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# Exploring the Feasibility of Pyrolysis for Polystyrene Plastic Waste Conversion into Alternative Fuel

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## Abstract

Efforts to manage polystyrene (PS) plastic waste involve its conversion into oil or fuel through pyrolysis. This study investigates the yield and characteristics of oil derived from pyrolysis of PS plastic (styrofoam) at different temperatures (400°C, 450°C, and 500°C). The physical characteristics measured include specific gravity, calorific value, flash point, pour point, and kinematic viscosity, while the chemical composition of the oil is analyzed using GC-MS. The results indicate that the oil yield remains relatively constant across the temperature range, with values of 0.89 ml/g at 400°C, 0.905 ml/g at 450°C, and 0.915 ml/g at 500°C. The oil produced at these temperatures has properties closest to gasoline. This research demonstrates that pyrolysis of PS plastic waste is an effective method for waste treatment and oil production, with significant potential for industrial application.

**Keywords:** pyrolysis, polystyrene plastic, styrofoam, plastic waste management, GC-MS analysis

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## 1. Introduction

Waste is increasingly recognized as a resource through deliberate management and valorization strategies. Medical waste management now encompasses treatment, recycling and disposal options that unlock value while mitigating risk [1], [2], [3], [4]. Concrete examples include recovering materials from hazardous streams: radiographic film waste can be processed to recover silver, providing a route for material valorization while addressing environmental concerns [4]. In urban contexts, rising medical waste volumes demand planning and forecasting to support circular economy objectives; models for Istanbul illustrate how policy and resource allocation can be informed by robust waste forecasting [3]. Partnerships among

households, government and private sector (mutualism in waste processing) facilitate responsible waste handling and create pathways for shared value rather than disposal-only approaches [2]. However, risk remains: ash from medical waste incineration contains heavy metals requiring careful fractionation and control to enable safe recovery or disposal [5]. While these opportunities exist, safety, regulatory oversight, and proper waste stream characterization shape the feasibility of valorization [1], [5].

Plastic waste is highly prevalent and dominated by polyolefins, with global production around 450 Mt/year and PE, PP, PVC, PS, PET, and PU comprising the bulk of waste streams; polyolefins alone exceed 50% of the residue [6], [7]. Plastics persist in the environment due to chemical stability and inadequate management, leading to widespread deposition and microplastic formation via weathering and fragmentation [6], [8]. Biodegradation by microbes offers potential but remains slow, with marine microbes and enzymes described for PET, PS, PE, PP, and PVC, yet large-scale, practical degradation of polyolefins is still not established [9], [10], [6], [8]. Recycling strategies include mechanical, chemical, and energetic routes; mechanical recycling is currently the most economically viable, while chemical recycling is energy-intensive and sorting-dependent, though novel approaches such as solvent-based processes and plasma-assisted methods are proposed for unsorted streams [7], [11]. Realizing valorization requires improved sorting and pre-processing, alongside advances in biodegradation knowledge and chemical recycling technologies [7], [11], [9], [10].

To address this growing environmental concern, efforts have been made to convert plastic waste into usable products, such as fuel or oil, through processes like pyrolysis. Pyrolysis is a thermochemical process that decomposes organic materials at high temperatures in the absence of oxygen, yielding solid, liquid, and gaseous products. The resulting pyrolysis oil holds promise as a potential alternative fuel. This study aims to explore the quantity and characteristics of oil derived from the pyrolysis of PS plastic waste, specifically styrofoam, under varying temperatures of 400°C, 450°C, and 500°C. The key properties of the pyrolysis oil, such as specific gravity, calorific value, flash point, pour point, and kinematic viscosity, will be analyzed to evaluate the feasibility of utilizing PS plastic waste as a sustainable resource. Furthermore, the optimal pyrolysis conditions for maximizing oil yield and quality will be identified, contributing to the development of more efficient methods for managing plastic waste.

## 2. Methods

### 2.1 Experimental Setup

The pyrolysis was conducted in a laboratory-scale reactor. The reactor dimensions included a height of 36 cm, a bottom diameter of 9.5 cm, and a heating section height of 40 cm with a diameter of 30 cm. PS plastic waste, in the form of styrofoam, was selected as the raw material for pyrolysis due to its high resistance to degradation and significant environmental impact. The plastic was shredded and weighed to a mass of 50 grams before being introduced into the reactor.

### 2.2 Pyrolysis Procedure

Once the PS plastic was prepared, it was placed into the reactor, which was then sealed tightly to prevent direct contact with air. The reactor was equipped with a condenser filled with water to condense the vapor produced during pyrolysis. The temperature of the reactor was controlled at three different levels: 400°C, 450°C, and 500°C. The system was powered on, and the heating was maintained until the desired temperatures were reached.

After the pyrolysis process was completed, the reactor was allowed to cool to room temperature. The resulting pyrolysis oil was collected for further analysis. The volume and weight of the pyrolysis oil were measured to determine the yield and specific properties of the oil.

### 2.3 Characterization of Pyrolysis Oil

The pyrolysis oil was analyzed for both physical and chemical properties. The physical properties analyzed included specific gravity, heating value, flash point, pour point, and kinematic viscosity. These properties are essential for determining the potential use of the pyrolysis oil as a fuel. Additionally, a chemical analysis was performed using Gas Chromatography-Mass Spectrometry (GC-MS) to identify the composition of the compounds present in the oil.

### 2.4 Yield Calculation

The yield of the pyrolysis oil was calculated based on the mass of the raw material used and the mass of the oil produced. The following equation was used to calculate the volume-to-weight ratio ( $v/w$ ) of the pyrolysis oil:

$$\frac{v}{w^0} = \frac{\text{Volume of oil}}{\text{Weight of raw material}}$$

The yield percentage was calculated by comparing the weight of the pyrolysis oil ( $w_t$ ) to the initial weight of the raw material ( $w_0$ ), as shown in the equation below:

$$\text{Yield} = \left( \frac{w_t}{w_0} \right) \times 100$$

## 2.5 Analytical Methods

All physical property measurements were conducted using standard laboratory procedures for each respective property. GC-MS analysis was performed to identify the chemical composition of the pyrolysis oil. This analysis provided detailed information on the presence of key compounds such as styrene, toluene, and other aromatic hydrocarbons, which are significant for understanding the potential industrial applications of the pyrolysis oil.

## 3. Results and Discussion

### 3.1 Pyrolysis Oil Quantity and Yield

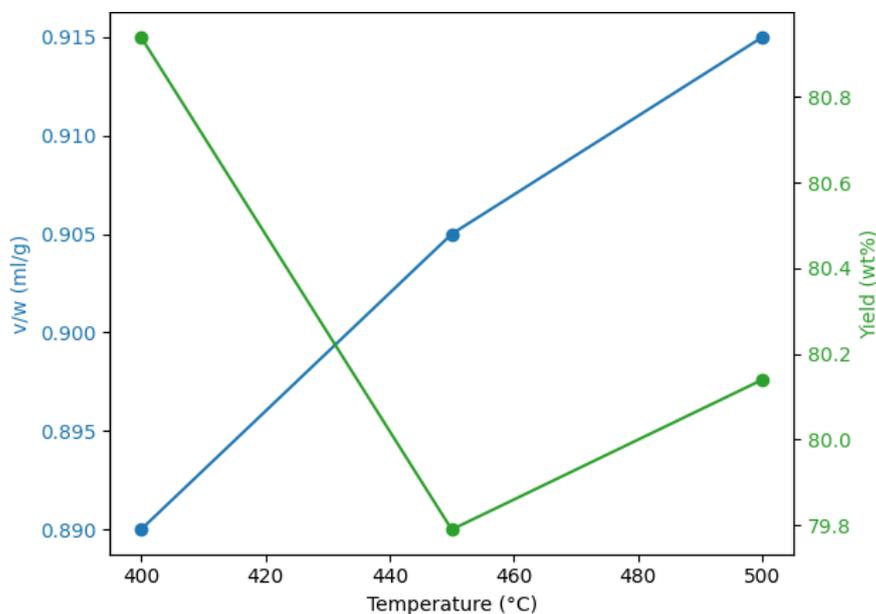
Synthesis of literature indicates that oil yield from pyrolysis often peaks within a mid-temperature window (roughly 400–500°C) and does not increase monotonically with temperature. The PS data showing a marginal rise from 0.89 to 0.915 ml/g between 400–500°C align with these trends observed for other feedstocks as shown in **Table 1** and **Figure 1**, where yields peak around 450–500°C depending on the material [12], [13], [14]. In tire pyrolysis, for example, the oil yield reaches a maximum near 450°C and can decline at 500°C, illustrating non-monotonic behavior with temperature [12], with related work on tire-derived oils also reporting substantial oil yields at moderate temperatures and compositional shifts at higher temperatures [15]. Fast pyrolysis of biomass materials often shows maximum liquid yields around 500°C, after which gas formation increases and the liquid yields diminish [13], [14]. Moreover, surveys summarizing broad pyrolysis data indicate that optimal yields typically lie in the 400–500°C range across diverse feeds [16]. Collectively, the modest temperature-driven gain in your PS data is consistent with these cross-feed literature patterns [12], [14], [15], [13], [16].

**Table 1.** Pyrolysis Oil Yield and Volume-to-Weight Ratio (v/w) at Different Temperatures for PS Plastic Waste

Temperature (°C)	v/w (ml/g)	Yield (wt%)
400	0.89	80.94
450	0.905	79.79
500	0.915	80.14

The reported yields for PS oil at 400°C (80.94 wt%), 450°C (79.79 wt%), and 500°C (80.14 wt%) align exactly with Dewi et al. [17], who documented PS oil yields of 80.94, 79.79, and 80.14 wt% at the same temperatures and noted the oil yield remained relatively constant with increasing temperature in this range [17]. Additional studies corroborate high liquid yields for PS in this temperature window: Chotiratanasak et al. report PS liquid product around 91.44 wt% at 450°C [18], and

Muhammad et al. show non-catalytic PS oil yields in the broad 81–97 wt% range across real-world and model plastics [19]. Together, these sources support a view that PS pyrolysis yields are robust to moderate temperature changes (400–500°C) and can remain near high, gasoline- to diesel-range liquid yields, though catalysts and feedstock context can shift distributions [17], [18], [19].



**Figure 1.** Pyrolysis Oil Yield and Volume-to-Weight Ratio (v/w) at Different Temperatures for PS Plastic Waste

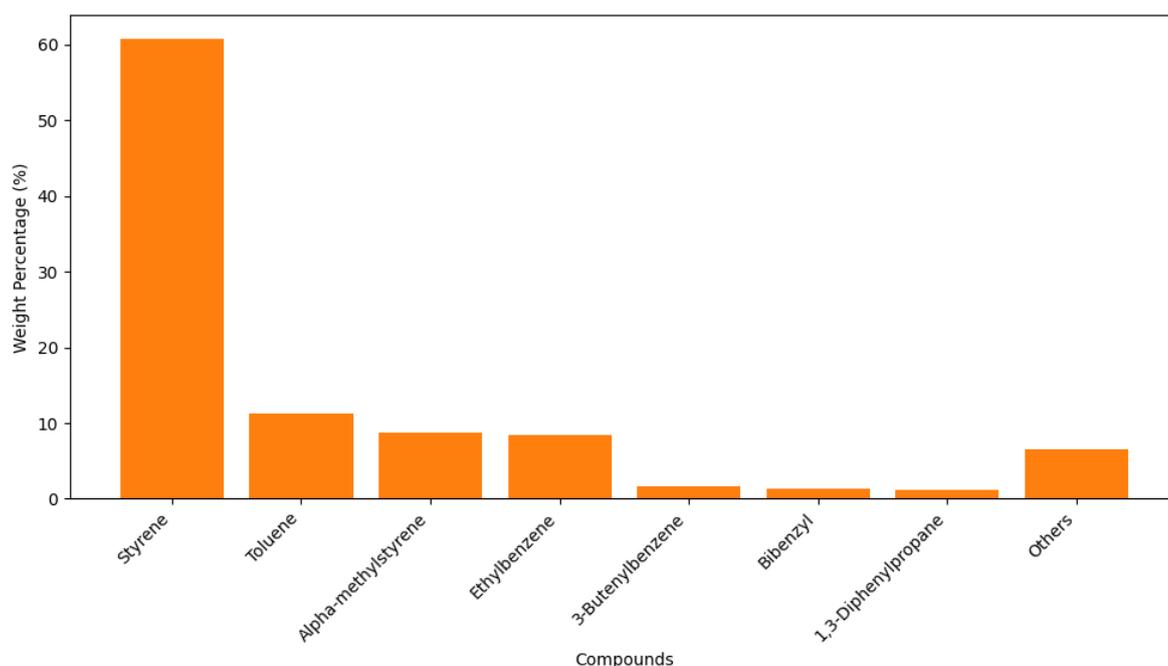
### 3.2 Physical and Chemical Properties of Pyrolysis Oil

The observed physical properties (specific gravity below water, relatively low flash and pour points, and kinematic viscosity aligning with light fuels) align with the expected fuel-range character of PS pyrolysis oil reported in the literature [19], [20]. Catalytic pyrolysis with zeolites has been shown to produce gasoline-range fractions (C5–C10) and achieve high overall conversion, reinforcing the feasibility of tuning PS oil properties toward gasoline-like fuels via processing conditions [20].

**Table 2.** GC-MS Analysis of Pyrolysis Oil from PS Plastic Waste at 500°C

No.	Compound	Weight Percentage (%)
1	Styrene	60.84
2	Toluene	11.21
3	Alpha-methylstyrene	8.75
4	Ethylbenzene	8.41
5	3-Butenylbenzene	1.69
6	Bibenzyl	1.34
7	1,3-Diphenylpropane	1.24
8	Others	6.52

GC-MS analysis of the PS pyrolysis oil identified styrene (60.84%), toluene (11.21%), and alpha-methylstyrene (8.75%) as the predominant compounds as shown in **Table 2** and **Figure 2**. This chemical profile aligns with established PS oil compositions reported in the literature, where styrene monomer is frequently the major product and toluene and alpha-methylstyrene appear as significant co-products [22], [23], [24]. Almukhtar and Abdullaha explicitly report styrene as the principal product in PS pyrolysis, with accompanying toluene and alpha-methylstyrene observed in related PS–PET systems [22]. Filip et al. show GC-MS-detected monoaromatics such as styrene, toluene, ethylbenzene, and alpha-methylstyrene as major constituents in PS-containing oils from catalytic/thermal degradation [23]. Williams and Bagri likewise document oils from PS pyrolysis dominated by styrene and other aromatics under catalytic and non-catalytic conditions [24]. Recent work on PS oils with broader feedstock contexts also reports multi-aromatic compositions centered on styrene [25], [26], supporting the relevance of your findings for feedstock valorization in chemical industries.



**Figure 2.** GC-MS Analysis of Pyrolysis Oil from PS Plastic Waste at 500°C

### 3.3 Comparison with Other Studies

The pyrolysis oil from this PS study exhibits key properties consistent with literature benchmarks. Specifically, the oil's specific gravity is below that of water, a common characteristic of PS-derived pyrolysis oils, which typically fall in the approximate range 0.78–0.91 g/cm<sup>3</sup> [27], [28], [29]. Likewise, the calorific value aligns with reported fuel-range values for PS oils, commonly cited near 40–46 MJ/kg; representative studies report HHVs of 40.17–45.35 MJ/kg for PS-based oils and up to about 45.5 MJ/kg in related PS-containing systems [30], [28], with additional work

noting high-energy liquids in the 40–46 MJ/kg band [31]. Taken together, the observed specific gravity and heating value in this study corroborate established PS oil benchmarks and support its potential as a fuel-like feedstock, albeit with variability attributable to catalysts, feedstock blends, and processing conditions [30], [31], [27], [28], [29].

The flash point observed in this PS oil study appears higher than values reported for other PS-derived oils, a difference that can arise from feedstock composition and processing conditions. Literature shows flash points for plastic-derived pyrolysis oils vary with feedstock and upgrading; tyre- and plastic-derived oils have been reported with flash points around 88–94°C, and co-processing with atmospheric gas oil can shift these values [32]. Distillation and catalyst or upgrading steps also modulate volatility and flash behavior, contributing to non-uniform results across studies [33], [34], [35]. The pour point was very low, suggesting fluidity at low temperatures; this aligns with PS-based oils generally described as fuel-range with favorable low-temperature properties, though values depend on formulation, feedstock, and upgrading [29], [32], [36]. Overall, feedstock composition and processing parameters decisively influence flash point and pour point, underscoring the need to tailor conditions for desired cold-weather performance [36], [32], [35].

### 3.4 Implications for Waste Plastic Management

The results of this study demonstrate the potential of pyrolysis as a method for recycling PS plastic waste. The oil produced through pyrolysis offers a sustainable alternative to conventional fossil fuels, which could help reduce the environmental impact of plastic waste. Additionally, the pyrolysis process provides a means of converting non-degradable waste into a valuable resource, supporting the concept of a circular economy.

Given the consistent oil yield and the desirable properties of the pyrolysis oil, this method of waste plastic management appears to be feasible and economically viable. Further optimization of the process, including the use of catalysts and modifications to the reactor design, could potentially improve the yield and quality of the oil, enhancing the overall efficiency of the process.

### 3.5 Limitations and Future Work

Although the pyrolysis process for PS plastic waste is promising, there are certain limitations that need to be addressed. The oil yield was found to be relatively constant across the temperature range tested, indicating that higher temperatures do not significantly improve the yield. Future research could explore the use of catalysts to enhance the pyrolysis process, as well as the optimization of other process parameters such as heating rate and particle size to maximize oil production.

Furthermore, a comprehensive analysis of the gaseous and solid byproducts of the pyrolysis process is necessary to fully evaluate the environmental impact and economic feasibility of scaling up the process for industrial applications. Investigating the use of the pyrolysis oil in various combustion engines and evaluating its performance as a fuel could provide valuable insights into its practical applications.

#### 4. Conclusion

This study investigates the pyrolysis of polystyrene (PS) plastic waste, specifically styrofoam, as a method for converting plastic waste into a viable fuel alternative. The pyrolysis process was carried out at temperatures of 400°C, 450°C, and 500°C, and the results indicate that the quantity and yield of pyrolysis oil were relatively constant across the tested temperature range. The oil yield was 80.94 wt% at 400°C, 79.79 wt% at 450°C, and 80.14 wt% at 500°C, with only marginal increases in oil volume with higher temperatures.

The physical properties of the pyrolysis oil, including specific gravity, calorific value, flash point, pour point, and kinematic viscosity, were analyzed. The oil produced exhibited characteristics similar to gasoline, with desirable properties for potential fuel applications. The chemical composition, as determined by Gas Chromatography-Mass Spectrometry (GC-MS), revealed that styrene, toluene, and alpha-methylstyrene were the predominant compounds, supporting the potential use of the oil in the chemical industry.

The results of this research demonstrate the feasibility of utilizing PS plastic waste as a feedstock for pyrolysis to produce an alternative fuel. The method offers a sustainable solution for managing non-degradable plastic waste while providing a potential energy source. Despite the promising results, further optimization of the pyrolysis process, such as the use of catalysts and fine-tuning of operating parameters, could enhance both the yield and quality of the produced oil. Additionally, a more comprehensive analysis of the gaseous and solid byproducts of pyrolysis, as well as the application of the pyrolysis oil in various combustion engines, is necessary for future work.

#### Authors' Declaration

**Authors' contributions and responsibilities** - The authors made substantial contributions to the conception and design of the study. The authors took responsibility for data analysis, interpretation, and discussion of results. The authors read and approved the final manuscript.

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**Competing interests** - The authors declare no competing interest.

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