Analysis and Characterization of Oils from the Pyrolysis of Polypropylene, Polystyrene, and Mixed Plastic Wastes.

A thesis
by

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DEPARTMENT OF MECHANICAL ENGINEERING
SONARGAON UNIVERSITY (SU)

SEPTEMBER 2025

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Submitted to the
DEPARTMENT OF MECHANICAL ENGINEERING
SONARGAON UNIVERSITY (SU)
In partial fulfillment of the requirements for the award of the degree
of
BACHELOR OF SCIENCE IN MECHANICAL ENGINEERING

SEPTEMBER 2025

APPROVAL

This is to certify that the project **"Analysis and Characterization of Oils from the Pyrolysis of Polypropylene, Polystyrene, and Mixed Plastic Wastes.".** By Khandker MD. Tarikur Rahman (ID: ME2201026078), MD. Abu Rahat (ID: ME2201026001), MD Mehedi Hasan (ID:ME2201026035), Abu Raihan (ID: ME2201026309), Mahadi Hasan Anik (ID: ME2201026245), has been carried out under my supervison. The Project has been carried out in partial fulfillment of the degree requirement of Bachelor of Science (B.Sc.) In Mechanical Engineering for 2025, its style and contents have been approved.

Signature of the supervisor

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LETTER OF TRANSMITTAL

September 2025

To

Niloy Sarker

Assistant Professor

Department of Mechanical Engineering.

Sonargaon University.

Subject: Submission of Project Report.

Dear Sir,

We are pleased to submit the project report on "Analysis and Characterization of Oils from the Pyrolysis of Polypropylene, Polystyrene, and Mixed Plastic Wastes." It was a great pleasure to work on such an important topic. The project has been done per your supervision instructions and according to the requirements of Sonargaon University.

We expect that the concerned authority will accept the project and we will remain happy to experiment further with what you may feel is necessary.

Thank You

Sincerely Yours,

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DECLARATION

This dissertation has been submitted as a thesis entitled "Analysis and Characterization of Oils from the Pyrolysis of Polypropylene, Polystyrene, and Mixed Plastic Wastes." to the Sonargaon University (SU) in partial fulfillment to the requirements for the degree of Bachelor of Science in Mechanical Engineering, Sonargaon University, Dhaka, Bangladesh. No part of the work referred to in the thesis has been submitted to support an application for another degree or qualification of this or any other university or institute of learning.

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ACKNOWLEDGMENT

We are grateful to all those who have contributed to completing this thesis on"Analysis and Characterization of Oils from the Pyrolysis of Polypropylene, Polystyrene, and Mixed Plastic Wastes.". First and foremost, we extend our most profound appreciation to our thesis advisor, **'Niloy Sarkar'** whose guidance, expertise, and encouragement have been invaluable throughout this research journey.

The authors are also grateful to **'Professor Md. Mostofa Hossain'** Head of the Department of Mechanical Engineering, and all the respected teachers of the Mechanical Engineering Department thank you for your cooperation and significant help in completing the thesis work successfully.

Their insightful feedback, unwavering support, and dedication have played a crucial role in shaping this study and enhancing its quality. We are also thankful to my thesis committee members for their valuable insights, constructive criticism, and scholarly input, which have enriched the content and rigor of this work. We are grateful to the Sonargaon University for providing the necessary resources and facilities for conducting this research and fostering an environment conducive to academic inquiry and intellectual growth. Furthermore, we would like to acknowledge the contributions of **'Niloy Sarkar'** for their assistance in data collection, analysis, and discussions, which have greatly facilitated the progress of this study. We owe a debt of gratitude to our family for their unwavering support, understanding, and encouragement throughout this endeavor. Their love, patience, and belief in us have motivated and strengthened us. Finally, we thank all the individuals, organizations, and institutions contributing to advancing knowledge and innovation in sustainable energy and waste management. Thank you all for your invaluable contributions and support.

Authors

Abstract

The fast rate of plastic waste production has posed a significant environmental concern at the global level. This issue is quite pertinent to my course on sustainability and environmental science as a university student. Polypropylene (PP) and polystyrene (PS) are some of the plastics that make up a large percentage of the municipal and industrial waste, and we have discussed this in our recent lab sessions. This cool, thermochemical, limited or no oxygen, decomposition is known as pyrolysis and promises to convert these wastes to useful liquid fuels. In our most recent project, we were working on the qualitative research of the pyrolytic oils obtained out of the plastic materials consisting of PP and PS, the assessment of their physicochemical properties and the potential use of the fuel source. This is an energy transition module. To determine whether the samples contained any hydrocarbons, aromatics, and other organic compounds, the oils were taken through Fourier Transform Infrared Spectroscopy (FTIR), Gas Chromatography-Mass Spectrometry (GC-MS), and elemental analysis. The results have shown that PP pyrolysis oil has a high proportion of alkanes and alkenes with PS pyrolysis oil mainly comprising of aromatic compounds including those of styrene. The paper shows the promise of using pyrolytic oils as an alternative source of fuel, but the refining and upgrading is required before the fuel can suit industrial usage.

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Chapter 1

Introduction

1.1 Introduction

The rapid growth of plastic production and consumption has led to severe environmental challenges due to the non-biodegradable nature of synthetic polymers. Among various plastics, polypropylene (PP), polystyrene (PS), and mixed plastics such as low-density polyethylene (LDPE) and high-density polyethylene (HDPE) constitute a significant portion of municipal and industrial solid waste. Conventional disposal methods, such as landfilling and incineration, pose environmental risks including soil contamination, greenhouse gas emissions, and the release of toxic by-products. Therefore, the conversion of waste plastics into value-added products has become a vital research focus in the pursuit of sustainable waste management and alternative energy resources.

Pyrolysis, a thermochemical decomposition process carried out in the absence of oxygen, has emerged as one of the most promising techniques for recovering energy-rich oils from waste plastics. The pyrolytic oil can serve as a substitute or blending component for conventional fuels, making the process attractive from both environmental and economic perspectives. However, the quality and composition of the pyrolysis oil depend strongly on the type of plastic feedstock, reaction temperature, heating rate, and catalyst presence. [1]

In particular, polypropylene-derived oils are typically rich in aliphatic hydrocarbons, making them suitable for gasoline and diesel-like applications, while polystyrene-derived oils predominantly contain aromatic compounds, which are valuable as chemical feedstocks. Oils from mixed plastic pyrolysis exhibit a more complex composition, reflecting interactions between different polymer structures during thermal cracking. Understanding these qualitative differences is crucial for optimizing pyrolysis conditions, improving oil quality, and identifying potential applications.[2]

The present study focuses on the qualitative analysis of oils obtained from polypropylene, polystyrene, and mixed plastic pyrolysis. By comparing the physical characteristics, chemical composition, and fuel-related properties of these oils, this research aims to highlight the potential of plastic pyrolysis as an effective waste-to-energy conversion method, while also addressing the challenges associated with the variability of feedstock and product quality.[2]

1.2 Objectives

The main objective of this research is to analyze the qualitative characteristics of oils derived from polypropylene (PP) and polystyrene (PS) pyrolysis in order to assess their potential as alternative energy sources or chemical feedstocks.

The specific objectives are:

- This study aims to produce liquid oil from the pyrolysis of polypropylene (PP), polystyrene (PS), and mixed plastics under controlled conditions.
- Various experimental analyses will be carried out to assess the properties of the produced oils.
- The chemical composition of the pyrolytic oils will be characterized using Fourier Transform Infrared Spectroscopy (FTIR).
- The qualitative characteristics of oils derived from different plastic types will be compared and contrasted.
- The study will also evaluate the potential applications of these oils as alternative fuels or as feedstocks for the petrochemical industry.

Chapter 2

Literature Review

2.1 Overview of Plastic Pyrolysis

Pyrolysis is a thermochemical reaction that warms the polymers under oxygen-restricted circumstances to break them apart, creating three broad products, including the condensable vapors (in the form of liquid oil), non-condensable gas, and char. The amount and structure of every product is greatly determined by the type of polymer, temperature, heating rate, residence time, reactor design and availability of catalysts. Recent reviews point to pyrolysis as a promising route to producing fuel-range hydrocarbon and chemical feedstocks out of plastic waste, with the heterogeneity of feedstocks and the requirement to upgrade the products being significant issues.[3]

2.2 Pyrolysis of Polypropylene (PP)

When subjected to traditional thermal pyrolysis, polypropylene normally yields a high volume of liquid and a low volume of char. The oils that are obtained after processing PP are predominantly composed of aliphatic hydrocarbons, i.e. linear and branched alkanes and alkenes. Their carbon values vary between gasoline-like and diesel like, with the operating temperature, and the residence time. Numerous studies have indicated that the PP pyrolysis oils are a wide blend of C6-C30 hydrocarbons, and generate large fuel-range fractions. This renders polypropylene as one of the most promising singular-polymer feedstock in the production of fuel. Temperature and heating rate are the major variables which influence the product mix. At higher temperature the distribution becomes towards lighter liquids and more non-condensables gases. [2]

2.3 Pyrolysis of Polystyrene (PS)

Compared to the behavior of polyolefins, pyrolysis of polystyrene is a more efficient way to reduce polymer mass and fasten its breakdown into single and oligomeric aromatic compounds, in particular, styrene, and dimers, trimers, and other substituted benzenes. The oils obtained are also high in aromatics and styrenic oligomers making them high in calorific values. They may be used as petrochemical feedstock, re-polymerize or as an aromatics recovery, though they are more aromatic and

may contain impurities, which make them less convenient as a direct substitute to diesel or gasoline. In depth reviews and experimental investigations validate the robust signature of styrene and describe pathways like catalytic pyrolysis and fractionation to improve the PS-derived liquids.[2]

2.4 Pyrolysis of Polyethylene (LDPE & HDPE)

Oils formed by low-density and high-density polyethylene (LDPE, HDPE) are mostly aliphatic as with polypropylene (PP), and can usually contain more long-chain hydrocarbons and waxy fractions depending on temperature. LDPE has a tendency to fracture to a larger combination of branched and straight alkanes and alkenes, but HDPE yields a greater proportion of straight chains. Polyethylene oils may be further processed or cracked down to give transportation fuels or chemical feedstocks. These products are very dependent on the pyrolysis temperature and presence of a catalyst in case the catalytic pyrolysis is utilized.[2]

2.5 Co-pyrolysis and Mixed Plastics (LDPE, HDPE, PP, PS)

The yields and composition are often non-additive, synergistic or antagonistic when mixed plastics are pyrolyzed.

When polymers interact, e.g. radical transfer between polystyrene and polyolefins, polymers can remodel cracking mechanisms and change the aromatics/aliphatics ratio.

The mixed streams of municipal or packaging waste typically provide more complex blend of oils, thereby raising the analysis challenge but also offering potential benefits, say polystyrene could increase aromatic content, which is required in some chemical processes, and studies of kinetics and TGA show that composition and operating conditions can be modelled and to some extent predictable, but overall heterogeneity still renders scaling up and standardisation more difficult.[2]

2.6 Analytical Techniques for Qualitative Oil Characterization

Complementary instrumental techniques are needed to properly characterize qualitatively pyrolysis oils:

- Gas Chromatography Mass Spectrometry (GC 3 -Py-GC-MS): the most common method of identifying and semi-quantifying volatile and semi-volatile substances, including alkanes, alkenes, aromatics, monomers, and oligomers. Recent developments enhance deconvolution and

quantification of highly complex and overlapping pyrolysis products that are produced by mixed waste feeds. PMC

- Fourier Transform Infrared Spectroscopy (FTIR): an efficient method of screening functional groups such as aromatic ring vibrations, C Hö stretches and oxygen containing groups to distinguish broad chemical categories between PS (aromatic) and PP/PE (aliphatic).
- Elemental (CHNS/O) and Physical Property Analysis: elemental composition, density, viscosity, and calorific value are all important in analyzing the potential of the fuel and its stability.
- Thermogravimetric Analysis with FTIR or MS (TG -FTIR, TG -MS): employs this method to examine the modes of degradation and correlate evolved gases to product distributions.[4]

2.7 Common qualitative/analytical techniques

Fourier Transform Infrared Spectroscopy (FTIR) – Identifies functional groups (C–H, C=C, aromatic rings).
Gas Chromatography–Mass Spectrometry (GC–MS) – Separates and identifies hydrocarbon compounds.
Ultraviolet–Visible (UV–Vis) Spectroscopy – Detects aromatic and conjugated compounds.
Elemental Analysis (CHNS) – Determines carbon, hydrogen, nitrogen, sulfur content.
Thermogravimetric Analysis (TGA) – Examines thermal degradation behavior.
Physical Property Tests – Density, viscosity, flash point, calorific value (fuel quality indicators).[2]

2.8 Typical qualitative differences

Property	Polypropylene (PP) Oil	Polystyrene (PS) Oil	Mixed (PP, PS, LDPE & HDPE)
Appearance	Clear, light yellow	Dark brown	Dark, viscous
Hydrocarbon Type	Mostly aliphatic	Mostly aromatic	Mixed aliphatic + aromatic
Odor	Mild petroleum-like	Strong styrene-like	Strong, mixed unpleasant
Quality	Cleaner, diesel-like	High octane but unstable	Lower quality, wide range
Stability	Moderate	Low (polymerizes)	Low
Applications	Diesel substitute, refining	Styrene recovery, gasoline blend	Requires upgrading, crude alternative

Table 2.1: Qualitative differences of Raw Materials

Best Practices

- Clean, shred, and sort plastics before pyrolysis.
- Maintain optimal temperature (PP: 400–500 °C, PS: 350–500 °C).
- Control heating rate and vapor residence time.
- Use catalysts to improve oil quality (optional).
- Follow safety protocols and proper product storage.

Common Pitfalls

- Using contaminated plastics.
- Excessive temperature → more gas, less oil.
- Improper heating rate or long residence → char or secondary cracking.
- Ignoring safety measures.
- Poor storage → oil degradation.

Chapter 3

Methodology:

3.1 Raw Materials

The raw materials used for this study are four common plastic types: Polypropylene (PP), Polystyrene (PS) & Mixed of Polypropylene (PP), Polystyrene (PS), LDPE and HDPE. These plastics are widely used in daily life and contribute significantly to plastic waste. The samples were collected from municipal solid waste streams, cleaned, dried, and shredded before pyrolysis.

3.2 Polypropylene (PP)

Source: Food containers, bottle caps, straws, medicine bottles, packaging films.
Properties: Semi-crystalline, lightweight, resistant to heat, higher melting point compared to LDPE and HDPE.
Reason for Selection: PP is one of the fastest-growing plastic waste streams and produces pyrolysis oils with broad hydrocarbon ranges.



Fig 3.1: Polypropylene (PP)

3.3 Polystyrene (PS)

Source: Disposable cups, cutlery, CD cases, packaging foam (Styrofoam).

Properties: Lightweight, brittle, good thermal insulation, aromatic polymer.

Reason for Selection: PS is widely used in packaging and produces pyrolysis oils rich in aromatics (especially styrene monomers).



Fig 3.2: Polystyrene (PS)

3.4 Size Reduction & Pre-Treatment

Collected plastics are reduced into flakes or granules (5–10 mm) using a granulator or cutting tools. Smaller, uniform size ensures efficient heat transfer during pyrolysis and improves reaction reproducibility.

Washing and cleaning for Remove dirt, food residues, oils, and additives that can interfere with pyrolysis and analytical characterization. Initial cold-water rinse to remove dust and loose contaminants. Detergent wash (0.5–1 wt% non-ionic surfactant) at 40–50 °C for 5–10 minutes with stirring.

Rinse with distilled water until neutral pH is achieved. If adhesive residues remain, small-scale solvent cleaning (ethanol or isopropanol) is applied.

Washed plastics are dried in a convection oven at 60 ± 5 °C for 2–4 hours to remove residual moisture. Moisture can lead to unwanted steam formation, secondary cracking reactions, and reduced oil yield.

3.5 Pyrolysis Setup



Fig 3.3: Pyrolysis unit

The pyrolysis process involved chopped and dried plastic as the raw material introduced into the reactor. A total of 10 kg of plastic was loaded into the reactor.

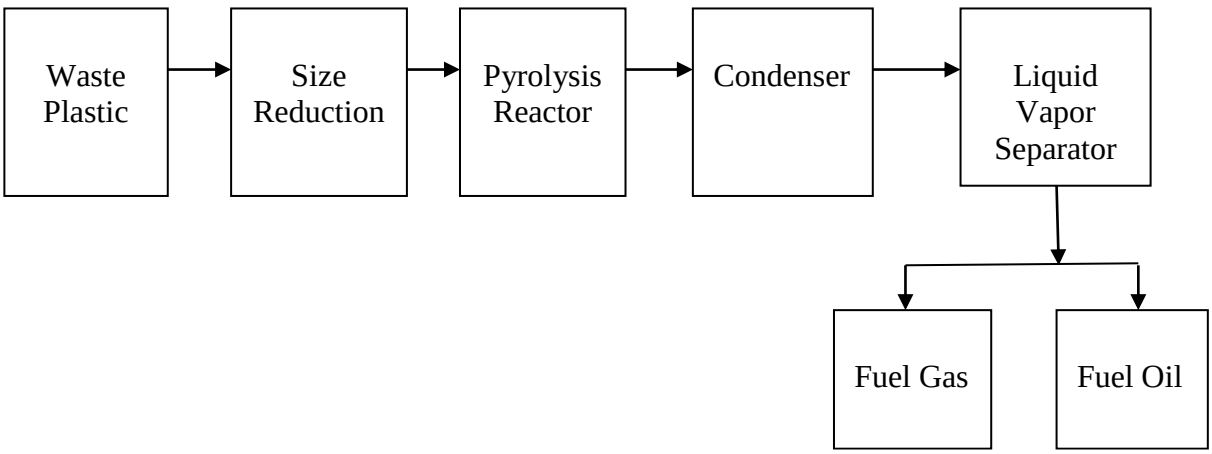


Fig: Flowchart Of pyrolysis process

The pyrolysis process lasted for 4 hours and was carried out at a temperature range of 250-350°C. The energy source used during pyrolysis was a stove that utilized LPG gas. The energy source turned off when the temperature during pyrolysis reached 350°C.

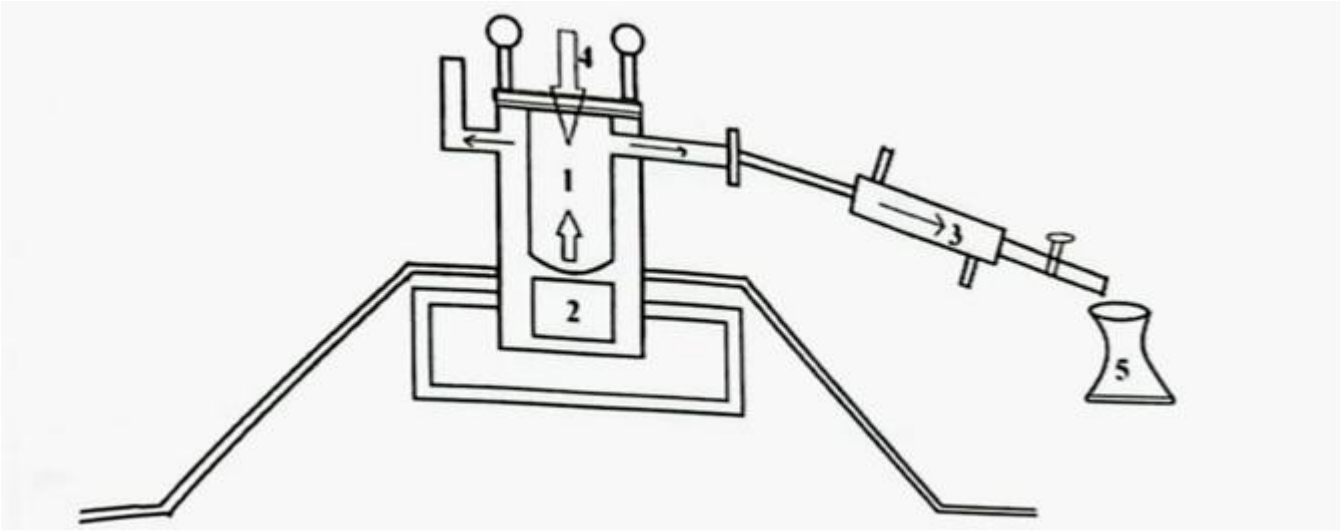


Fig 3.4: Line diagram of Pyrolysis Unit.



Fig 3.5: Temperature Gun

3.6 Pyrolysis Data

Different oil types are extracted from other plastic waste in the pyrolysis reaction. For our thesis, we used Polypropylene, Polystyrene & Mixed of Polypropylene, Polystyrene, LDPE & HDPE plastic for analysis. Finally we produced pyrolysis oil. Such oil acts as the petrol, diesel and kerosene.

3.6.1 Polypropylene (PP)

Total weight of Polypropylene: 01 kg

Total extract oil: 710 ml



Fig 3.6: Pyrolysis oil of Polypropylene

Table NO	Time	Temperature (˚C)	Pressure (kgf/cm2)	Remarks
1.	10.50	30	0.1	Start Time
2.	11.00	93	0.1	(Oil & Gas release both valve close)
3.	11. 10	135	0.4	
4.	11.20	172	0.7	
5.	11.30	182	-	(Oil & Gas release both valve open)
6.	11.40	202	-	Oil Extraction start Time: 11:45 Total Oil at this time- 30 ml
7.	11.50	215	-	Total Oil at this time- 250 ml
8.	12.00	200	-	Total Oil at this time- 480 ml
9.	12. 10	195	-	Total Oil at this time- 650 ml
10.	12. 20	190	-	Total Oil at this time- 710 ml End time

Table 3.1: Experimental Data of Polypropylene pyrolysis oil

Total Residue Weight: 0.245 kg



Fig 3.7: Residue of Polypropylene

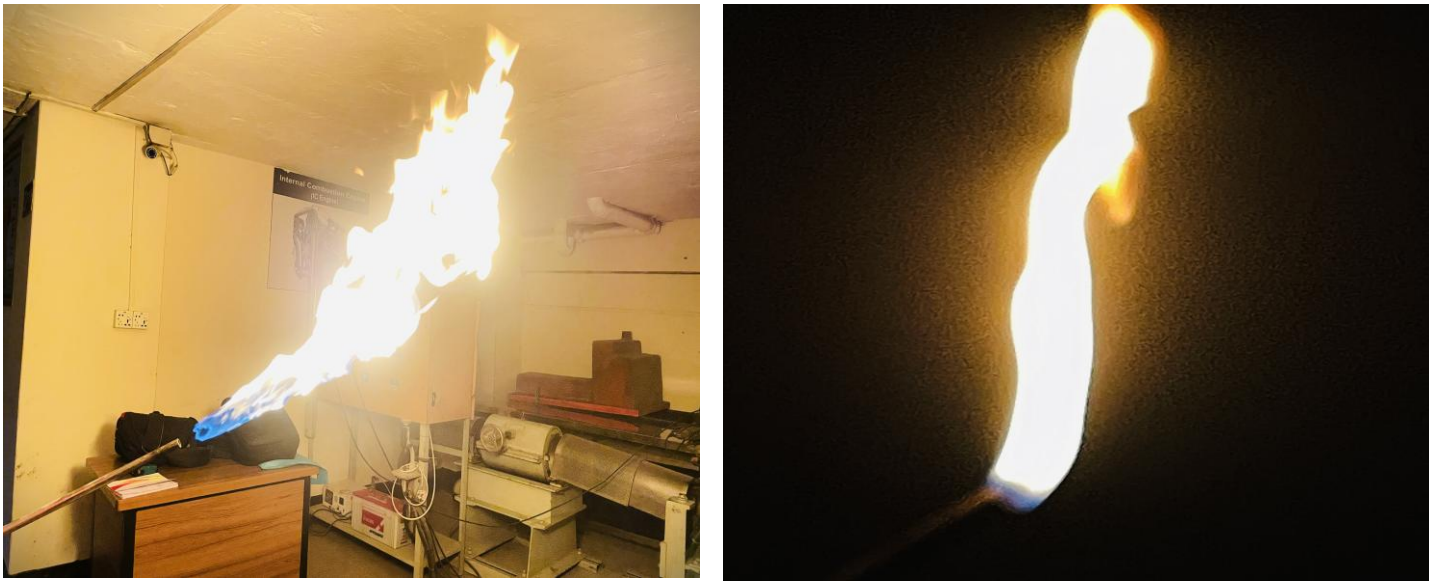


Fig 3.8: Flame of emitted gas.



Fig 3.9: Flame of Polypropylene pyrolysis oil.

3.6.2 Polystyrene (PS)

Total weight of Polystyrene: 01 kg

Total extract oil: 550 ml



Fig 3. 10: Pyrolysis oil of Polystyrene

Table NO	Time	Temperature (˚C)	Pressure (kgf/cm2	Remarks
1.	13:20	30	0	Start Time
2.	13:30	98	0.2	(Oil & Gas release both valve close)
3.	13:40	140	0.6	
4.	13:50	180	0.9	
5.	14:00	173	-	(Oil & Gas release both valve open)
6.	14:10	186	-	Oil Extraction start Time: 14:02 Total Oil at this time- 50 ml
7.	14:20	210	-	Total Oil at this time- 150 ml
8.	14:30	215	-	Total Oil at this time- 380 ml
9.	14:40	210	-	Total Oil at this time- 470 ml
10.	14:50	200	-	Total Oil at this time- 550ml End time

Table 3.2: Experimental Data of Polystyrene pyrolysis oil

Total Residue Weight: 0.351 kg

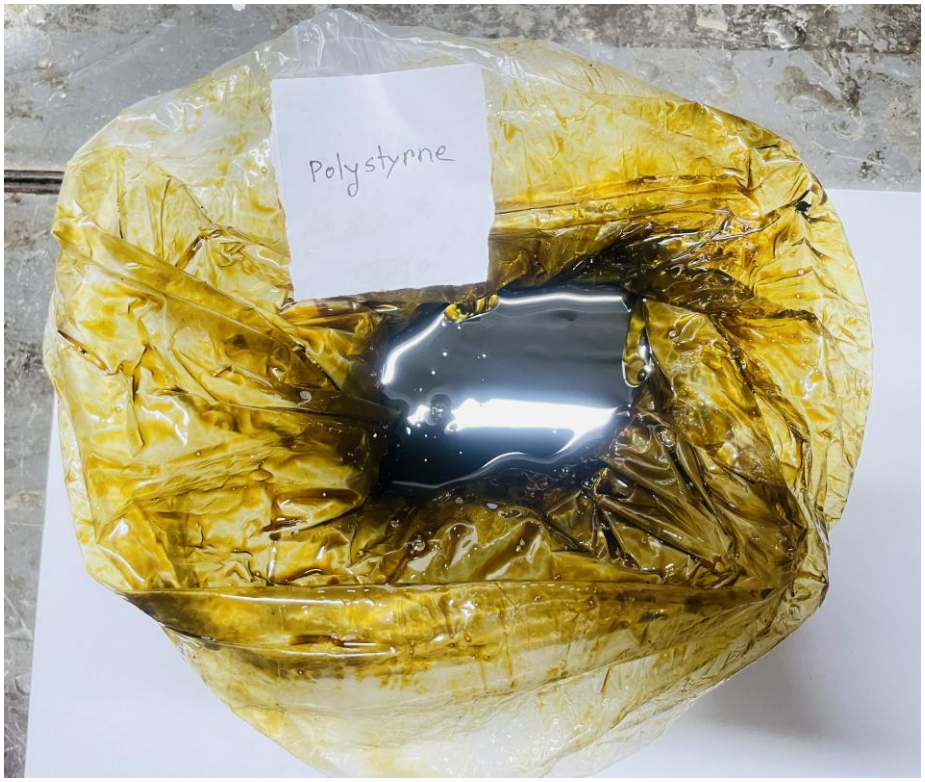


Fig 3.11: Residue of Polystyrene





Fig 3.12: Flame of Emitted Gas



Fig 3.13: Flame of Polystyrene pyrolysis oil.

3.6.3 Mixed (Mixed of LDPE, HDPE, Polypropylene & Polystyrene):

Total weight of LDPE: 0.250 kg
Total weight of HDPE: 0.250 kg
Total weight of Polypropylene: 0.250 kg
Total weight of Polystyrene: 0.250 kg
Total extract oil: 450 ml



Fig 3.14: Pyrolysis oil of Mixed plastic

Table No	Time	Temperature (˚C)	Pressure (kgf/cm^2)	Remarks
1.	13:10	30	0	Start Time
2.	13:20	105	0.2	(Oil & Gas release both valve close)
3.	13:30	141	0.6	
4.	13:40	179	0.9	
5.	13:50	200	-	(Oil & Gas release both valve open) Oil Extraction strat Time: 13:50
6.	14:00	210	-	Total Oil at this time- 70 ml
7.	14:10	206	-	Total Oil at this time- 190 ml
8.	14:20	195	-	Total Oil at this time- 300 ml
9.	14:30	190	-	Total Oil at this time- 450 ml

Table 3.3: Experimental Data of Mixed pyrolysis oil

Total Residue Weight: 0.347 kg



Fig 3.15: Residue of mixed Plastic



Fig 3.16: Flame of emitted gas

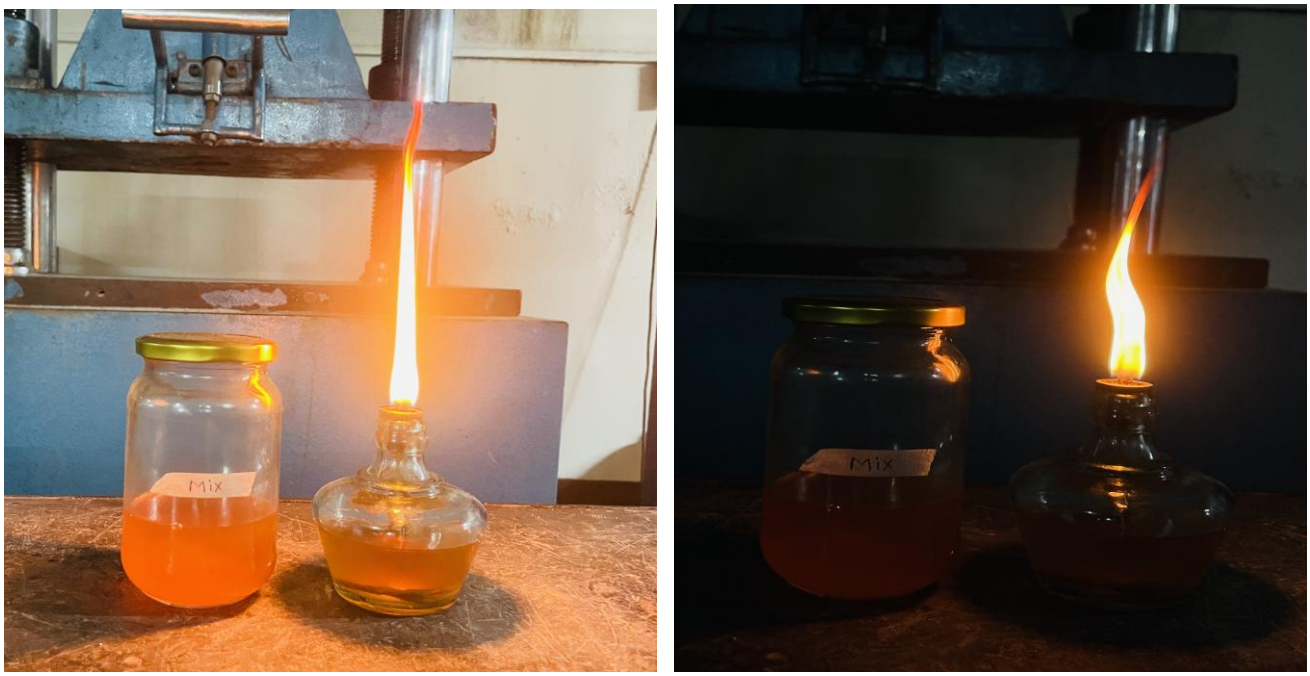


Fig 3.17: Flame of Mixed Plastic pyrolysis oil.

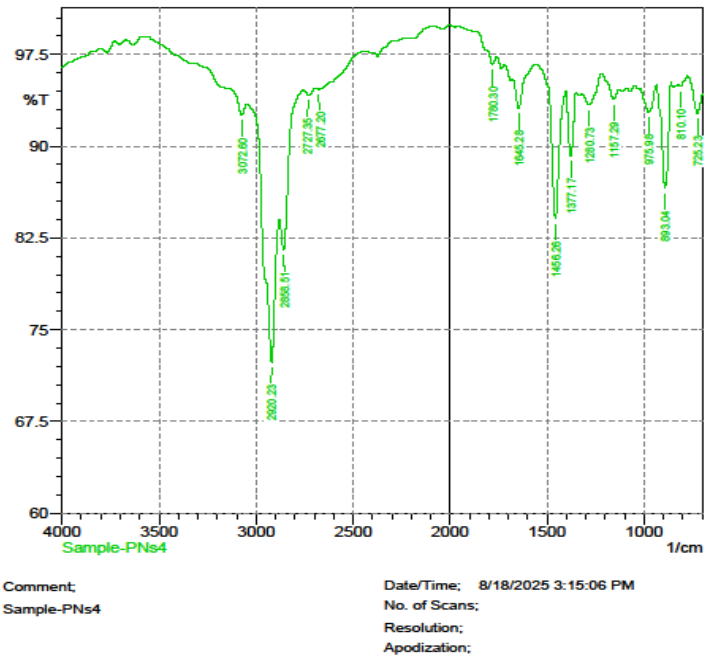
Chapter 4

Result and Discussion

4.1 FTIR Analysis

Fourier Transform Infrared Spectroscopy (FTIR) is greatly used in identifying the chemical composition of the pyrolysis oil produced by waste plastics. During the pyrolysis process, the long polymer chains break down into smaller sized hydrocarbons creating a complex mixture of alkanes and alkenes, aromatics and occasionally oxygenated compounds. FTIR can be used to obtain data on the functional groups that are found in these oils by measuring characteristic vibrational frequencies. The C-H stretching, C=C stretching, and sometimes C=O or O-H absorption regions are typical of the alkanes and alkenes respectively and olefins, aromatics and oxygenated species are found respectively. This type of characterization is necessary to determine the quality of oil, to compare it to conventional fuels, and to determine how useful it is in energy recovery or to a petrochemical product.

4.1.1 Sample PNs4 (Polypropylene feedstock)



SHIMADZU

CARS, DU

	Peak	Intensit	Corr. In	Base (H	Base (L	Area	Corr. Ar
1	725.23	92.668	2.148	775.38	698.23	2.065	0.35
2	810.1	94.878	0.292	819.75	777.31	0.9	0.027
3	893.04	86.543	8.578	935.48	862.18	3.079	1.482
4	975.98	92.766	2.053	1018.41	937.4	2.304	0.431
5	1157.29	93.613	1.236	1219.01	1130.29	2.073	0.213
6	1280.73	93.363	1.582	1323.17	1220.94	2.645	0.415
7	1377.17	89.215	5.23	1402.25	1352.1	1.944	0.699
8	1456.26	84.072	11.15	1558.48	1404.18	5.241	2.205
9	1645.28	93.101	2.681	1676.14	1560.41	2.476	0.465
10	1780.3	96.676	0.915	1807.3	1759.08	0.604	0.1
11	2677.2	94.653	0.273	2694.56	2439.95	4.451	0.279
12	2727.35	94.14	0.503	2754.35	2696.48	1.45	0.067
13	2858.51	81.538	4.165	2877.79	2756.28	5.812	0.559
14	2920.23	72.35	13.981	3045.6	2879.72	12.581	4.113
15	3072.6	92.538	1.264	3269.34	3047.53	5.255	0.289

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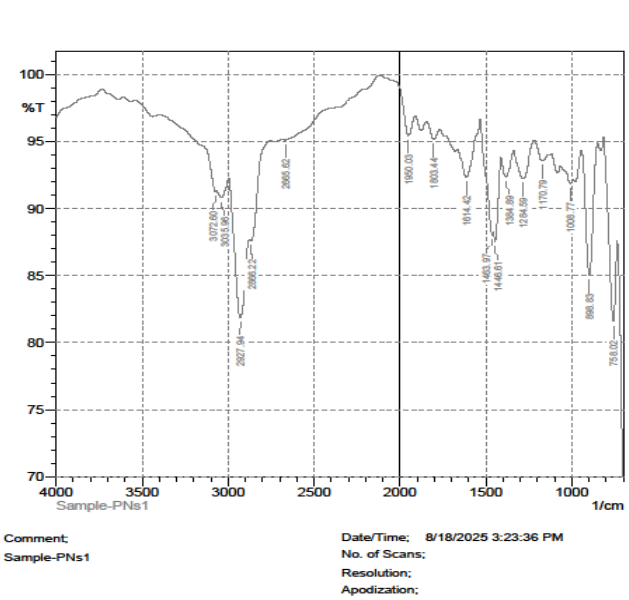
Fig 4.1: FTIR Analysis report of Polypropylene oil by CARS,DU

Peak assignments

Wavenumber (cm^{-1})	Assignment	Interpretation
2920.2, 2858.5	Aliphatic C–H stretching (CH_2/CH_3)	Strong hydrocarbon chain content, typical of PP-derived oils
1456.3, 1377.2	CH_2/CH_3 deformation (bending)	Branched-chain hydrocarbons, consistent with PP cracking products
1645.3	C=C stretching (alkene)	Unsaturated products formed during pyrolysis
1780.3, 1807.0	C=O stretching (carbonyls)	Presence of oxygenated species such as ketones, aldehydes, or esters
725.2	Out-of-plane C–H bending	Could indicate long-chain CH_2 wagging or trace styrene contamination
3072.6	Aromatic/olefinic C–H stretching	Minor unsaturation or contamination

FTIR results show strong aliphatic C–H stretching (2920, 2858 cm^{-1}) and bending modes, indicating that the oil is mainly composed of saturated hydrocarbons. Minor peaks for unsaturation (1645 cm^{-1}) and weak carbonyls (1780–1807 cm^{-1}) suggest small amounts of olefins and oxygenates. Overall, PNs4 resembles diesel in structure, but its olefinic and oxygenated compounds may lower stability, requiring hydrotreatment before direct fuel use.

4.1.2 Sample PNs1 (Polystyrene feedstock)



	Peak	Intensit	Corr. In	Base (H	Base (L	Area	Corr. Ar
1	758.02	81.585	8.114	813.96	736.81	4.749	1.686
2	898.83	85.036	9.558	943.19	850.61	4.307	2.079
3	1008.77	91.858	0.563	1064.71	991.41	2.492	0.07
4	1170.79	93.575	0.866	1217.08	1139.93	2.058	0.175
5	1284.59	92.231	2.453	1338.6	1219.01	3.572	0.757
6	1384.89	92.368	1.632	1411.89	1340.53	2.232	0.339
7	1446.61	87.495	1.998	1456.26	1413.82	1.983	0.262
8	1463.97	88.027	0.846	1531.48	1458.18	2.809	0.224
9	1614.42	92.347	2.948	1664.57	1533.41	3.562	0.981
10	1803.44	95.155	1.044	1843.95	1764.87	1.513	0.184
11	1950.03	95.444	2.023	2113.98	1909.53	1.542	0.087
12	2665.62	95.11	0.223	2686.84	2405.23	4.831	0.279
13	2866.22	87.604	0.545	2873.94	2756.28	4.219	0.107
14	2927.94	81.894	7.766	2995.45	2875.86	7.995	2.459
15	3035.96	90.808	0.899	3064.89	2997.38	2.682	0.169
16	3072.6	91.247	0.156	3396.64	3066.82	6.992	0.009

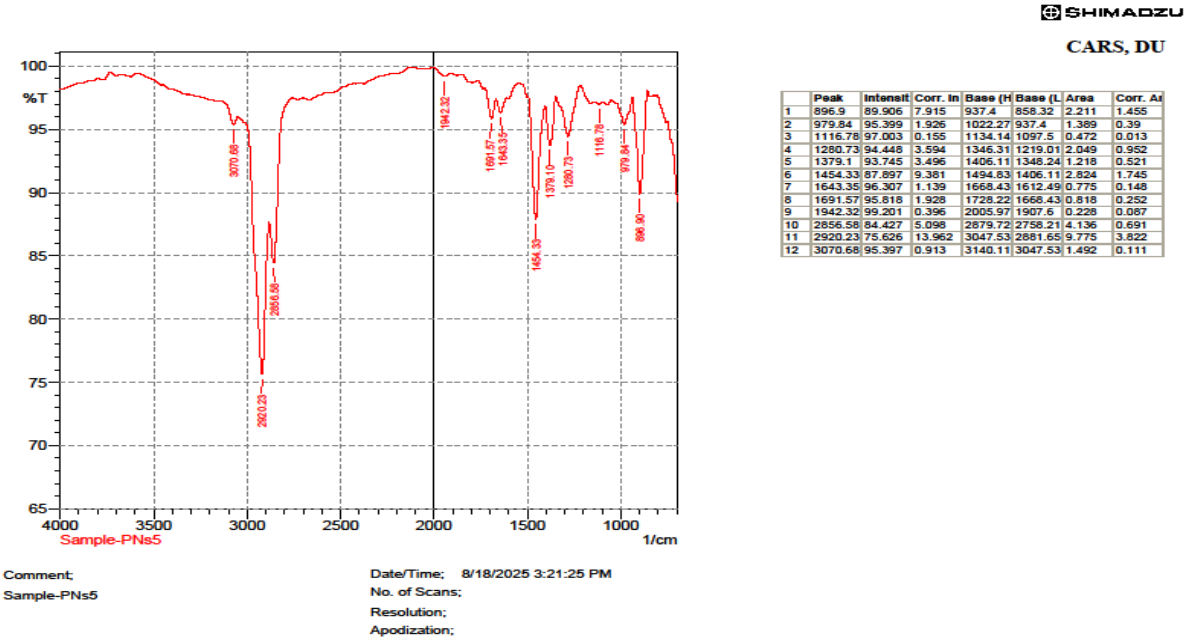
Fig 4.2: FTIR Analysis report of Polystyrene oil by CARS,DU

Peak assignments

Wavenumber (cm^{-1})	Assignment	Interpretation
3072.6, 3035.9	Aromatic C–H stretching	Styrene-derived aromatic hydrocarbons
1614.4, 1580–1500	Aromatic C=C stretching	Confirms aromatic ring structures
758.0, 898.8	Out-of-plane aromatic C–H bending	Characteristic of mono-substituted benzene
2927.9, 2866.2	Aliphatic C–H stretching	Aliphatic fragments from side chains or secondary cracking
1950–2113	Overtones / aromatic combination bands	Common in aromatic systems

The spectrum is dominated by aromatic C–H stretching (3030–3070 cm^{-1}) and ring vibrations near 1600 cm^{-1}, with diagnostic out-of-plane aromatic bands at 758 and 898 cm^{-1}. These features confirm a styrenic, aromatic-rich composition. While this makes PNs1 less suitable for clean fuel use (due to high soot potential), it is valuable as a chemical feedstock for aromatic and styrene recovery.

4.1.3 Sample PNs5 (Mixed plastics: PP, PS, LDPE & HDPE)



	Peak	Intensit	Corr. In	Base (H	Base (L	Area	Corr. Ar
1	896.9	89.906	7.915	937.4	858.32	2.211	1.455
2	979.84	95.399	1.926	1022.27	937.4	1.389	0.39
3	1116.78	97.003	0.155	1134.14	1097.5	0.472	0.013
4	1280.73	94.448	3.594	1346.31	1219.01	2.049	0.952
5	1379.1	93.745	3.496	1406.11	1348.24	1.218	0.521
6	1454.33	87.897	9.381	1494.83	1406.11	2.824	1.745
7	1643.35	96.307	1.139	1668.43	1612.49	0.775	0.148
8	1691.57	95.818	1.928	1728.22	1668.43	0.818	0.252
9	1942.32	99.201	0.396	2005.97	1907.6	0.228	0.087
10	2856.58	84.427	5.098	2879.72	2758.21	4.136	0.691
11	2920.23	75.626	13.962	3047.53	2881.65	9.775	3.822
12	3070.68	95.397	0.913	3140.11	3047.53	1.492	0.111

Fig 4.3: FTIR Analysis report of Mixed plastic oil by CARS,DU

Peak assignments

Wavenumber (cm^{-1})	Assignment	Interpretation
2920.2, 2856.6, 2879.7	Aliphatic C–H stretching	Polyolefin-derived hydrocarbons (from PE, PP)
1454, 1379	CH_2/CH_3 deformation	Typical of long hydrocarbon chains
1643–1691	C=C stretching	Unsaturated/aromatic structures
3070–3072	Aromatic C–H stretching	Styrene-derived contribution from PS fraction
1942–2006	Overtone/combination bands	Minor aromatic signatures
725–899	Out-of-plane CH bending	Mixture of aliphatic chain wagging and aromatic fingerprints

PNs5 exhibits a combination of aliphatic C–H bands (from LDPE, HDPE, PP) and aromatic peaks (from PS), along with minor oxygenates. Its mixed profile positions it between diesel-like and gasoline-like fuels. However, variability in composition and the presence of oxygenated compounds require refining or upgrading for consistent fuel application.

4.1.4 Comparative Summary

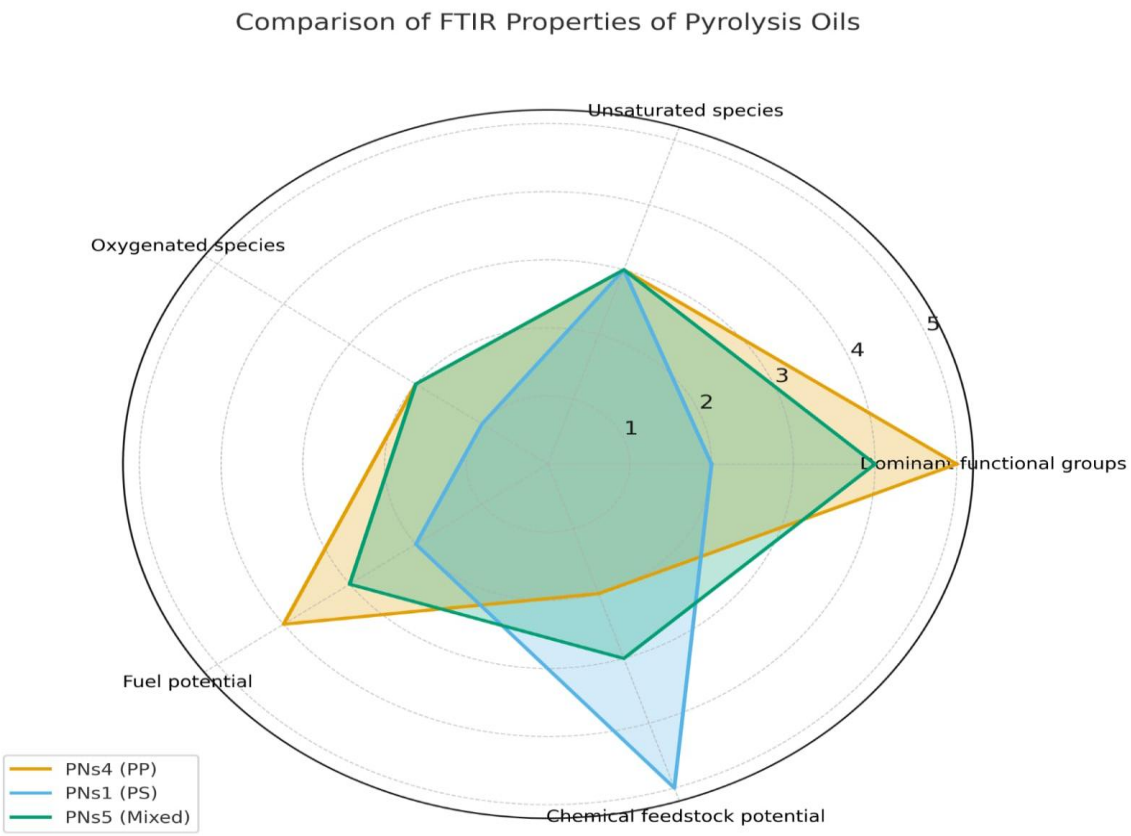


Fig 4.4: Comparison of FTIR of Pyrolysis Oils

Property	PNs4 (PP)	PNs1 (PS)	PNs5 (Mixed)
Dominant functional groups	Aliphatic CH_2/CH_3	Aromatic rings, styrenic CH	Aliphatic + Aromatic
Unsaturated species	Present (1645 cm^{-1})	Present (ring vibrations, weak olefins)	Present
Oxygenated species	Minor (1780–1807 cm^{-1})	Very minor	Minor
Fuel potential	Closer to diesel, needs upgrading	High aromatic, poor cetane	Variable, requires upgrading
Chemical feedstock potential	Low	High (styrene recovery)	Moderate

4.1.5 Comparison of Pyrolysis Oils with Conventional Fuels

PNs4 (PP oil): High aliphatic content and good combustion cleanliness, making it closest to diesel, but oxygenates lower its stability.

PNs1 (PS oil): Dominated by aromatic content, similar to gasoline/furnace oil, but with limited fuel potential due to soot formation.

PNs5 (Mixed oil): Lies in between, showing both aliphatic and aromatic features, reflecting its mixed feedstock origin.

Diesel: Aliphatic-rich, very clean combustion, highest direct fuel potential.

Gasoline: Balanced between aliphatic and aromatic, high fuel potential but moderate combustion cleanliness.

Furnace oil: Strongly aromatic, with high soot emissions, lowest combustion cleanliness.

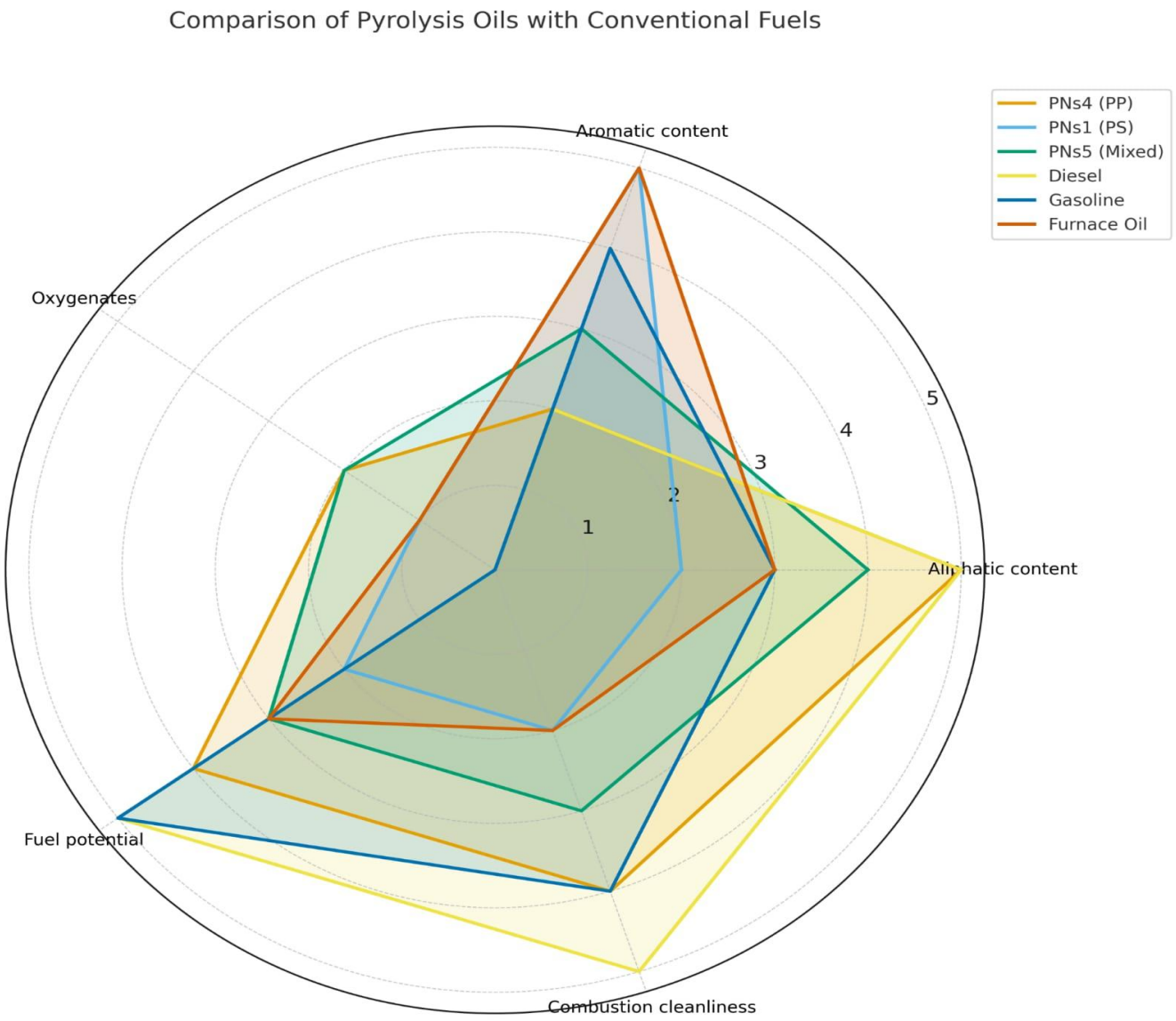


Fig 4.5: Comparison of pyrolysis oil with Conventional fuels

4.2 Flash Point Analysis of Pyrolysis oils

4.2.1 Experimental Data

1.Polypropylene oil:

Oil=3ml

$T_{primary}$= 29.0 ˚C

Sl No	T_{flash} (˚C)	Flash Time
1	44.1	0 minute 47 second.
2	44.0	0 minute 49 second.
3	43.9	0 minute 47 second.

Table 4.1: Experimental data of Flash point of Polypropylene pyrolysis oil.

T_{flash}= 44.0 ˚C

Flash Time= 0 minute 47 second.

2.Polystyrene oil:

Oil=3ml

$T_{primary}$= 29.7 ˚C

Sl No	T_{flash} (˚C)	Flash Time
1	66.1	1 minute 4 second.
2	65.9	1 minute 2 second.
3	66.1	1 minute 5 second.

Table 4.2: Experimental data of Flash point of Polystyrene pyrolysis oil

T_{flash}= 66.0 ˚C

Flash Time= 1 minute 3 second.

3.Mix oil:

Oil=3ml

$T_{primary}$= 29.7 ˚C

Sl No	T_{flash} (˚C)	Flash Time
1	52.1	0 minute 52 second.
2	53.2	0 minute 51 second.
3	52.4	0 minute 50 second.

Table 4.3: Experimental data of Flash point of Mixed pyrolysis oil

T_{flash}= 52.6 ˚C

Flash Time= 0 minute 51 second.

4.2.2 Flash Point Analysis and Comparison

.This section provides the flash point analysis of different plastic pyrolysis oils compared with conventional fuels. Flash point is an essential safety parameter that indicates the lowest temperature at which vapors of a fuel ignite when exposed to a flame

Flash Point Data

Fuel Type	Avg. Flash Point (°C)	Flash Time (s)	Remarks
Polypropylene Oil	44.0	47	Highly volatile
Polystyrene Oil	66.0	63	Most stable among oils
Mixed Oil	52.6	51	Moderate volatility
Diesel	62.0	-	Stable conventional fuel
Petrol	-40.0	-	Extremely volatile

4.2.3 Flash Point Comparison Chart

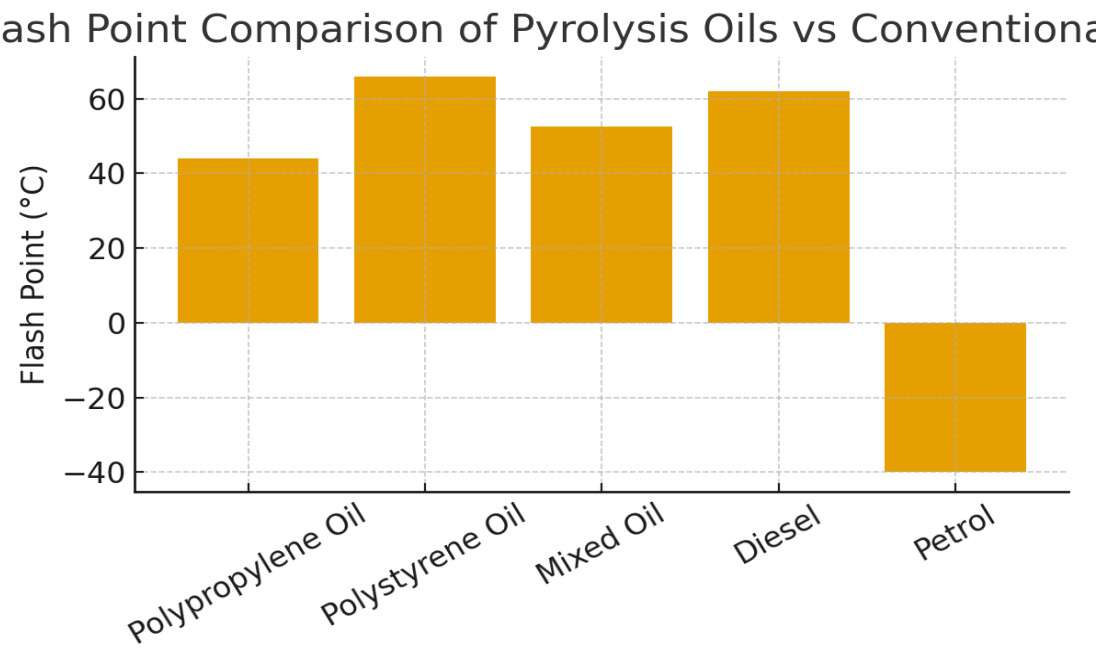


Fig 4.6: Comparison of Flash point between Pyrolysis oils and Conventional fuels

4.3 Viscosity Analysis of Pyrolysis oils

4.3.1 Experimental Data

1. Polypropylene oil:

Total Oil= 5ml

Total Water = 5ml

We know,

$\eta_{oil} = \eta_{water} \times (t_{oil}/t_{water})$

Where,

η_{oil}= Viscosity of oil.

η_{water}= Viscosity of water.

t_{oil} = Time taken by oil.

t_{water} = Time taken by water.

SL No	η_{water} (mPa.s)	t_{oil} (s)	t_{water} (s)	η_{oil} (mPa.s)
1	0.8509	537	462	0.99
2	0.8509	520	470	0.94
3	0.8509	530	466	0.97

Table 4.4: Experimental data of Viscosity of Polypropylene pyrolysis oil

Final Result: (0.99+0.94+0.97)/3 =0.97 mPa.s

2. Polystyrene Oil:

Total Oil= 5ml

Total Water = 5ml

We know,

$\eta_{oil} = \eta_{water} \times (t_{oil}/t_{water})$

Where,

η_{oil}= Viscosity of oil.

η_{water}= Viscosity of water.

t_{oil} = Time taken by oil.

t_{water} = Time taken by water.

SL No	η_{water} (mPa.s)	t_{oil} (s)	t_{water} (s)	η_{oil} (mPa.s)
1	0.8509	529	462	0.97
2	0.8509	520	470	0.94
3	0.8509	538	466	0.98

Table 4.5: Experimental data of Viscosity of Polystyrene pyrolysis oil

Final Result: (0.97+0.94+0.98)/3 =0.96 mPa.s

3.Mixed Oil:

Total Oil= 5ml

Total Water = 5ml

We know,

$\eta_{oil} = \eta_{water} \times (t_{oil}/t_{water})$

Where,

η_{oil}= Viscosity of oil.

η_{water}= Viscosity of water.

t_{oil} = Time taken by oil.

t_{water} = Time taken by water.

SL No	η_{water} (mPa.s)	t_{oil} (s)	t_{water} (s)	η_{oil} (mPa.s)
1	0.8509	592	462	1.09
2	0.8509	590	470	1.07
3	0.8509	594	466	1.08

Table 4.6: Experimental data of Viscosity of Mixed pyrolysis oil

Final Result: (1.09+1.07+1.08)/3 =1.08 mPa.s

4.3.2 Viscosity Analysis and Comparison

Viscosity is a critical parameter that influences the flow behavior of fuels, injection process, and atomization in combustion engines. The viscosity of plastic pyrolysis oils was compared with conventional fuels such as diesel and petrol.

Viscosity Data

Fuel Type	Viscosity (mPa·s)	Remarks
Polypropylene Oil	0.97	Low viscosity, close to petrol
Polystyrene Oil	0.96	Lowest viscosity, easy flow
Mixed Oil	1.08	Slightly higher, moderate flow
Diesel	2.5	Significantly higher viscosity
Petrol	0.6	Very low, highly volatile

Viscosity Comparison Chart

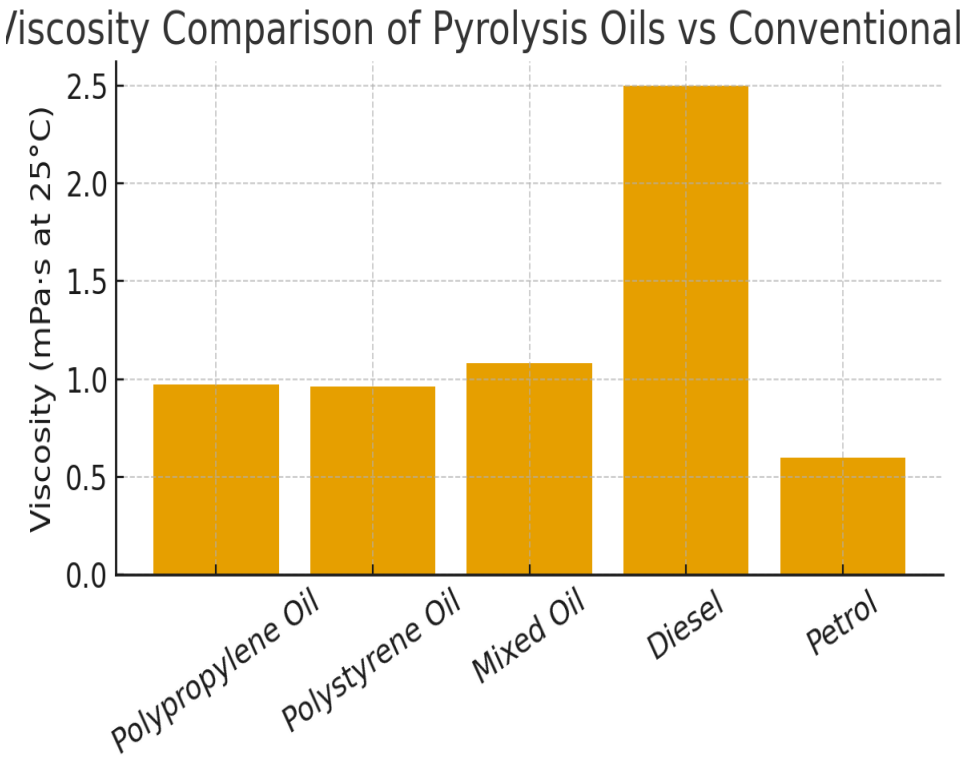


Fig 4.7: Comparison of Viscosity between Pyrolysis oils and Conventional fuels

4.4 pH Analysis of Pyrolysis oils



Fig 4.8: pH Testing

.4.1 Experimental Data

1. Polypropylene : PH-5
2. Polystyrene : PH-6
3. Mix oil : PH-6

4.4.2 pH Analysis and Comparison

The pH value is an important characteristic of fuels, indicating their acidic or alkaline nature. Acidic fuels can cause corrosion in storage tanks, pipelines, and engine components, whereas fuels closer to neutral pH are safer for long-term usage.

pH Data

Fuel Type	pH Value	Remarks
Polypropylene Oil	5	Acidic, corrosion risk
Polystyrene Oil	6	Slightly acidic, safer
Mixed Oil	6	Slightly acidic, safer
Diesel	6.5	Nearly neutral, stable
Petrol	7.0	Neutral, non-corrosive

pH Comparison Chart

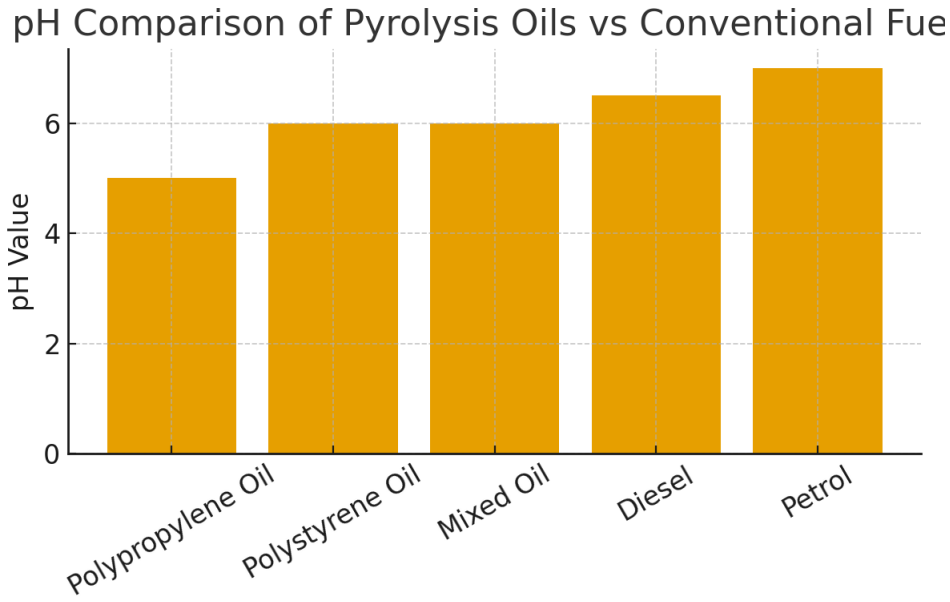


Fig 4.9: Comparison of pH between Pyrolysis oils and Conventional fuels

4.5 Density Analysis of Pyrolysis oils

4.5.1 Experimental Data

1.Polypropylene Oil:

Mass of oil,m= 0.0045 kg

Volume of oil,v = 5×10^{-6} m^3

Density= (m/v)

$=(0.0045/5\times10^{-6})$

$= 900kg/m^3$

2.Polystyrene Oil:

Mass of oil,m= 0.005 kg

Volume of oil,v = 5×10^{-6} m^3

Density= (m/v)

$=(0.005\times10^{-6})$

$= 1000kg/m^3$

3.Mix Oil:

Mass of oil,m= 0.004 kg

Volume of oil,v = 5×10^{-6} m^3

Density= (m/v)

$=(0.004/5\times10^{-6})$

$= 800kg/m^3$

4.5.2 Density Analysis and Comparison

Density is a fundamental property of fuels, influencing energy content per unit volume, combustion efficiency, and suitability for engines. Plastic pyrolysis oils show variations in density compared with conventional fuels such as diesel and petrol.

Density Data

Fuel Type	Density (kg/m³)	Remarks
Polypropylene Oil	900	Comparable with diesel
Polystyrene Oil	1000	Higher than diesel, denser fuel
Mixed Oil	800	Lower than diesel, lighter fuel
Diesel	830	Standard for CI engines
Petrol	740	Lightest, highly volatile

Density Comparison Chart

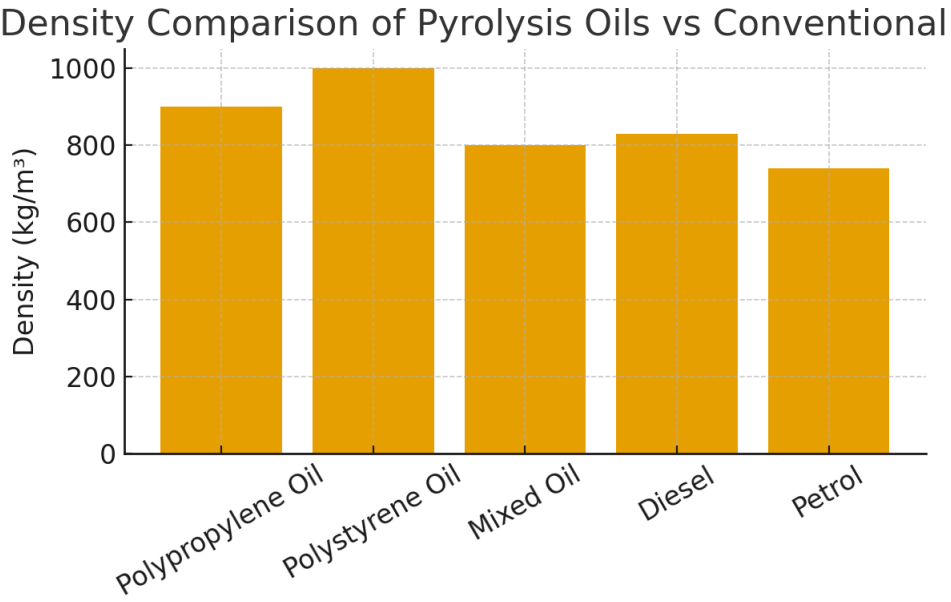


Fig 4.10: Comparison of Density between Pyrolysis oils and Conventional fuels

4.6 Net Calorific value analysis of pyrolysis oils

4.6.1 Experimental Data:

1.Polypropylene oil:

We know,

Net Calorific value = $(m_{water} \times c \times \Delta T)/ m_{oil}$

Where,

m_{water} =Mass of water,

c= Specific heat of water,

ΔT= Temperature rise of water,

m_{oil} = Mass of oil burned ,

SL No	m_{water} (kg)	c (kJ/kg℃)	T_1 ˚C	T_2 ˚C	ΔT (T_2- T_1) ˚C	m_{oil} (kg)	CV kJ/kg
1	0.1	4.18	29.5	71.3	41.8	0.005	3494.48
2	0.1	4.18	30.0	70.5	40.5	0.005	3385.80
3	0.1	4.18	30.0	74.5	44.5	0.005	3720.20

Table 4.7: Experimental data of Calorific value of Polypropylene pyrolysis oil

Final Result: CV= (3494.48+3385.80+3720.20)/3= 3533.50 kJ/kg

02.Polystyrene oil:

We know,

Net Calorific value = $(m_{water} \times c \times \Delta T)/ m_{oil}$

Where,

m_{water} =Mass of water,

c= Specific heat of water,

ΔT= Temperature rise of water,

m_{oil} = Mass of oil burned ,

SL No	m_{water} (kg)	c (kJ/kg℃)	T_1 ˚C	T_2 ˚C	ΔT $(T_2- T_1)$ ˚C	m_{oil} (kg)	CV kJ/kg
1	0.1	4.18	29.8	48.1	18.3	0.005	1529.88
2	0.1	4.18	30.0	50.2	20.2	0.005	1688.72
3	0.1	4.18	30.0	52.4	22.4	0.005	1872.64

Table 4.8: Experimental data of Calorific value of Polystyrene pyrolysis oil

Final Result: CV= (1529.88+1688.72+1872.64)/3= 1697.08 kJ/kg

03.Mixed oil:

We know,

Net Calorific value = $(m_{water} \times c \times \Delta T)/ m_{oil}$

Where,

m_{water} =Mass of water,

c= Specific heat of water,

ΔT= Temperature rise of water,

m_{oil} = Mass of oil burned ,

SL No	m_{water} (kg)	c (kJ/kg℃)	T_1 ˚C	T_2 ˚C	ΔT $(T_2- T_1)$ ˚C	m_{oil} (kg)	CV kJ/kg
1	0.1	4.18	29.5	62.8	33.3	0.005	2783.88
2	0.1	4.18	30.0	65.2	35.5	0.005	2967.80
3	0.1	4.18	29.0	64.0	35.0	0.005	2926.00

Table 4.9: Experimental data of Calorific value of Mixed pyrolysis oil

Final Result: CV= (2783.88+2967.80+2926.00)/3= 2892.56 kJ/kg

4.6.2 Calorific Value Results

Fuel Type	Calorific Value (kJ/kg)	Remarks
Polypropylene Oil	3533.50	Highest among tested oils
Polystyrene Oil	1697.08	Lowest calorific value
Mixed Oil	2892.56	Intermediate value
Diesel	43,000 – 46,000	High, transport fuel
Petrol	44,000 – 47,000	High, transport fuel
Furnace Oil	40,000 – 42,000	Industrial heating

4.6.3 Calorific Value Comparison Chart

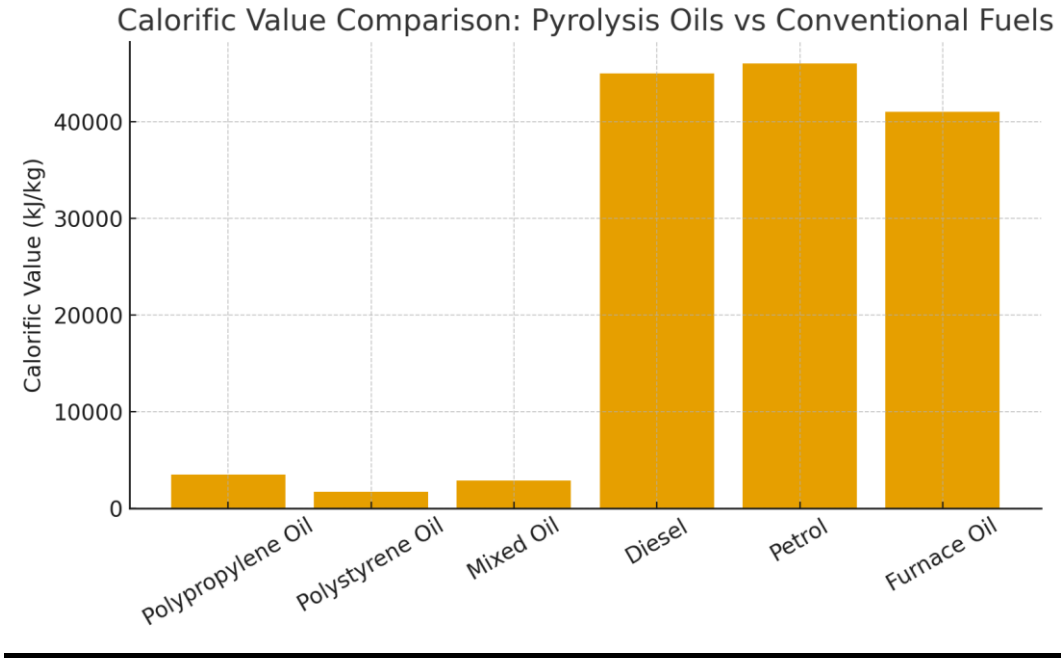


Fig 4.11: Comparison of CV between Pyrolysis oils and Conventional fuels

The method we used to measure calorific value burning a small amount of oil to heat water and then calculating from the temperature rise is simple and effective for a quick estimate, but it does have its limitations. A big issue is that not all the heat from the burning fuel goes into the water; some is lost to the surroundings, the container or through radiation. Sometimes the fuel doesn't burn completely, especially with complex oils like those from plastic pyrolysis, which means less energy is released than expected. Volatile parts of the fuel can also evaporate before they burn, further lowering the results. On top of that, the method assumes water's heat capacity is constant, even though it changes slightly with temperature. Another limitation is that it doesn't account for the hidden heat in the water vapor formed during combustion, so what's measured is closer to the net calorific value rather than the true gross value. Finally, because the experiment uses small quantities, even tiny measurement errors in mass or temperature can have a big impact. All of these factors mean the value we get in the lab will almost always be lower than the real energy content of the fuel.

Chapter 5

Conclusion

5.1 Conclusion

The qualitative analysis of pyrolysis oils derived from Polypropylene (PP), Polystyrene (PS), and mixed plastics (PP, PS, LDPE, and HDPE) highlights the distinct chemical and physical characteristics of the oils depending on the type of feedstock used.

- **Polypropylene-derived oil** was found to contain predominantly aliphatic hydrocarbons with lighter fractions, resembling gasoline-range fuels. Its high yield of straight-chain hydrocarbons suggests potential for fuel blending after suitable refining.
- **Polystyrene-derived oil** showed a high concentration of aromatic compounds, particularly styrene monomers and other aromatic derivatives. These aromatic-rich fractions are more suited for chemical recovery and as feedstock in the petrochemical industry rather than direct fuel use.
- **Mixed plastic-derived oil** exhibited a broad range of hydrocarbon compounds, combining both aliphatic and aromatic fractions. The presence of waxy residues and heavier hydrocarbons indicated reduced stability compared to PP oil but broader applicability after upgrading and distillation.

5.2 Limitations of the Study

- **Limited Feedstock Range**
    - The study focused on PP, PS, and mixed plastics (PP, PS, LDPE, HDPE). Other common plastics such as PET, PVC, or multilayer composites were not analyzed due to experimental constraints.
- **Qualitative Approach**
    - The analysis was primarily qualitative. While FTIR and GC–MS characterization identified functional groups and compound classes, detailed quantitative composition was not determined.

- **Process Scale**
    - Experiments were conducted at laboratory scale. The scalability of results to pilot or industrial levels may present challenges in terms of process efficiency, energy consumption, and environmental impact.
- **Absence of Catalysts**
    - The pyrolysis process was non-catalytic. The influence of catalysts on yield, selectivity, and product quality was not investigated, though catalytic pyrolysis is widely recognized as an improvement pathway.
- **Fuel Property Testing**
    - Key fuel properties such as calorific value, viscosity, density, and emission behavior were not experimentally measured. These would be critical for evaluating direct application as fuel.

5.3 Future Scope of Research

- **Comprehensive Feedstock Study**

Expand analysis to include other plastics (PET, PVC, multilayer packaging) to better represent real-world mixed waste streams.

- **Catalytic Pyrolysis**

Explore the use of catalysts (e.g., zeolites, silica-alumina, metal oxides) to enhance selectivity toward high-value fuel fractions and reduce unwanted by-products.

- **Co-Pyrolysis**

Investigate co-pyrolysis with biomass or other organic wastes to improve oil stability, reduce aromatic dominance (especially in PS oils), and enhance environmental sustainability.

- **Quantitative & Property Analysis**

Perform quantitative GC–MS, proximate and ultimate analyses, and standard fuel testing (calorific value, viscosity, flash point, pour point, emissions) to assess suitability as transportation fuels.

- **Process Optimization & Scale-Up**

Optimize parameters such as temperature, residence time, and heating rate for maximum yield and desired product composition.

Conduct pilot-scale studies to assess economic feasibility, energy efficiency, and emission control systems.

- **Life Cycle & Environmental Assessment**

Evaluate the overall environmental benefits and carbon footprint of plastic-to-oil pyrolysis compared to landfilling, incineration, or recycling.

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