prompting some countries to produce liquid fuels from alternative sources.

This revival of interest is primarily observed in countries with competitive advantages in terms of source availability. The term "unconventional liquids" encompasses syncrude, synthetic fuels, and renewable fuels. Syncrude is derived from bitumen in oil sands or shale oil. Shale oil has gained popularity, especially in the USA, as an alternative to crude oil. Synthetic fuels are produced through processes such as coal-to-liquid (CTL), gas-to-liquid (GTL), and biomass-to-liquid (BTL). CTL technologies include pyrolysis, direct coal liquefaction, and indirect coal liquefaction. GTL involves converting natural gas into longer-chain hydrocarbons. BTL technology produces synthetic gases from non-food plant sources. Different cost structures exist for these unconventional liquid fuels, affecting their market entrance prices. Market entrance and shut-down prices are essential cost components for these sources. The market entrance price covers operating costs and provides the expected rate of return to investors. The shut-down price determines the price level at which production stops.

The study delves into the structure of the liquid fuel market, discussing the characteristics of a competitive market and considering factors such as the number of producers, market entry barriers, and the impact of OPEC (Organization of the Petroleum Exporting Countries) on market structure. Unconventional liquid fuels, while alternatives to crude oil, face higher production costs compared to conventional fuels. They become economically competitive only when crude oil prices rise. The analysis of various sources indicates that biofuels, despite their advantages in market entrance and shut-down prices, have more economic potential. GTL presents an attractive option but requires a substantial initial investment. Syncrude sources are competitive but have high capital costs, making them less attractive. CTL is the least preferable due to high market entrance prices, capital costs, and low shut-down prices, posing high risk in an unstable market.

To conclude, the study underscores the potential of unconventional liquid fuel sources as alternatives to conventional oil by evaluating market structures, capital costs, and price criteria, presenting biofuels as the more advantageous option compared to other sources.

CHAPTER 3

MATERIALS AND RESEARCH METHODOLOGY

3.1 PLASTIC TYPES BEING USED

Low-density polyethylene (LDPE) is a type of thermoplastic made from monomer ethylene, it has low melting point and is known for its flexibility, transparency, toughness and packaging applications. Some common examples include squeezable bottles, garbage bags, plastic gloves, and single-use containers.

Figure 4: A piece of packaging foam made from LDPE

Figure 5: A Ziploc bag made from LDPE

High-density polyethylene (HDPE) is a thermoplastic polymer produced from the monomer ethylene. With a high strength-to-density ratio, HDPE is used in the production of plastic bottles, corrosion-resistant piping, geomembranes and plastic lumber. Some common examples of HDPE are plastic bottles, milk jugs, shampoo bottles, bleach bottles, cutting boards, and piping.

Figure 6: HDPE jerry cans resist softening and swelling from aromatic components of fuels

Figure 7: The monobloc chair made using HDPE

Polyethylene terephthalate (PET) is the most common thermoplastic polymer resin of the polyester family and is used in fibers for clothing, containers for liquids and foods, and thermoforming for manufacturing, and in combination with glass fiber for engineering resins.

Figure 8: A finished PET bottle

Polypropylene (PP), also known as polypropene, is a thermoplastic polymer used in a wide variety of applications. It is produced via chain-growth polymerization from the monomer propylene.

Figure 9: Polypropylene lid of a Tic Tac box

Figure 10: Bottle caps made using Polypropylene

3.2 OTHER MATERIALS AND APPARATUS:

1. **Variety of Plastics** like Polyethylene terephthalate, Polypropylene, HDPE and LDPE
2. **Pyrolyser,** the primary reactor for the thermal degradation of plastics
3. **Glass Bottles** to collect samples, aiding separation and analysis of pyro-oil
4. **Water and ice cubes** serving as coolants, condensing the oil vapors during the process.
5. **Containers** to act as condensers and collectors for oil.
6. **Bomb Calorimeter** for characterizing the sample to find the calorific value.
7. **Specific gravity bottle** to find the density of the sample
8. **Brookfield viscometer** to find the viscosity of the sample.

3.4 FLOW DIAGRAM

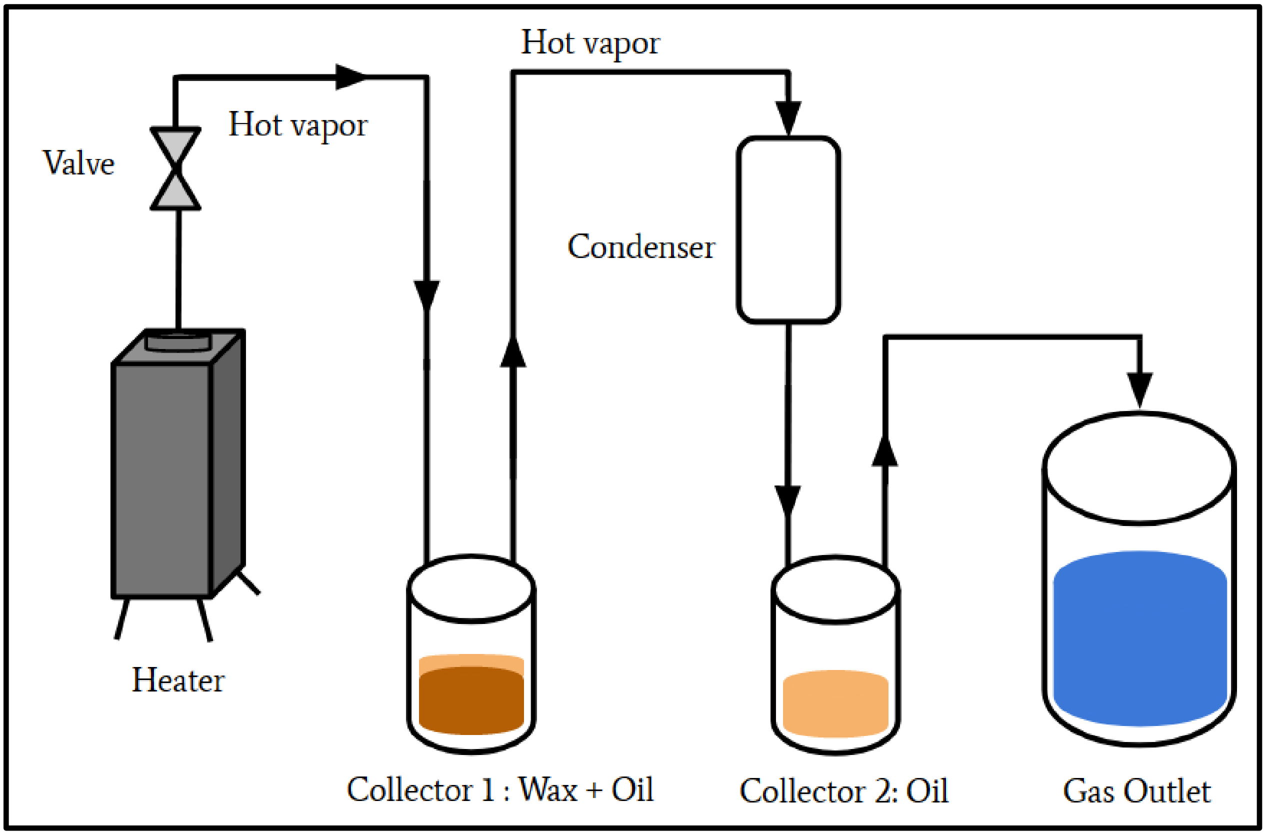

Figure 11: Flow diagram of Pyrolysis process

3.3 PROCEDURE

1. **Plastic Segregation:** Different types of plastics will be meticulously sorted and segregated based on their material composition. Each plastic type will be cut into smaller pieces, ensuring sizes are less than 5 cm for effective processing.

2. **Reactor Setup:**

   Choose an appropriate reactor material (e.g., high-temperature resistant stainless steel) with sufficient capacity.

   Ensure seals meet high-temperature and inert atmosphere requirements.

   Make 2 holes the size of the pipe diameter into top face of 2 containers (C1 and C4).

Make singular holes the size of diameter of the pipe both top and bottom face the other 2 containers (C2 and C3) to make a makeshift condenser.

A pipe is attached to the reactor that connects it to a hole of C1. Another pipe is attached to the 2nd hole of the reactor which after made to pass through C2 and C3, is connected to C4.

Carefully seal the left off spaces with M seal around the holes with pipes passing through the.

1 kg of the specific plastic type will be introduced into the reactor for each experiment.

3. **Temperature Control:** The reactor will be precisely maintained at a constant temperature of 420°C. The desired temperature will be achieved gradually, with a controlled heating rate of 10°C per minute.

4. **Reaction Duration:** The plastic will undergo the thermal degradation process for a standardized duration of 30 minutes.

5. **Oil and Water Separation:** Oil generated during the process will form a distinct layer on the top of the water, serving as a coolant. Gasses produced will be condensed within a specialized pipe, resulting in the formation of an oil layer on the cool water surface.
   The oil-water mixture will be collected and later separated using a separating funnel.

6. **Experimental Cycles:** Multiple experimental cycles (15-20) will be conducted with various plastic types to obtain a diverse range of oils for comprehensive characterization.

7. **Leakage Prevention:** Stringent measures will be implemented to prevent leakages and spill-offs. An adequately sized collection bottle, positioned near the exit valve, will ensure containment and prevent any environmental impact.

8. **Quality Control:** Regular checks and quality control assessments will be performed to ensure the reliability and repeatability of the results.

Figure 12: Plastic Collection

Figure 13: Plastic Segregation (Manually)

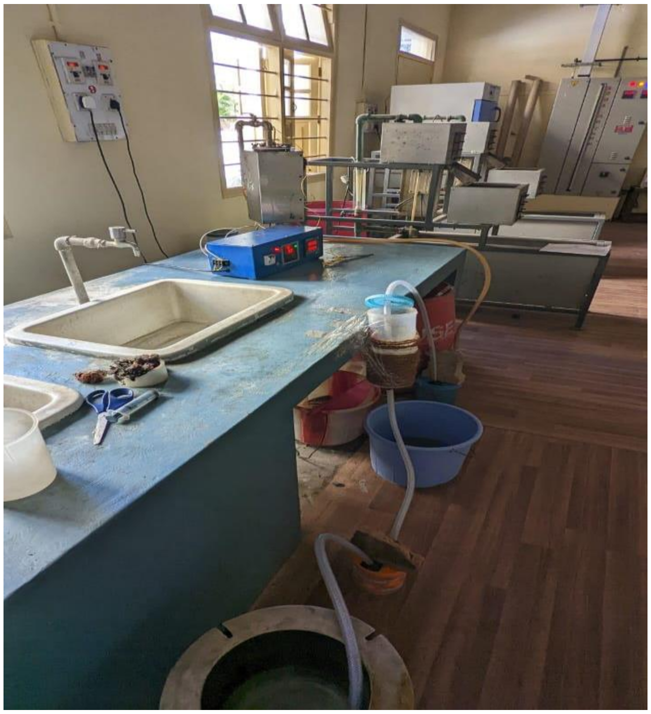

Figure 14: Modified set-up

Figure 15: Container containing Oil + Wax

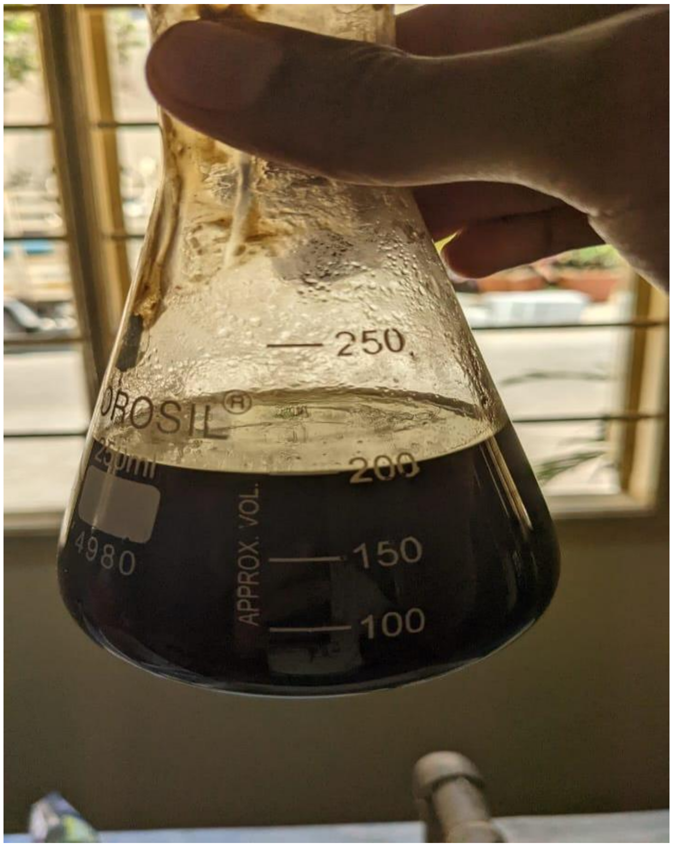

Figure 16: Pyro-oil+Wax Yield

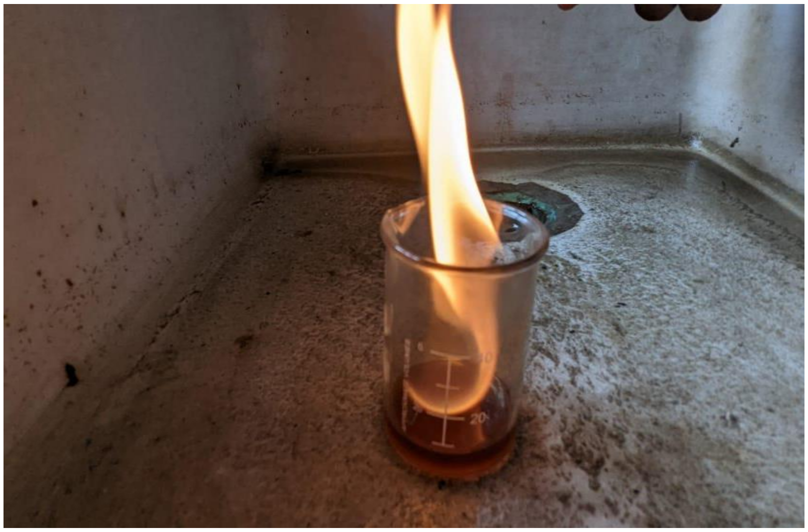

Figure 17: Testing the yielded pyro-oil + wax

3.5 CHARACTERIZATION

1. **Density:**

   The specific gravity measurement is conducted to assess the mass per unit volume of pyro oil in comparison to water. This information is vital for understanding the overall density of the fuel. The density, in turn, influences the feasibility of storing and transporting pyro oil.

   Test Method: Specific Gravity Measurement

   Procedure: Fill a specific gravity flask with pyro oil, measure its weight, and compare it to the weight of an equal volume of water. This helps determine the density of the pyro oil relative to water.

2. **Viscosity:**

   The viscometer test is performed to quantify the flow behavior and resistance of pyro oil. This information is crucial for assessing the suitability of the fuel for various applications. Understanding viscosity guides the design of processing equipment and ensures optimal performance in practical scenarios.

   Test Method: Brookfield Viscometer

   Procedure: Pour pyro oil into the Brookfield Viscometer with pyro oil, and a suitable spindle is put inside the oil, The spindle rotates inside the oil measuring the resistance to the flow and giving the viscosity as a result.

3. **Calorific Value:**

   The bomb calorimeter test is conducted to determine the heat released during the combustion of pyro oil. This information is essential for evaluating the energy content of the fuel. Calorific value data is crucial for understanding the efficiency of the fuel and its potential applications in various industries.

   Test Method: Bomb Calorimeter

   Procedure: Ignite a known mass of pyro oil in the bomb calorimeter, measure the temperature change in surrounding water, and calculate the calorific value. This provides insights into the fuel's energy content.

4. **Conversion Yield:**

The conversion yield calculation is performed to assess the efficiency of the pyrolysis process, determining the amount of pyro oil produced per unit of feedstock. This information is critical for process optimization, resource management, and evaluating the overall sustainability of the production method.

Test Method: Calculation based

Procedure: Measure the volume of pyro oil produced and divide it by the mass of the feedstock used for pyrolysis. This calculation provides a quantitative measure of the conversion yield.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 RESULTS

Iteration no.	Plastic type used	Mass of Feedstock (g)	Mass of Wax obtained (g)	Volume of Oil obtained (ml)	Mass of Solid char obtained (g)	Reactor Temperature (°C)
1	PET	400	37	7	8	380
2	PP	500	241	10	57	380
3	PET	400	42	2	12	420
4	PET	300	31	5	4	400
5	HDPE	300	180	24	8	520
7	PP	500	259	19	52	420
8	PP	250	150	12	25	420
9	PP	300	136.5	15	28	420
10	HDPE	400	298	29	13	520
11	LDPE	400	270.4	21	14	420

12	LDPE	400	278.8	17	19	420
13	MIXED	400	276.7	35	11	480
14	MIXED	400	283.4	27	14	480
15	MIXED	400	280.7	32	17	480

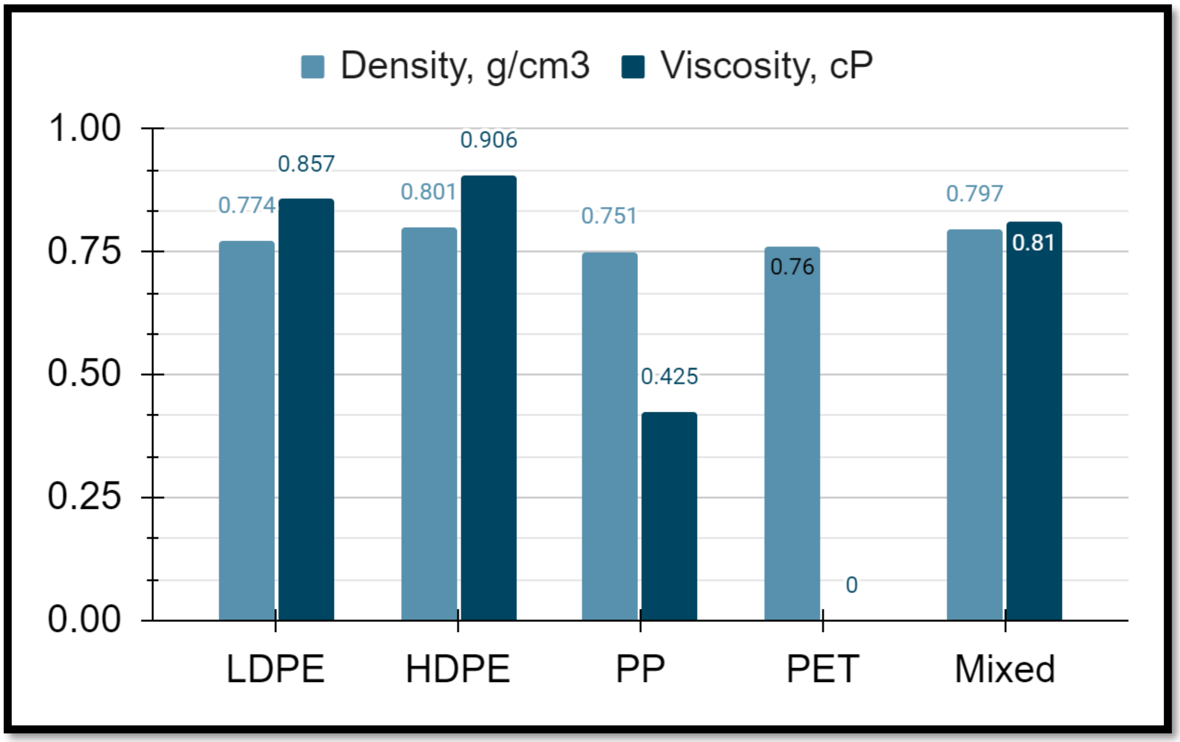

Figure 18: Graph indicating density & Viscosity

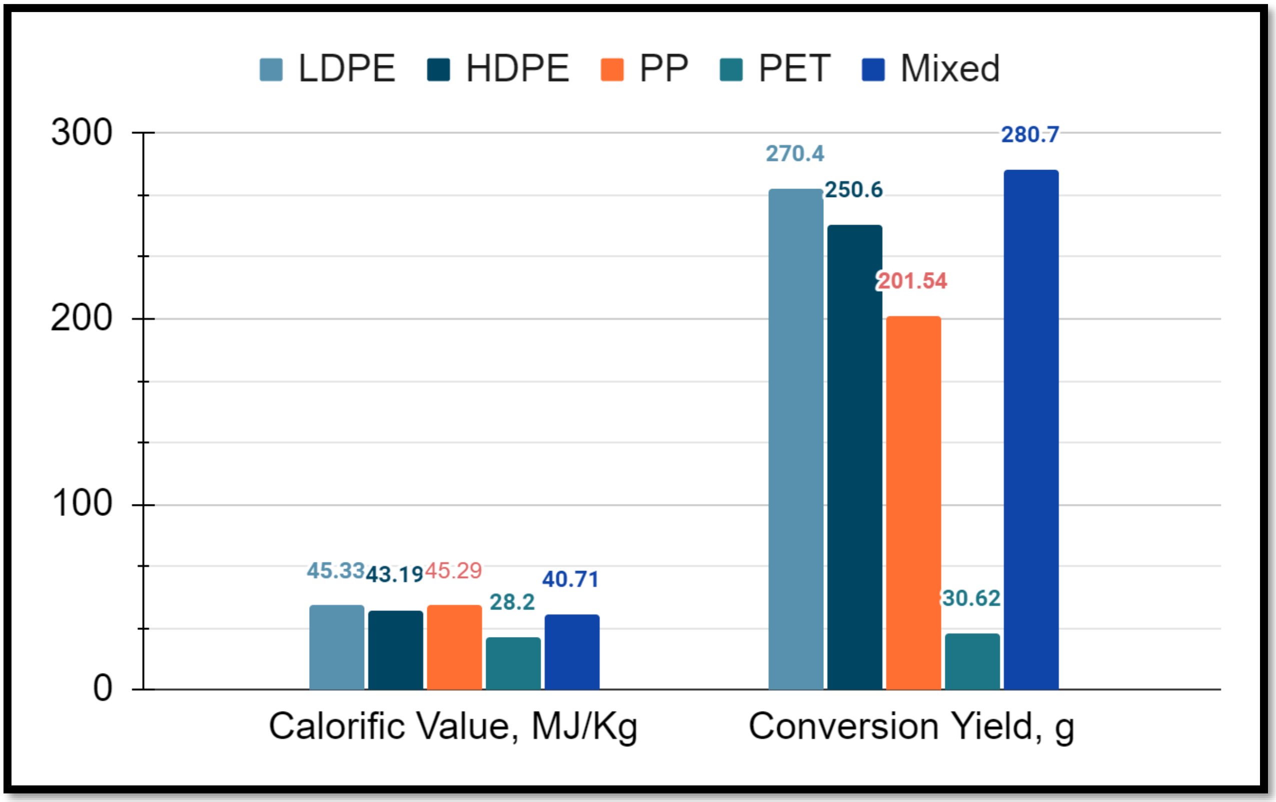

Figure 19: Graph indicating Calorific value & Conversion yield

1. LDPE has the highest conversion yield among the four plastic types (280.7 g) from a feedstock of 400 g.

2. In terms of viscosity, HDPE is more viscous among the other plastic types (0.9 cP)

3. The conversion yield for mixed plastic waste was 280.7 g where the following ratios were considered (in grams) **137:128:114:21**; LDPE: HDPE: PP: PET.

4. Percentage of plastic converted in the pyrolysis process 67.6% (LDPE), 62.6% (HDPE), 50.3% (PP), 7.6% (PET), 70.1% (MIXED).

4.2 DISCUSSION

The table presents experimental results from a series of pyrolysis tests on different types of plastics. Each iteration involves a different plastic type, feedstock mass, and reactor temperature, with measured outcomes including the mass of wax, volume of oil, and mass of solid char obtained. Below is a detailed discussion of the results:

Plastic Types and Feedstock Mass:

- PET (Polyethylene Terephthalate): Tested in three iterations (1, 3, and 4) with feedstock masses of 400g, 400g, and 300g.
- PP (Polypropylene): Tested in five iterations (2, 7, 8, and 9) with feedstock masses ranging from 250g to 500g.
- HDPE (High-Density Polyethylene): Tested in two iterations (5 and 10) with feedstock masses of 300g and 400g.
- LDPE (Low-Density Polyethylene): Tested in two iterations (11 and 12) with a feedstock mass of 400g.
- MIXED: Tested in three iterations (13, 14, and 15) with a feedstock mass of 400g.

Reactor Temperatures:

The reactor temperatures vary significantly across the tests, ranging from 380°C to 520°C.

Output Analysis:

Wax Production:

- Highest Yield: HDPE at 520°C (Iteration 10) with 298g.
- Lowest Yield: PET at 380°C (Iteration 1) with 37g.

Oil Production:

- Highest Volume: MIXED plastics at 480°C (Iteration 13) with 35ml.
- Lowest Volume: PET at 420°C (Iteration 3) with 2ml.

Solid Char Production:

- Highest Mass: PP at 380°C (Iteration 2) with 57g.
- Lowest Mass: PET at 400°C (Iteration 4) with 4g.

Observations:

1. PET:
    a. Lower wax yield at 380°C and 400°C compared to 420°C.
    b. Oil yield is minimal, especially at 420°C.
    c. Solid char production is relatively low in all iterations.

2. PP:
    a. High wax yield at both 380°C and 420°C.
    b. Oil production is moderate, peaking at 420°C.
    c. Solid char production is highest at 380°C and significantly lower at other temperatures.

3. HDPE:
    a. Consistently high wax yield at 520°C.
    b. Oil yield is relatively high.
    c. Solid char production remains moderate.

4. LDPE:
    a. High wax production at 420°C.
    b. Oil production varies but remains moderate.
    c. Solid char production is moderate.

5. MIXED:
    a. High wax production at 480°C.
    b. Oil yield is highest among all tests.
    c. Solid char production varies but is moderate.

6. Temperature Influence: Higher temperatures generally increase wax and oil yields. PET yields the least amount of wax and oil, suggesting it may not be as efficient for pyrolysis compared to other plastics.

7. Plastic Type: HDPE and LDPE show high wax production, making them favorable for pyrolysis processes aiming for wax output. PP also produces substantial wax but with higher char residues.

8. Mixed Plastics: Show significant yields in both wax and oil, suggesting potential for mixed plastic waste management via pyrolysis.

CHAPTER 5

CONCLUSIONS

5.1 CONCLUSION

By analyzing and comparing the constituents of various plastics, the project aimed to identify optimal combinations, foreseeing the purpose of achieving the highest possible conversion yield. This sought-after yield, particularly in the form of pyro-oil, holds promise as a sustainable and crucial fuel source for various industrial operations. Here we see sand is a great addition in the reactor as it increases the conversion yield and makes it an even heating across the plastic wastes. It's noticed that Polypropylene when heated at around 300ºC for 5 hours gives the best yield. The project heralds a new chapter in recycling methodologies by pushing the boundaries of waste separation techniques. Its core ethos lies in the transformative process of converting a substantial volume of plastic waste into valuable, usable products. This endeavor, aiming to address the alarming demands for sustainable solutions, represents a monumental step towards a more environmentally conscious future. The urgency to explore alternative fuel sources is underlined by the rapid depletion of traditional energy reserves, and this project's focus on converting plastic waste into usable fuel stands as a pivotal opportunity to meet this need. In essence, this project not only grapples with the pressing challenge of plastic pollution but also presents a visionary pathway towards sustainability. Its outcomes signify a paradigm shift in waste management practices, offering pragmatic and applicable solutions that not only mitigate environmental concerns but also pave the way for a more sustainable, eco-friendly future, aligning with the global commitment to a greener, cleaner planet. The future scope of this project encompasses deeper exploration and fine-tuning of optimal plastic combinations to enhance conversion yields, an emphasis on refining waste separation techniques for improved recycling processes, and the potential for expanding the applications of pyro-oil as a sustainable energy source across various industries. Moreover, the project's future trajectory involves scaling up the developed methodologies for practical implementation, potentially initiating pilot projects or collaborative ventures with industry stakeholders to assess feasibility on a larger scale.

5.2 SCOPE FOR FUTURE WORK

The future scope of this project encompasses deeper exploration and fine-tuning of optimal plastic combinations to enhance conversion yields, an emphasis on refining waste separation techniques for improved recycling processes, and the potential for expanding the applications of pyro-oil as a sustainable energy source across various industries.

- The project's future trajectory involves scaling up the developed methodologies for practical implementation, potentially initiating pilot projects or collaborative ventures with industry stakeholders to assess feasibility on a larger scale.
- Optimization: could focus on identifying the ideal reactor temperature for each plastic type to maximize desirable outputs (wax/oil).
- Consideration of mixed plastic pyrolysis, given its high output yields, could be beneficial for waste management.
- Product Recycling: Investigate methods to reintegrate pyrolysis products back into the production cycle, contributing to a circular economy. For example, pyrolysis oil can be used as a feedstock for new plastic production.
- Policy and Incentives: Work with policymakers to develop incentives for the adoption of pyrolysis technologies and support regulatory frameworks that promote sustainable waste management practices.
- Oil Upgradation: Develop methods to upgrade the quality of pyrolysis oil to make it more suitable for use as a fuel or chemical feedstock. This may include hydrodeoxygenation, cracking, or other refining techniques.
- Wax Utilization: Investigate potential applications for the wax produced, such as in the production of lubricants, adhesives, or as a raw material in various industries.
- Oil Upgradation: Develop methods to upgrade the quality of pyrolysis oil to make it more suitable for use as a fuel or chemical feedstock. This may include hydrodeoxygenation, cracking, or other refining techniques.
- Wax Utilization: Investigate potential applications for the wax produced, such as in the production of lubricants, adhesives, or as a raw material in various industries.

REFERENCES

1. Idumah, Christopher Igwe, and Iheoma C. Nwuzor. “Novel Trends in Plastic Waste Management.” *SN Applied Sciences*, vol. 1, no. 11, 15 Oct. 2019, https://doi.org/10.1007/s42452-019-1468-2.

2. Eze, Wilson Uzochukwu, et al. “Plastics Waste Management: A Review of Pyrolysis Technology.” *Clean Technologies and Recycling*, vol. 1, no. 1, 2021, pp. 50–69, https://doi.org/10.3934/ctr.2021003.

3. Ram Jatan Yadav, Shivam Solanki, Sarthak Saharna. “Pyrolysis of Waste Plastic into Fuel.” *International Journal of Recent Technology and Engineering*, vol. 9, no. 1, 30 May 2020, pp. 2600–2605, https://doi.org/10.35940/ijrte.a2662.059120.

4. Li, Dan, et al. “*Study on the Pyrolysis Behaviors of Mixed Waste Plastics*.” Renewable Energy, vol. 173, no. C, 2021, pp. 662–674, ideas.repec.org/a/eee/renene/v173y2021icp662-674.html.

5. Erturk, Mehmet. “Economic Analysis of Unconventional Liquid Fuel Sources.” *Renewable and Sustainable Energy Reviews*, vol. 15, no. 6, 2011, pp. 2766–2771, ideas.repec.org/a/eee/rensus/v15y2011i6p2766-2771.html.

6. Meijer ,Emmerik, et al.“RIVER PLASTIC EMISSIONS TO THE WORLD’S OCEANS”*theoceancleanup*.theoceancleanup.com/sources/. Accessed .Nov10,2023

7. SONS, SHIV DIAL. “Supertek, Borosilicate Glass Test Tube with Rim 100 x 25 Mm, 30 Ml Capacity, Superior Heat & Chemical Durability - Pack of 100.” *Amazon.in: Industrial & Scientific*, 27 Oct. 2016, www.amazon.in/Supertek-Glass-Test-Tube-Capacity-Pack/dp/B01MRGA6DM?th=1.

8. FZN. "FZN Reagent Bottles Graduated Storage Borosilicate Glass Bottle with Blue Screw Cap (500 ML) - Set of 1." *Https://Www.Amazon.in/*, www.amazon.in/dp/B0BMM2Y7R7?ref_=cm_sw_r_apan_dp_F34YJ6YQGTN771DGPG7S&language=en-IN&th=1. Accessed 22 Mar. 2024.

APPENDIX

MSDS Data Sheet

Section 1. Identification of substance or mixture

- No specific dangerous chemical were in ingredients/reactant,
- Products include flammable gases escape from the reactor, hot and flammable solid char, flammable pyro oil.

Section 2. Hazard Identification

- Risk of fire breakout
- Risk of burning while handling reaction products and reactor.
- Risk of lung disease on overexposure to toxic gases from pyrolysis.

Section 3. Composition and information on hazardous products

- The reactor cools down to room temperature in 3-4 hrs.
- Pyro oil cools down to room temperature in 15-20 mins.
- Composition of toxic gases mainly include ethene, propene, butadiene and other hydrocarbons.

Section 4: First- aid measures

- Required kit for first aid treatment in case of burning.
- Instant treatment for severe injuries with availability rapid ambulance support.

Section 5: Firefighting measures

- 2 exit routes available for emergencies.
- Preventative Inspections and maintenance.
- Presence of sand and fire extinguishers.

Section 6: Accidental release measures

- Instant evacuation system with 2 exits.
- Preventative handling drills for reactor.
- 5 exhaust and 12 windows for the escape of gases to environment.

Section 7. Handling and storage

- Pyro oil is stored in the borosilicate glass bottle
- Wax is stored in the flask.
- Reactor and clamps handled very carefully using gloves.

Section 8. Exposure controls and personal protection

- Toxic gases exposure minimized with the presence of 5 exhaust.
- Personal protective N95 masks are used in the lab.
- Gloves are used for handling chemicals.

Section 9. Physical and Chemical Properties of Substance Handling

- Pyro Oil:
  - Physical State: Liquid
  - Color: Dark brown to black
  - Odor: Characteristic, pungent
  - Boiling Point: Varies (typically between 150°C and 350°C)
  - Melting Point: Not applicable

- Flash Point: Low (below 50°C, highly flammable)
- Solubility: Insoluble in water, soluble in organic solvents
- Density: Approximately 0.8-0.9 g/cm^3

➢ Handling:

- Volatility: High, may form explosive mixtures with air.
- Flammability: Highly flammable; handle with care to avoid ignition sources.
- Storage: Store in tightly closed containers in a cool, well-ventilated area away from heat sources, sparks, and open flames.

Section 10. Stability and Reactivity

- Stability: Stable under recommended storage conditions.
- Conditions to Avoid: Avoid heat, sparks, open flames, and other ignition sources.
- Materials to Avoid: Strong oxidizing agents.
- Hazardous Decomposition Products: Thermal decomposition can produce toxic fumes including carbon monoxide, carbon dioxide, and other organic compounds.

Section 11. Toxicological Information

- Acute Toxicity: May cause irritation to the eyes, skin, and respiratory tract.
- Skin Contact: Prolonged or repeated contact may cause dermatitis.
- Eye Contact: Can cause severe irritation.
- Inhalation: Inhalation of vapors may cause respiratory irritation, dizziness, nausea, and headaches.
- Ingestion: Harmful if swallowed; can cause gastrointestinal irritation and central nervous system effects.
- Chronic Effects: Prolonged exposure may lead to long-term health effects such as organ damage.

Section 12. Ecological Information

- Ecotoxicity: Harmful to aquatic life with long-lasting effects.
- Persistence and Degradability: The product is expected to be persistent in the environment.
- Bioaccumulation Potential: Potential for bioaccumulation in aquatic organisms.
- Mobility in Soil: Low mobility in soil; may adsorb to sediments and soil particles.

Section 13. Disposal Considerations

- Waste Disposal Methods: Dispose of in accordance with local, regional, national, and international regulations. Incineration or landfill disposal should be conducted at approved facilities.
- Contaminated Packaging: Dispose of as unused product. Do not reuse containers unless properly cleaned.

Section 14. Regulatory Information

- Regulatory Status: Ensure compliance with relevant local, national, and international regulations.
- Hazard Symbols: Flammable, Toxic, Harmful to the environment.

- Risk Phrases: R10 (Flammable), R20/21/22 (Harmful by inhalation, in contact with skin and if swallowed), R51/53 (Toxic to aquatic organisms, may cause long-term adverse effects in the aquatic environment).
- Safety Phrases: S16 (Keep away from sources of ignition - No smoking), S36/37 (Wear suitable protective clothing and gloves), S61 (Avoid release to the environment. Refer to special instructions/safety data sheets).

ANNEXURE