

Enhancing pyrolysis oil yield and quality via low-temperature catalytic pyrolysis of PET waste over activated carbon derived from euxideroxylon zwageri

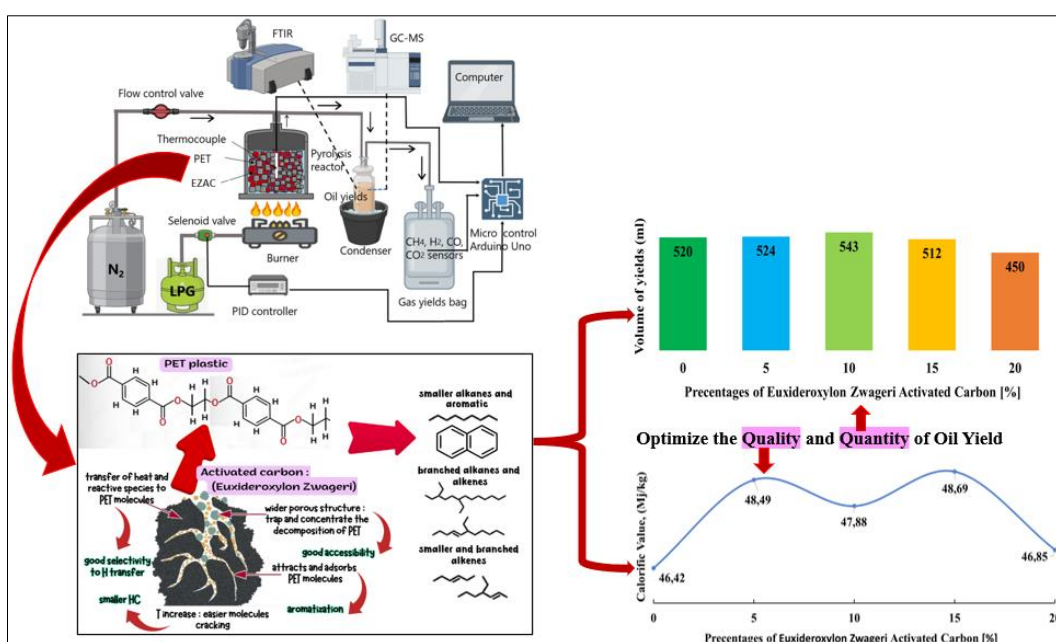
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Highlights:

- Euxideroxylon zwageri biomass-derived activated carbon (EZAC) enhances both oil yield and calorific value.
- TGA profiles for PET and EZAC support the selected 350 °C operating temperature and show the distinct thermal responses of the PET feedstock and the carbonaceous EZAC medium and EZAC addition increases oil yield relative to non-catalytic PET pyrolysis.
- An optimum feed ratio of PET:EZAC = 90:10 (w/w) achieves the highest oil yield (543 mL; 80.8 wt%) and gasoline-like properties (RON 97; HHV 47.88 MJ/kg; density 0.772 g/mL; kinematic viscosity 2.384 cSt; flash point 13 °C; C7–C10 fraction 62.95%).
- EZAC promotes H₂ and CH₄ formation, indicating intensified cracking and catalytic reforming reactions.

Abstract

This study evaluates the low-temperature pyrolysis of post-consumer polyethylene terephthalate (PET) from room temperature to 350 °C using biomass-derived activated carbon from Euxideroxylon zwageri (EZAC) as a renewable catalyst/adsorbent. PET–EZAC blends (100:0, 95:5, 90:10, 85:15, and 80:20; total feed 500 g) were processed in a fixed-bed reactor under an inert atmosphere. EZAC significantly shifted product distribution and exhibited an optimum at PET:EZAC = 90:10 (w/w), which produced the maximum oil yield of 543 mL (404 g; 80.8 wt%) and exceeded

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the oil yield from non-catalytic PET pyrolysis. Under this optimum condition, fuel-relevant properties improved, yielding an research octane number (RON) of 97 and a higher heating value (HHV) of 47.88 MJ/kg; the flash point and kinematic viscosity decreased to 13 °C and 2.384 cSt, respectively, while density remained nearly constant (0.772 g/mL). GC–MS results showed the most gasoline-like composition at PET:EZAC = 90:10, dominated by the C7–C10 fraction (62.95%) with a balanced hydrocarbon-class distribution (Alkanes 64.64%, Olefin 27.61%, and Aromatics 7.75%). MQ sensor-based gas profiles further suggested that EZAC accelerated the onset of H₂ and CH₄ formation, with peak sensor responses of 745 ppm for H₂ and 871 ppm for CH₄ at 20% EZAC. Overall, EZAC is a promising renewable material for steering secondary reactions during low-temperature PET pyrolysis, thereby improving both oil yield and oil quality.

Keywords: Pyrolysis; PET waste; EZAC; Oil yield; Activated carbon; Fuel-relevant properties

1. Introduction

Plastics are widely used because they are practical, versatile, and inexpensive. However, the rapid growth of plastic consumption, accompanied by population growth, urbanization, economic expansion, and excessive resource exploitation, has intensified global solid waste generation, particularly in developing countries, with plastic waste reported to comprise at least 12% of total municipal solid waste. This condition has placed increasing pressure on the environment, as waste management systems remain inadequate due to limited infrastructure, low recycling rates, and insufficient disposal facilities [1], [2], [3], [4]. Worldwide plastic production has surpassed 390 million tons annually, yet the recycling rate remains low (approximately 9%), creating a persistent imbalance between production and the capacity for collection, recycling, and disposal [5], [6], [7], [8]. Consequently, plastic waste continues to accumulate in terrestrial and aquatic environments, generating substantial ecological impacts. Because most plastics degrade slowly under natural conditions, safe disposal is costly and represents a transboundary challenge [9], [10], [11]. These pressures have stimulated the development of technologies that not only reduce plastic waste, but also valorize it into more sustainable energy resources and chemicals [12], [13], [14].

Pyrolysis is a promising thermochemical pathway for mitigating plastic pollution while supporting circular economy strategies. Waste plastic pyrolysis has emerged as an effective approach for reducing plastic waste accumulation by converting hard-to-recycle plastics into liquid and gaseous fractions, including waste plastic oil (WPO), which can be further utilized as an alternative fuel or chemical feedstock [15], [16], [17], [18]. Through this conversion pathway, pyrolysis not only supports plastic waste valorization but also reduces dependence on virgin fossil resources and strengthens resource recovery within a circular economy framework. Pyrolysis can be performed either without catalysts or in the presence of catalytic materials. Non-catalytic pyrolysis is operationally simpler because it avoids reactive additives; however, it often yields products with broader, less controllable distributions and lower-quality liquid fractions than catalytic processes [19], [20], [21], [22], [23], [24], [25]. In contrast, catalysts can lower the apparent activation energy, promote polymer chain scission, and steer secondary reactions (e.g., cracking, deoxygenation, and aromatization), which can improve the yield and quality of the liquid product.

In this work, polyethylene terephthalate (PET) was selected as the feedstock because it is extensively used in post-consumer packaging and contributes substantially to plastic waste streams [1], [2], [3], [5], [6], [7], [8]. The catalyst/medium examined was activated carbon derived from *Euxideroxylon zwageri*, hereafter referred to as EZAC. Owing to its porous structure and high surface area, activated carbon can function as a catalytic/adsorptive medium that enhances vapor–solid contact and facilitates secondary reactions of pyrolysis vapors, potentially increasing condensable yields and improving fuel-relevant properties of the resulting oil [26]. For PET pyrolysis, EZAC is expected to provide abundant surface sites and weak acid–base functionalities that promote secondary cracking and decarboxylation/decarbonylation, while suppressing heavy-fraction (tar) formation through adsorption of reactive intermediates. In addition, π – π interactions between the Aromatic carbon surface and Aromatic intermediates may influence product selectivity toward gasoline-range Aromatics [27], [28].

Increasing the temperature indeed accelerates volatilization and condensate formation; however, at excessively high temperatures, secondary cracking reactions convert the liquid fraction into gas. Consequently, the product distribution shifts toward gaseous products and the recoverable condensate yield declines [29], [30]. This condition also increases the likelihood of secondary reactions that convert part of the liquid products into non-condensable gases, while

simultaneously raising the heating energy requirement, which is not always proportional to the resulting oil yield [31]. Considering liquid-product recovery and preliminary fuel-quality indicators, operating within a moderate temperature range and controlling condensation conditions may provide a practical approach for improving condensable liquid recovery [32], [33]. This integrated assessment is intended to clarify how EZAC concentration influences product selectivity and the balance between liquid and gas formation, thereby supporting the potential utilization of PET waste as a resource for liquid-fuel precursor production within a circular-economy framework. Low-temperature pyrolysis (room temperature to 350 °C) was selected as a moderate thermal condition to evaluate PET conversion and condensable product formation while limiting excessive formation of non-condensable gases. Prior studies have suggested that intermediate operating windows (approximately 220–420 °C) can increase liquid production and reduce gas formation relative to higher temperatures [2], [6]. Moreover, 350 °C is sufficient to initiate PET decomposition while remaining compatible with the thermal stability of the activated carbon used in this study.

Despite this potential, PET pyrolysis is still commonly conducted at intermediate-to-high temperatures and/or with mineral or zeolitic catalysts. As a result, energy requirements and the oil-gas trade-off are not always evaluated in an integrated manner within a single experimental design. Studies focused specifically on low-temperature PET pyrolysis to maximize the liquid fraction while suppressing gas formation remain limited, particularly those employing locally sourced, biomass-derived activated carbon catalysts. Accordingly, the novelty of this study lies in applying EZAC as a renewable biomass-derived catalyst/adsorbent for low-temperature PET pyrolysis (≤ 350 °C) and systematically evaluating the effect of EZAC loading on (i) product distribution (oil, solid, and gas), (ii) oil yield properties (heating value, octane number, density, kinematic viscosity, and flash point), (iii) functional-group and hydrocarbon-composition changes (FTIR/GC–MS), and (iv) the evolution of major gases (H_2 , CH_4 , CO , and CO_2). This integrated assessment is intended to clarify how EZAC concentration influences product selectivity and the balance between liquid and gas formation, thereby strengthening the potential utilization of PET waste as a resource for liquid-fuel precursor production within a circular-economy framework.

Conventional catalytic plastic pyrolysis has frequently employed zeolite-based catalysts, metal-loaded zeolites, natural minerals, or commercial activated carbons to enhance cracking, aromatization, and product selectivity [34], [35], [36], [37], [38]. Although these catalysts are effective, their preparation cost, regeneration requirements, and dependence on commercial or mineral resources may limit broader implementation in decentralized waste-treatment systems. In this context, EZAC offers a different approach because it is derived from locally available biomass and can function simultaneously as a porous catalytic and adsorptive medium. Therefore, the novelty of this study lies in evaluating *Euxideroxylon zwageri*-derived activated carbon as a renewable catalyst/adsorbent for low-temperature PET pyrolysis and in linking EZAC loading with product distribution, oil properties, functional-group changes, GC–MS composition, and gas-evolution behavior.

Therefore, this study aims to determine the impact of varying EZAC concentrations on PET pyrolysis by comparing non-catalytic runs with EZAC-assisted runs. The effect of EZAC addition is assessed through oil yield measurements and comprehensive characterization of the oil's physical properties (higher heating value, research octane number, flash point, density, and kinematic viscosity), chemical features (FTIR and GC–MS), and gas formation (H_2 , CH_4 , CO , and CO_2).

2. Methods

2.1. Pyrolysis Feedstocks

2.1.1. Polyethylene terephthalate (PET)

Post-consumer PET beverage bottles were used as the feedstock. The bottles were washed to remove surface contaminants, and the labels and caps were removed. The cleaned PET was cut into flakes of approximately 1 × 1 cm to improve feed homogeneity and facilitate reactor loading. Thermal decomposition behavior of PET was evaluated by thermogravimetric analysis (TGA). The TGA results indicated that PET began to melt at 250 °C, while the primary degradation commenced at 314.34 °C and proceeded rapidly to a maximum degradation temperature of 358.89 °C. Under the same test conditions, EZAC showed a substantially higher degradation temperature (449.55 °C), indicating sufficient thermal stability within the operating range used in this study (≤ 350 °C) and supporting its application as a catalyst/adsorbent.

2.1.2. Euxideroxylon zwageri activated carbon (EZAC)

The preparation procedure for Euxideroxylon zwageri derived activated carbon (EZAC) is illustrated in Figure 1. Euxideroxylon zwageri biochar produced via pyrolysis was ground and sieved

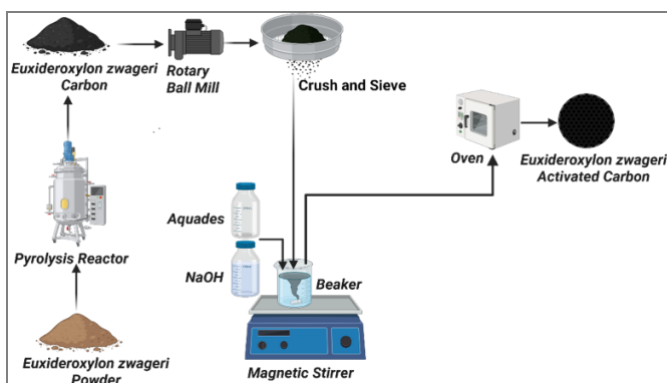
to pass a 200 mesh screen. Chemical activation was performed using 1.5 M NaOH at room temperature for 2 h under magnetic stirring (200 rpm), using a biochar-to-solution ratio of 2.5 g:50 mL [39]. After activation, the solid was washed with distilled water until the filtrate approached neutral pH (pH 6-7) to remove residual activating agent and surface impurities. The material was then dried at 120 °C for 8 h. The chemical composition of the catalyst precursor is summarized in Table 1, including flavonoid, phenolic, antioxidant, cellulose, lignin, pentosan, and silica contents.

Table 1.

Chemical composition
of the catalyst
precursor

Type of analysis	Content
Flavonoids	470.99 mg EQ/100 g
Phenolics	2892.48 mg GAE/100 g
Antioxidants	175.77 ppm
Cellulose	58.1 %
Lignin	28.9 %
Pentosan	12.7 %
Silica	0.3 %

Figure 1.
Schematic of the
manufacturing
process for
Euxideroxylon
zwageri-derived
activated carbon
catalyst (EZAC)



2.2. Experimental Setup and Procedures

The experimental procedure followed the authors' previous study [33]. Pyrolysis experiments were performed in a stainless steel fixed-bed reactor designed to provide uniform heating and controlled reaction conditions. The reactor had an internal diameter of 20 cm and a height of 15 cm. For each run, a total feed mass of 500 g was loaded using PET:EZAC mass ratios of 100:0, 95:5, 90:10, 85:15, and 80:20. These ratios were selected to evaluate the influence of EZAC loading on product distribution (liquid, solid, and gas) and on the physicochemical properties of the resulting oil. In an in-situ configuration, EZAC was thoroughly mixed with PET flakes inside the reactor before sealing. To ensure an inert environment and prevent unwanted oxidation, the reactor was purged with nitrogen at 10 mL/min for 10 min prior to heating.

Heating was supplied by an LPG fired burner under slow-pyrolysis conditions. The reactor was heated from ambient temperature to 350 °C at an average heating rate of 16 °C/min, and the temperature was monitored continuously using a K-type thermocouple positioned in the reactor core. The target temperature (350 °C) was selected because it is sufficient to promote PET decomposition while limiting excessive formation of non-condensable gases, as reported previously [6], [14]. Because temperature strongly governs product selectivity favoring condensable liquids at relatively lower temperatures and increasing gas formation at higher temperatures stable thermal control was required for reproducible comparisons among runs. Reactor temperature was monitored continuously using a K-type thermocouple positioned in the reactor core and connected to a proportional integral derivative (PID) controller. The PID system maintained the set point at 350 °C by regulating burner heat input via a solenoid valve. After reaching 350 °C, the reactor temperature was maintained for 69 min to complete the pyrolysis process. The estimated vapor residence time in the hot zone was approximately 21 min, calculated from the effective reactor free volume and the gas/vapor flow rate under the applied operating conditions.

Volatile products exited the reactor through a copper transfer line and entered a condensation unit. Condensation was achieved using a 500 cm copper coil (9.5 mm diameter) immersed in an ice bath to enhance heat removal and convert condensable vapors into liquid oil. Non-condensable gases were directed to an in-line sensor array for real-time monitoring. The sensor suite consisted of MQ-4 (CH₄), MQ-8 (H₂), MQ-7 (CO), and MQ-135 (CO₂), interfaced with an Arduino Uno for continuous data logging [40], [41], [42]. After completion of heating, the reactor was allowed to cool to room temperature. The condensed liquid product was collected and its volume recorded, while the remaining solid residue was recovered and weighed. All PET:EZAC ratios were evaluated in a single run using an identical procedure to enable a direct comparison

across the various feed compositions, because each PET:EZAC ratio was tested in a single run, the results are interpreted as comparative preliminary trends, and replicate experiments are required to quantify uncertainty and reproducibility. The operating parameters, particularly the heating rate and temperature, were strictly regulated via an control system. This control strategy was used to improve operational consistency and comparability among the PET:EZAC ratios.

2.3. Yield Measurements and Product Analysis

Pyrolysis products were separated into liquid, gas, and solid fractions. Each fraction was quantified to determine yields and was characterized using appropriate analytical methods.

2.3.1. Liquid fraction (liquid yield)

Condensed oil was collected from the condenser and its volume was measured. Oil yield related properties were determined, including higher heating value (HHV) using a bomb calorimeter, octane number using a Coordinating Fuel Research (CFR) engine (the RON measurement of PET pyrolysis oil is tested directly after the pyrolysis process, (not tested after phase separation, or after distillation). RON measurements are intended only as an early indicator of fuel-relevant properties, not evidence that PET pyrolysis oil can be directly used as commercial gasoline), flash point using a Pensky Martens apparatus, density using a pycnometer, and kinematic viscosity using a Brookfield viscometer. Chemical characterization was performed by Fourier transform infrared spectroscopy (FTIR) and gas chromatography–mass spectrometry (GC-MS).

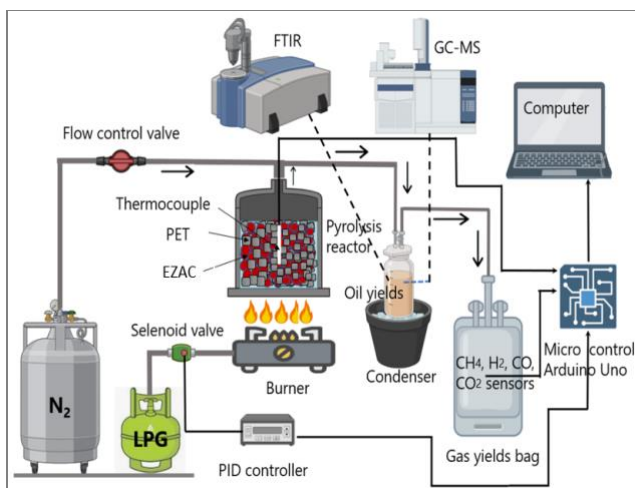
2.3.2. Gas fraction (gaseous yield)

Non-condensable gases were monitored to evaluate changes in CH_4 , H_2 , CO , and CO_2 formation. Concentrations were recorded continuously throughout each run using the Arduino-integrated sensor array. The MQ-series sensors were used to obtain time-resolved comparative gas profiles; therefore, the gas data were interpreted as trend-based or semi-quantitative indicators rather than calibrated absolute gas compositions. The profiles were used to assess how EZAC influences gas formation, with particular attention to H_2 and CH_4 as fuel-relevant components.

2.3.3. Solid fraction (solid yield)

After cooling, the solid residue remaining in the reactor was recovered and weighed gravimetrically. These data were used to calculate solid yield and to support the overall mass balance. Yields and product properties obtained at different PET:EZAC ratios were compared to evaluate the effect of EZAC loading on pyrolysis performance and oil quality. A schematic of the experimental installation (reactor, condenser, PID temperature control, and gas sensors) is provided in Figure 2.

Figure 2.
Schematic of the PET–EZAC pyrolysis experimental set-up



3. Results and Discussion

3.1. Thermal Behavior of PET and EZAC

The TGA (Thermogravimetric Analysis) curve of the PET plastic sample (Figure 3a) exhibited a single major thermal degradation stage with high thermal stability prior to decomposition. The material remained relatively stable up to approximately 300 °C, indicating strong resistance to thermal degradation at low and intermediate temperatures. The onset degradation temperature was observed at 314.34 °C, while the endset degradation temperature occurred at 423.08 °C, indicating that the main decomposition process took place within this temperature range. A sharp and significant mass loss was recorded for PET, which was associated with the breakdown of the polymer chains and the release of volatile degradation products. PET exhibited nearly complete

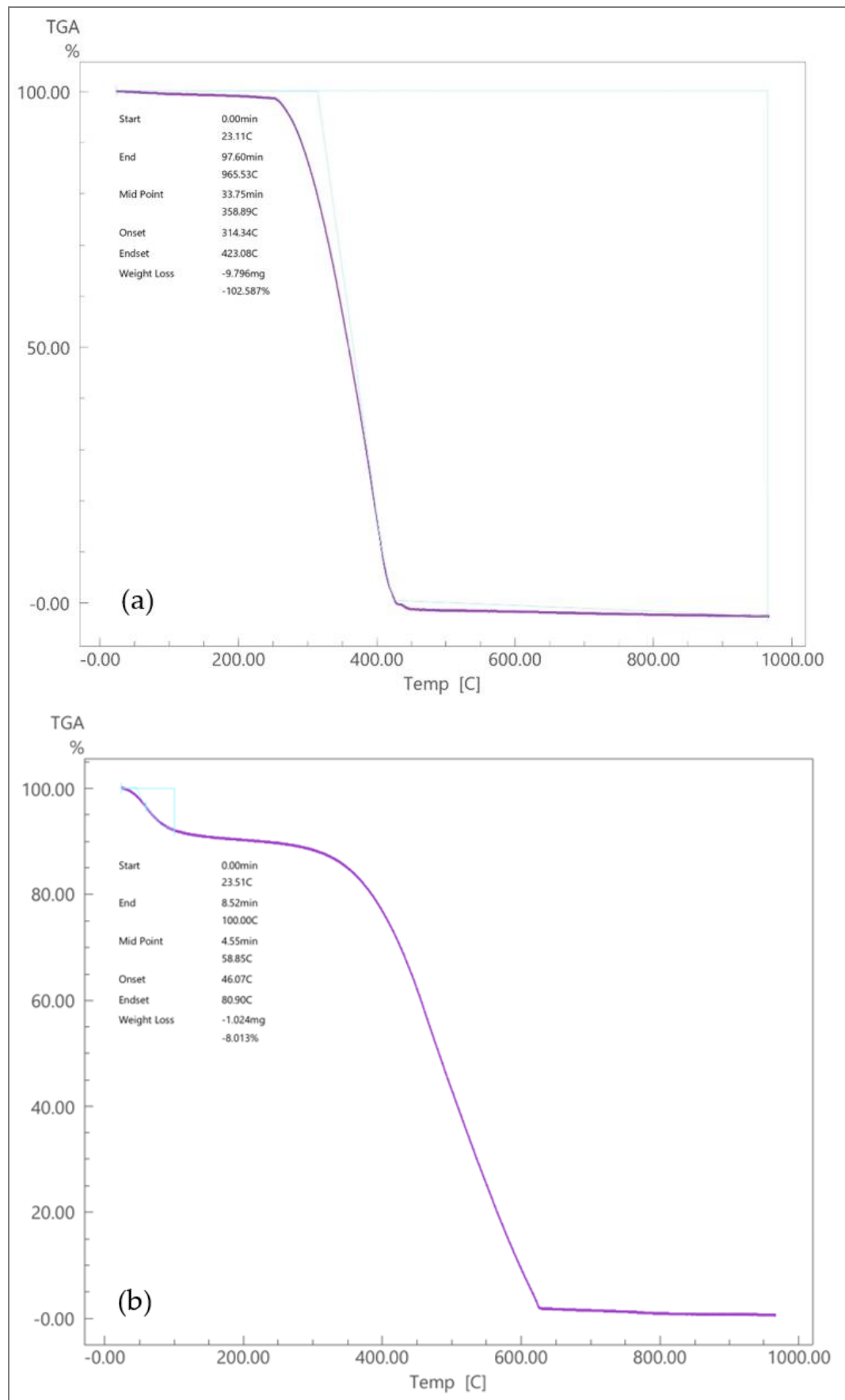


Figure 3.
TGA profiles of:
(a) PET;
(b) EZAC
used to support the
selected low-
temperature pyrolysis
condition

thermal degradation, with an approximate mass loss of 100% and negligible residual mass at the end of the TGA analysis. The midpoint degradation temperature was identified at 358.89 °C, indicating the maximum decomposition region of the polymer matrix. After 450 °C, the TGA curve became nearly constant with negligible residual mass, suggesting that the PET sample underwent

almost complete thermal decomposition with minimal char residue remaining at high temperatures. These findings confirm the characteristic thermal degradation behavior of PET and indicate its relatively high thermal stability before rapid decomposition occurs. This indicates that 350 °C lies within the active PET degradation region and can initiate substantial decomposition under the present reactor conditions.

The results of the TGA EZAC (Figure 3b) revealed the thermal degradation behavior of the three stages of the material. An initial weight loss of approximately 8.01% was observed within the temperature range of 23.5–100 °C, which was mainly attributed to the evaporation of physically adsorbed moisture and volatile compounds. This was followed by a relatively stable region up to approximately 350 °C, indicating good thermal stability before the onset of major decomposition. The primary thermal degradation occurred in the range of 350–650 °C, characterized by a significant mass reduction associated with the decomposition of the main structural components of the material. Beyond 650 °C, the TGA curve became nearly constant with only a small residual mass remaining, suggesting that most organic constituents had decomposed completely, leaving thermally stable inorganic or carbonaceous residues.

3.2. Product Distribution

Pyrolysis of PET with EZAC produced three primary fractions: liquid oil, solid residue, and non-condensable gas. The relative yields of these fractions varied substantially with the PET:EZAC ratio, indicating that EZAC loading strongly influences reaction pathways and product selectivity. Overall, moderate EZAC addition increased the liquid fraction, whereas higher EZAC loadings increased the solid fraction (Figure 4).

The initial increase in oil yield at low-to-moderate EZAC dosages suggests that EZAC promoted secondary vapor-phase reactions that favored condensable product formation. In contrast, the rise in the solid fraction at higher EZAC loadings likely reflects the combined effects of (i) the intrinsic mass contribution of EZAC (a non-volatile solid retained in the reactor) and (ii) increased carbon deposition (coke/char) and/or pore blockage caused by secondary polymerization/condensation of reactive intermediates on the carbon surface. Together, these effects can divert carbon away from the condensable phase and reduce the effective availability of active sites at excessive EZAC dosages, thereby shifting the distribution toward the solid fraction.

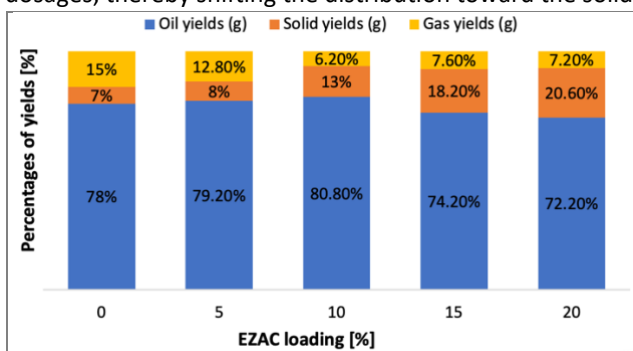


Figure 4.
Product yields from
PET–EZAC pyrolysis

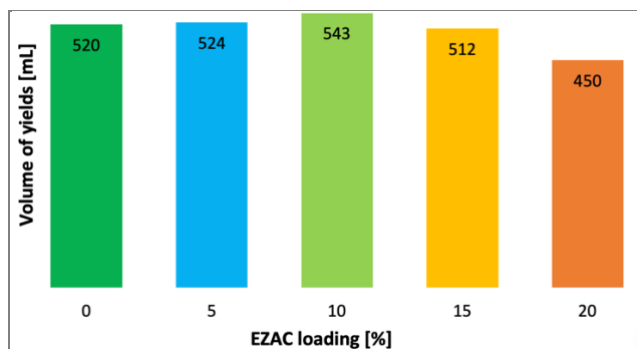
Pyrolysis of PET in the presence of EZAC produced three main fractions: liquid oil, solid residue, and non-condensable gas (Figure 4). For all experiments, the total feed mass was fixed at 500 g; therefore, the yield of each fraction is reported as a percentage of the initial feed to enable direct comparison among PET:EZAC ratios.

3.2.1. Liquid product formation

As shown in Figure 4, the oil yield increased with low EZAC addition, reached an optimum, and then declined at higher EZAC loadings. Non-catalytic PET pyrolysis produced 390 g of oil (78.0%). Incorporation of 5% EZAC increased the oil yield slightly to 396 g (79.2%), and the highest oil yield was obtained at 10% EZAC (PET:EZAC = 90:10, w/w), reaching 404 g (80.8%). Further increases in EZAC reduced the oil yield to 371 g (74.2%) at 15% EZAC and 361 g (72.2%) at 20% EZAC. This response indicates that moderate EZAC loading promotes liquid formation, whereas excessive EZAC shifts carbon away from the liquid phase toward the solid and/or gas phases.

The oil-volume trend (Figure 5) corroborated the mass-yield results. The collected volume increased from 520 mL (0% EZAC) to 524 mL (5% EZAC) and peaked at 543 mL (10% EZAC), before decreasing to 512 mL (15% EZAC) and 450 mL (20% EZAC). Collectively, these data confirm an optimum operating window at PET:EZAC = 90:10 under the tested conditions. Remarkably, no operational issues regarding condenser blocking or clogging were observed throughout the pyrolysis process. This stands in contrast to conventional PET pyrolysis, which typically suffers from downstream line blockages caused by the sublimation of terephthalic acid. The absence of clogging in this system is heavily attributed to the Euxideroxylon zwageri-based activated carbon (EZAC); its highly porous structure successfully trapped or catalytically cracked these heavy condensable vola-

Figure 5.
Liquid yield volume
from PET–EZAC
pyrolysis



hydrocarbons (C7–C10 fraction at 62.95%) and a minimal presence of heavy wax-forming oligomers (>C20). At this loading, EZAC promoted mild cracking and rearrangement reactions, producing condensable compounds within a molecular-weight and boiling-range more favorable for liquid recovery (e.g., mild cracking and rearrangement), producing condensable compounds within a molecular-weight/boiling-range more favorable for liquid recovery. In contrast, at 15–20% EZAC, the reduction in oil yield/volume is plausibly associated with increased residue formation (char/coke) and partial pore blockage or active-site coverage by deposited carbon, which can diminish effective catalytic performance. In addition, the larger solid fraction at elevated EZAC loadings (including the mass contribution of EZAC itself) inherently reduces the fraction of carbon recovered as liquid. This pattern aligns with reports that excessive biomass/catalyst loading can increase solid formation and drive unfavorable secondary pathways, ultimately reducing liquid yield and/or compromising liquid quality [33], [43].

3.2.2. Solid product formation

Figure 4 also highlights a trade-off among product fractions as EZAC loading increased. The apparent solid fraction rose with increasing EZAC loading. Non-catalytic PET pyrolysis produced 35 g of solid residue (7.0%). With EZAC addition, the solid yield increased to 40 g (8.0%) at 5% EZAC, 65 g (13.0%) at 10% EZAC, 91 g (18.2%) at 15% EZAC, and 103 g (20.6%) at 20% EZAC. The solid yield reported in **Figure 3** represents the apparent recovered solid fraction. In catalytic runs, this fraction includes both the retained EZAC catalyst and newly formed solid carbonaceous residues such as char and/or coke. Therefore, the increase in apparent solid yield with increasing EZAC loading should not be attributed solely to enhanced char formation. To better interpret the catalyst effect, the corrected solid residue can be estimated by subtracting the initial EZAC mass from the recovered solid mass as following Eq. (1) and the results are shown in **Table 2**.

This correction indicates that the apparent increase in solid yield is strongly influenced by the retained EZAC mass. The remaining corrected solid fraction is more representative of newly formed

$$m_{\text{corrected solid}} = m_{\text{recovered solid}} - m_{\text{initial EZAC}} \quad (1)$$

Table 2.
Apparent and corrected
solid residues after
subtracting initial EZAC
mass

EZAC loading	Initial EZAC mass	Recovered solid	Corrected solid residue
0%	0 g	35 g	35 g
5%	25 g	40 g	15 g
10%	50 g	65 g	15 g
15%	75 g	91 g	16 g
20%	100 g	103 g	3 g

char/coke, although further post-reaction catalyst characterization is required to distinguish char deposition, coke formation, and catalyst mass retention more accurately.

3.2.3. Gas product formation

The gas fraction (**Figure 4**) responded nonlinearly to EZAC addition. Non-catalytic PET pyrolysis generated 75 g of gas (15.0%). The gas yield decreased to 64 g (12.8%) at 5% EZAC and reached a minimum at 10% EZAC (31 g; 6.2%). With further EZAC addition, the gas yield increased slightly to 38 g (7.6%) at 15% EZAC and 36 g (7.2%) at 20% EZAC.

The reduction in gas yield at low-to-moderate EZAC dosages ($\leq 10\%$) is consistent with the increased liquid fraction, implying that a larger share of volatilized products fell within readily condensable ranges. At higher EZAC loadings, part of the volatile stream may undergo additional cracking and/or reforming, leading to a modest rebound in gas formation, although still below the non-catalytic condition. The non-condensable gas comprised light components such as H_2 , CH_4 , CO , and CO_2 , together with other light hydrocarbons, reflecting chain scission and secondary transformations during PET pyrolysis.

3.3. Pyrolysis Products for Liquid and Gaseous Fuels (Hydrogen and Methane)

3.3.1. Oil product

The pyrolysis oils obtained from PET–EZAC experiments were evaluated using preliminary fuel-property indicators, including heating value, octane number, density, kinematic viscosity, and flash point. These properties varied with PET:EZAC ratio, indicating that EZAC influences secondary reaction pathways and, consequently, product composition. Visual inspection (**Figure 6**) showed broadly similar oil coloration across treatments and an overall gasoline-like appearance. However, visual observations are qualitative and do not reliably indicate chemical similarity; therefore,

Figure 6.
Snapshot of PET–EZAC
pyrolysis oil products
with loadings: (a) 0%;
(b) 5%; (c) 10%; (d)
15%; (e) 20%

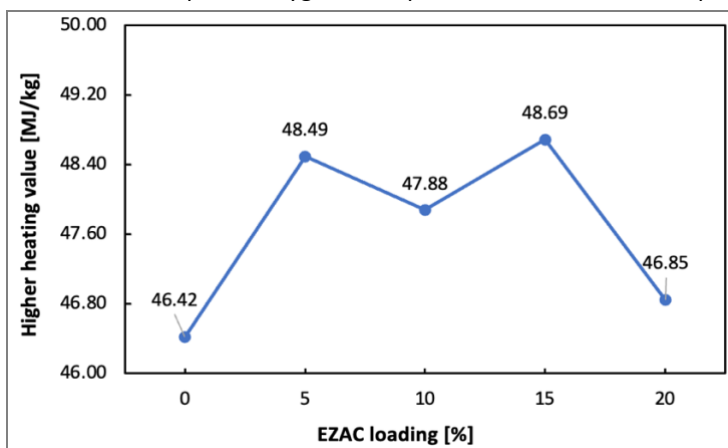


compositional analysis (e.g., GC–MS) is necessary to resolve changes in dominant compounds that may not be apparent from appearance alone.

3.3.1.1. Higher heating value

As shown in **Figure 7**, the higher heating value (HHV) of the oils ranged from 46.42 to 48.69 MJ/kg. The lowest HHV was obtained under non-catalytic conditions (46.42 MJ/kg), whereas the highest value was recorded at PET:EZAC = 85:15 (48.69 MJ/kg). For context, commercial liquid fuels have been reported to exhibit HHVs of approximately 42.5379–46.0548 MJ/kg [32], indicating that the present oils fall within to above this reference range. The increase in HHV at certain EZAC loadings may reflect enrichment in higher-energy hydrocarbon fractions and/or a reduced contribution of specific oxygenated species; however, this interpretation should be corroborated

Figure 7.
Higher heating value of
PET–EZAC pyrolysis
oils at different ratios

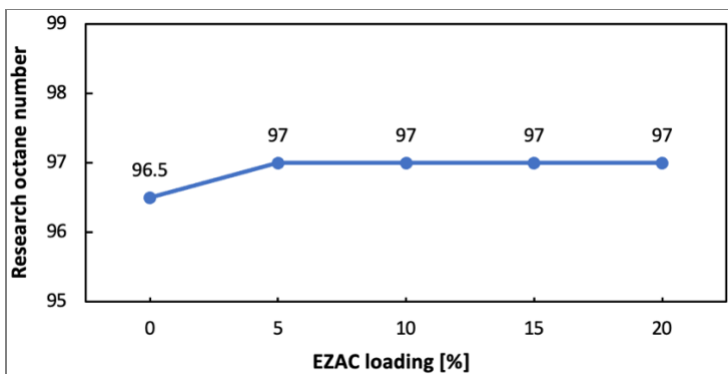


using compositional data (GC–MS) and ideally elemental analysis. Although HHV is a favorable indicator, practical feasibility as a drop-in fuel requires additional assessment of parameters such as volatility, stability, and impurity content, and may require fractionation and/or upgrading depending on the intended application.

3.3.1.2. Research octane number

Figure 8 presents the research octane number (RON) of the pyrolysis oils produced at different PET:EZAC mass ratios. RON reflects the resistance of a fuel to knock (auto-ignition) in spark-ignition engines and is therefore commonly used as an initial indicator of gasoline quality. The non-catalytic PET oil (100:0) exhibited a RON of 96.5, whereas oils obtained with EZAC addition (95:5, 90:10, 85:15, and 80:20) showed a slightly higher and identical RON value of 97. Overall, EZAC increased

Figure 8.
Research octane
number of PET–EZAC
pyrolysis oils at
different ratios



RON relative to the non-catalytic condition, although the improvement was marginal. From an application perspective, a RON of 97 is within the range typically associated with high octane gasoline marketed in Indonesia. Nevertheless, suitability for practical use should not be inferred from RON alone

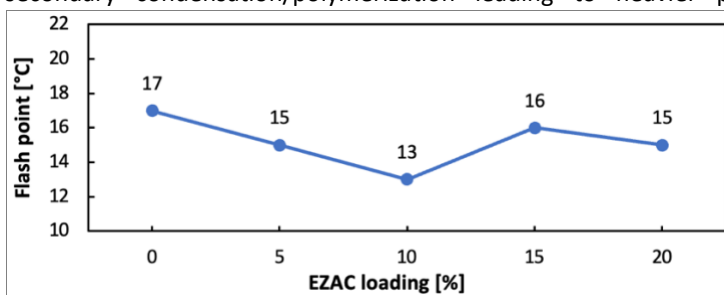
because fuel performance and safety are also governed by volatility, oxidative stability, gum formation tendency, and impurity levels. Although the measured RON values provide useful information on the knock-resistance tendency of the liquid product, they should not be interpreted as evidence that the PET-derived pyrolysis oil is directly equivalent to commercial gasoline. PET-derived pyrolysis oil is chemically complex and may contain oxygenated compounds, unsaturated species, and other impurities. Therefore, additional upgrading, fractionation, stability testing, and standard fuel-specification analysis are required before practical application as transportation fuel. Accordingly, the relationship between RON and compositional changes induced by EZAC is further interpreted using the GC–MS results (Figure 13).

3.3.1.3. Flash point

Flash point is the lowest temperature at which a fuel releases sufficient vapor to ignite momentarily in the presence of an ignition source. It is closely related to volatility and is therefore an important parameter for fuel handling and safety. As shown in Figure 9, the oil produced by non-catalytic PET pyrolysis exhibited a higher flash point than oils obtained with EZAC addition, indicating that EZAC promoted formation of more volatile components. Among the catalytic conditions, the lowest flash point was observed at 10% EZAC (13 °C), suggesting an increased contribution of light, gasoline-range fractions under the optimum PET:EZAC ratio. At higher EZAC loadings, the flash point increased to 16 °C (15% EZAC) and 15 °C (20% EZAC). This upward shift may reflect a greater proportion of less volatile components (i.e., heavier fractions) and/or compositional changes induced by excessive catalyst loading (e.g., enhanced secondary condensation/polymerization leading to heavier products). This interpretation

should be evaluated alongside GC–MS results to confirm whether the hydrocarbon distribution shifts toward heavier fractions at higher EZAC contents.

Figure 9.
Flash point of PET–EZAC
pyrolysis oils at
different ratios

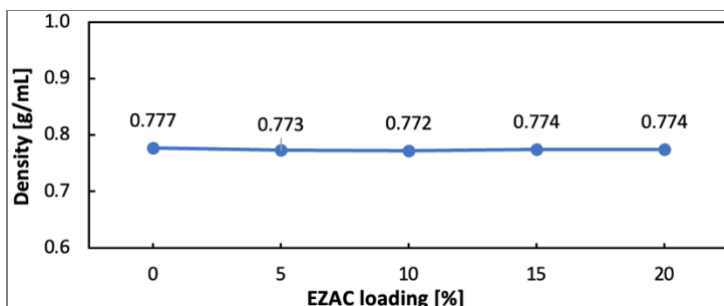


3.3.1.4. Density

Density is a key physical property that significantly influences fuel injection, atomization, and combustion behavior. As illustrated in Figure 10, an increase in EZAC loading resulted in a marginal decrease in the density of the pyrolysis oil. The pyrolysis oil derived from non-catalytic PET pyrolysis exhibited a density of 0.777 g/mL, whereas the oil obtained with the addition of EZAC fell within a narrower range of 0.772–0.774 g/mL. For comparison, commercial gasoline typically displays a density of approximately 0.715–0.770 g/mL [28], [44]. These density profiles indicate that the produced pyrolysis oil aligns closely with the gasoline density spectrum and approaches the density threshold of petroleum-based aviation fuels, which ranges between 0.775 and 0.840 g/mL [45]. Although the measured density of the pyrolysis oil is slightly higher than that of commercial

gasoline, a higher density does not inherently imply superior fuel performance. Consequently, direct in-engine performance testing is required in future studies to fully evaluate its viability.

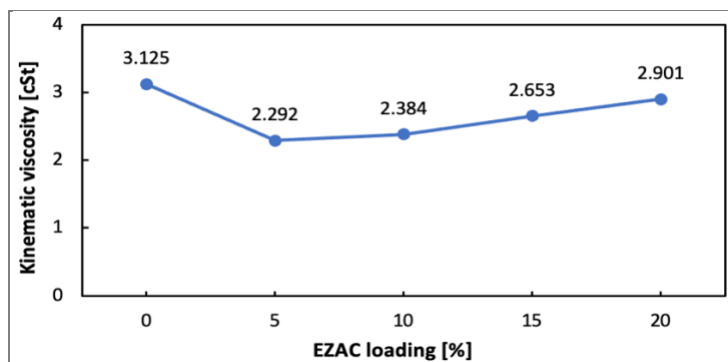
Figure 10.
Density of PET–EZAC
pyrolysis oils at
different ratios



3.3.1.5. Kinematic viscosity

Kinematic viscosity describes a fluid's resistance to flow and directly influences atomization, spray formation, and flow behavior in fuel-handling systems. As shown in Figure 11, kinematic viscosity decreased with increasing EZAC loading, consistent with the slight decrease in density and suggesting a higher contribution of lighter and/or shorter-chain compounds in the oil. The non-

Figure 11.
Kinematic viscosity of
PET–EZAC pyrolysis
oils at different ratios



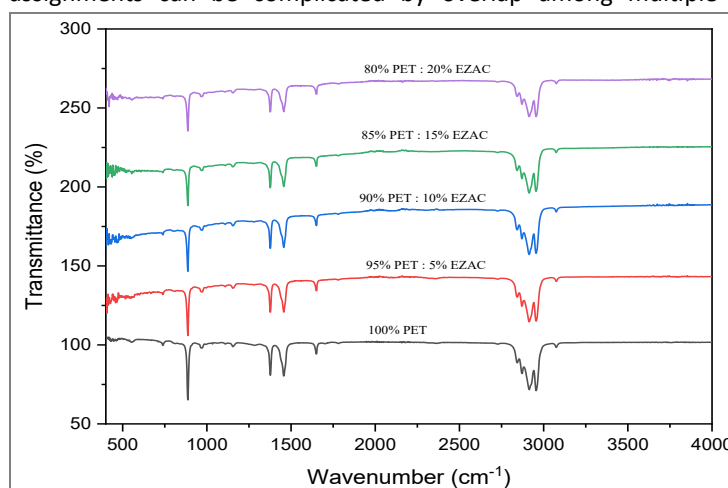
catalytic PET oil exhibited a kinematic viscosity of 3.125 cSt, whereas oils produced with EZAC addition showed lower values in the range of 2.292–2.901 cSt, indicating that EZAC generally promoted the formation of less viscous oils.

3.3.1.6. Fourier transform infrared spectroscopy (FTIR)

Figure 12 presents the FTIR spectra of pyrolysis oils obtained at different PET:EZAC ratios. The oil produced under non-catalytic conditions showed characteristic bands associated with PET-derived and hydrocarbon structures, including carbonyl/ester groups ($\text{C}=\text{O}$ stretching at 1720 cm^{-1}), Aromatic structures ($\text{C}-\text{H}$ out-of-plane bending at $700\text{--}900\text{ cm}^{-1}$), and aliphatic chains ($\text{C}-\text{H}$ stretching at $2850\text{--}2950\text{ cm}^{-1}$). Following EZAC addition, several bands changed in intensity and additional features appeared in specific regions, indicating that EZAC altered the functional-group composition of the oil.

In particular, bands observed around $3300\text{--}3400\text{ cm}^{-1}$ may be attributed to $\text{O}-\text{H}$ stretching, while signals in the $1000\text{--}1200\text{ cm}^{-1}$ region are commonly associated with $\text{C}-\text{O}$ stretching vibrations. These changes suggest that oxygen-containing functionalities may be present and/or redistributed across samples as a consequence of EZAC-assisted secondary reactions. Nevertheless, FTIR provides primarily qualitative or semi-quantitative information and band assignments can be complicated by overlap among multiple functional groups. Therefore,

Figure 12.
The formation of
functional groups in
oil yields as measured
by FTIR



confirmation of specific compounds and detailed compositional shifts requires complementary analysis, particularly GC–MS. Overall, the FTIR results indicate that EZAC can modify the dominant functional groups in PET-derived oils, which is consistent with the observed changes in physical properties such as flash point and kinematic viscosity.

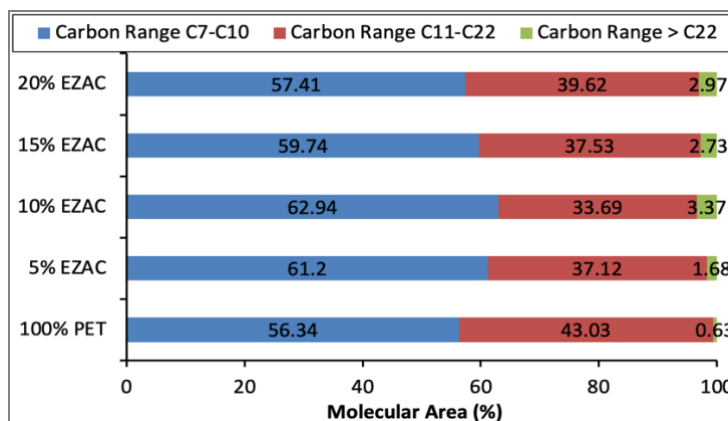
3.3.1.7. Gas chromatography–mass spectrometry (GC–MS)

GC–MS was used to assess the carbon-number distribution of the pyrolysis oils as an initial indicator of whether the product is enriched in gasoline-range components or shifted toward heavier fractions (e.g., kerosene/diesel). **Figure 13** summarizes the carbon-range profiles for each PET:EZAC ratio. This information is relevant because carbon number influences volatility and combustion behavior and is commonly used for a preliminary classification of pyrolysis-derived liquid fuels [7], [46].

Under non-catalytic conditions, the oil was dominated by the C7–C10 fraction (56.34%). EZAC addition increased the relative abundance of C7–C10 across all tested ratios, with the maximum observed at PET:EZAC = 90:10 (62.95%). Relative to non-catalytic PET pyrolysis, the C7–C10 fraction increased by 8.63% (5% EZAC), 11.73% (10% EZAC), 6.03% (15% EZAC), and 1.07% (20% EZAC). Meanwhile, the C11–C22 fraction remained substantial (33.69–43.03%), whereas the heavy fraction ($>\text{C}22$) was consistently minor (0.63–3.37%). These results indicate that EZAC primarily promotes a shift toward lighter products while limiting formation of very heavy components.

The predominance of the C7–C10 fraction (56.34–62.95%) suggests that the PET–EZAC oils are largely within the gasoline-range/light naphtha domain [34], [35]. Mechanistically, this enrichment suggests enhanced secondary cracking and vapor-phase upgrading, which increased

Figure 13.
Oil yields carbon range
profile distribution



the proportion of smaller condensable molecules. However, classification based solely on carbon-number ranges remains a preliminary indicator; practical fuel suitability also depends on broader specifications, including the stability/oxidative resistance, and impurity content.

3.3.1.8. Hydrocarbon-class distribution (Alkanes, Olefin, and Aromatics)

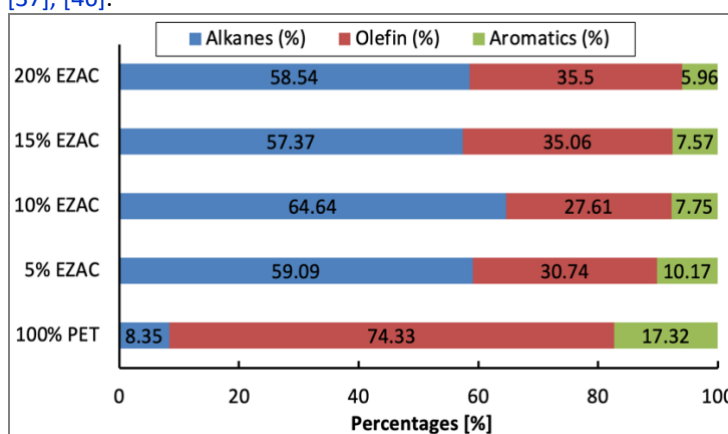
The distribution of Alkanes, Olefin, and Aromatics in PET–EZAC pyrolysis oils provides further insight into the secondary reaction pathways during pyrolysis. In general, EZAC alters the balance among cracking, hydrogen-transfer reactions, dehydrogenation, isomerization, and aromatization. However, the compositional changes with increasing EZAC loading are not entirely monotonic, particularly for Alkanes and Olefin.

Under non-catalytic conditions, the pyrolysis oil from 100% PET was strongly dominated by Olefin (74.33%), followed by Aromatics (17.32%), while the Alkane fraction was relatively low (8.35%). This result indicates that, in the absence of EZAC, PET pyrolysis favored the formation of unsaturated hydrocarbons, suggesting extensive cracking and dehydrogenation reactions. The relatively high Aromatic fraction also suggests the occurrence of cyclization and condensation reactions during thermal degradation.

The addition of EZAC substantially changed the hydrocarbon-class distribution. At PET:EZAC = 95:5, the Alkane fraction increased sharply to 59.09%, while Olefin decreased to 30.74% and Aromatics declined to 10.17%. This indicates that even a low EZAC loading significantly promoted secondary upgrading reactions, particularly those leading to a higher proportion of saturated hydrocarbons. At PET:EZAC = 90:10, the Alkane fraction reached its highest value (64.64%), accompanied by the lowest Olefin content (27.61%) and a further reduction in Aromatics (7.75%). This composition suggests that the 90:10 ratio provided the most favorable extent of secondary upgrading, converting reactive unsaturated intermediates into more stable hydrocarbon fractions.

At higher EZAC loadings, namely 15–20%, the hydrocarbon distribution showed a slight shift away from the optimum observed at 10% EZAC. At PET:EZAC = 85:15, Alkanes decreased to 57.37%, while Olefin increased to 35.06% and Aromatics slightly decreased to 7.57%. A similar tendency was observed at PET:EZAC = 80:20, where Alkanes slightly increased to 58.54%, Olefin remained relatively high at 35.50%, and Aromatics further decreased to 5.96%. These results indicate that excessive EZAC loading did not further improve Alkane selectivity. Instead, excessive EZAC loading may have promoted additional secondary cracking, leading to a partial increase in Olefin formation. Nevertheless, the Aromatic fraction consistently decreased with increasing EZAC loading, suggesting that EZAC may suppress excessive aromatization or promote further transformation of Aromatic precursors under these conditions. Similar trends, including enhanced isomerization and Olefin formation during catalytic plastic pyrolysis, have been reported in related studies [7], [36], [37], [46].

Figure 14.
Distribution of
aromatic, alkane, and
olefin compounds in
oil yields of PET-EZAC
pyrolysis



Considering the combined indicators in Figure 13 and Figure 14, PET:EZAC = 90:10 appears to be the closest to gasoline-like characteristics because it produced the highest C7–C10 fraction (62.95%) and the most favorable hydrocarbon-class distribution, characterized by the highest Alkane content

(64.64%), the lowest Olefin content (27.61%), and a relatively low Aromatic fraction (7.75%). A higher Alkane fraction indicates more stable oil constituents, while controlled Olefin and Aromatic contents may support fuel performance without becoming overly dominant. In contrast, very high Olefin content may reduce oxidative stability due to oxidation and polymerization tendencies, while excessive Aromatics are typically undesirable because of emissions and regulatory considerations. Therefore, the 90:10 PET:EZAC ratio represents a practical compromise between gasoline-like compositional indicators, hydrocarbon stability, and expected fuel quality.

3.3.1.9. Complete GC-MS peak reports for each PET:EZAC ratio

Note for **Table 3** to **Table 7**: The GC-MS data are presented as instrument peak-area percentages and tentative library matches. The hydrocarbon/compound-group column is retained as an operational grouping from the peak report and is not intended to imply that the liquid product contains only conventional hydrocarbon oil yield components.

Table 3.
Complete GC-MS peak
report of PET-derived
pyrolysis oil yield from
100% PET

Peak	R,Time	Area	Area (%)	Height	Peak Report Height (%)	Base m/z	Name	Formula	Hydrocarbon class
1	3707	91123993	1.03	48226092	1.54	70.10	Heptanal	C7H14O	Olefin
2	4592	99700735	1.12	44584771	1.43	83.05	Cyclopentane, 1,1,3,4-tetramethyl-, cis-	C9H18	Aromatic
3	5104	183868743	2.07	83239590	2.67	112.05	Cyclohexane, 1,2,3-trimethyl-, (1.alpha.,2.beta	C9H18	Aromatic
4	5349	827488444	9.33	267887496	8.58	44.85	trans-2,3-Epoxyoctane	C8H16O	Olefin
5	5728	349116744	3.93	132209985	4.23	126.15	1-Heptene, 2-isohexyl-6-methyl-	C14H28	Olefin
6	6137	105887075	1.19	44872218	1.44	109.05	Cyclohexene, 3,3,5-trimethyl-	C9H16	Aromatic
7	6744	233608853	2.63	97425230	3.12	43.95	1-Octanol	C8H18O	Alkane
8	7348	163517562	1.84	61250349	1.96	82.15	Cyclohexane, 1-propenyl-	C9H16	Aromatic
9	8312	52092358	0.59	23367571	0.75	56.05	2-Methyl-1-nonene	C10H20	Olefin
10	9949	96615954	1.09	46338929	1.48	41.05	1-Undecene	C11H22	Olefin
11	10361	345448258	3.89	119903350	3.84	57.95	trans-2,3-Epoxyoctane	C8H16O	Olefin
12	11026	67713754	0.76	27572663	0.88	41.00	1-Undecene	C11H22	Olefin
13	11963	68156838	0.77	30128872	0.96	83.05	Bicyclo[3.1.1]heptan-3-one, 2,6,6-trimethyl-,	C10H16O	Aromatic
14	12415	842707213	9.5	247546113	7.93	57.90	trans-2,3-Epoxyoctane	C8H16O	Olefin
15	13871	221283247	2.49	82047303	2.63	83.05	3-Hexadecene, (Z)-	C16H32	Olefin
16	14346	48418096	0.55	23554167	0.75	56.05	3-Undecene, 8-methyl-	C12H24	Olefin
17	14586	428106863	4.82	152504870	4.88	41.95	7-Octadecyne, 2-methyl-	C19H36	Olefin
18	14668	187290494	2.11	79322102	2.54	55.15	Bicyclo[3.1.1]heptane, 2,6,6-trimethyl-	C10H16O	Aromatic
19	14896	207972400	2.34	79829927	2.56	125.10	1,1'-Bicyclohexyl, 2-propyl-, trans-	C15H28	Aromatic
20	15190	58548961	0.66	16570429	0.53	43.05	n-Nonadecanol-1	C19H40O	Alkane
21	15389	134511497	1.52	49816929	1.60	125.10	Cyclohexane, 1,1'-(1-methylethylidene)bis-	C15H28	Aromatic
22	16122	138671016	1.56	52982564	1.70	69.15	1,1'-Bicyclohexyl, 2-propyl-, trans-	C15H28	Aromatic
23	16474	67607934	0.76	32335409	1.04	69.05	2-Undecene, 4,5-dimethyl-, [R*,R*-(E)]-	C13H26	Olefin
24	17019	105055352	1.18	32958159	1.06	43.00	Dodecane, 2,6,11-trimethyl-	C15H32	Alkane
25	17454	101202219	1.14	42985454	1.38	43.00	Octadecane, 1-(ethenyl)-	C20H40O	Olefin
26	17899	23098275	0.26	10323303	0.33	69.05	4-Methyl-dodecan-1-ol	C13H28O	Alkane
27	17682	45805059	0.52	19324219	0.62	55.05	1,19-Eicosadiene	C20H38	Olefin
28	18425	113231797	1.28	40804635	1.31	69.05	3-Tetradecene, (E)-	C14H28	Olefin
29	18970	857780267	9.67	259424834	8.31	86.00	1,2-Epoxy-nonane	C10H18O	Olefin
30	19196	683491862	7.7	189198445	6.06	71.95	trans-2,3-Epoxydecane	C10H20O	Olefin
31	19426	736567293	8.3	228952399	7.33	86.00	1,2-Epoxy-nonane	C10H18O	Olefin
32	20155	101366028	1.14	43335000	1.39	69.05	11-Methyldodecanol	C13H28O	Alkane
33	20862	224325341	2.53	87856870	2.81	82.05	9-Octadecen-1-ol, (Z)-	C18H36O	Olefin
34	21312	67493656	0.76	28035594	0.90	69.05	(E)-Tetradec-11-en-1-yl 2,2,3,3,4,4,4-heptaflu	C14H26O	Olefin
35	24512	176229212	1.99	70954940	2.27	69.05	3-Eicosene, (E)-	C20H40	Olefin
36	25161	123953071	1.4	41509601	1.33	69.05	11-Methyldodecanol	C13H28O	Alkane
37	25409	40206587	0.45	17813525	0.57	69.05	2-Hexyl-1-octanol	C14H30O	Alkane
38	26207	94784263	1.07	37266936	1.19	69.05	10-Dodecen-1-ol, 7,11-dimethyl-	C14H28O	Olefin
39	27783	39797390	0.45	14692047	0.47	73.00	Cyclooctasiloxane, hexadecamethyl-	C16H48O8Si	Aromatic
40	29367	54866225	0.63	20795691	0.67	69.05	Tricosyl trifluoroacetate	C25H47F3O2	Olefin
41	29973	56199550	0.63	17289366	0.55	69.05	1-Dodecanol, 2-hexyl-	C18H38O	Alkane
42	31176	37014818	0.42	13810921	0.44	73.00	Cyclononasiloxane, octadecamethyl-	C18H54O9Si	Aromatic
43	34197	40634712	0.46	14693933	0.47	73.05	Cyclodecasiloxane, eicosamethyl-	C20H60O10Si	Aromatic
44	36967	347270035	0.39	13811933	0.44	73.00	Cyclononasiloxane, hexadecamethyl-	C16H48O8Si	Aromatic
45	39491	37697353	0.42	15609078	0.50	73.00	Cyclononasiloxane, octadecamethyl-	C18H54O9Si	Aromatic
46	44080	58893039	0.66	18181405	0.58	73.05	Cyclononasiloxane, octadecamethyl-	C18H54O9Si	Aromatic

Table 4.
Complete GC-MS peak
report of PET-derived
pyrolysis oil yield from
95% PET:5% EZAC

Peak	R,Time	Area	Area (%)	Height	Peak Report Height (%)	Base m/z	Name	Formula	Hydrocarbon class
1	2.397	358199474	0.83	168919617	1.53	52.05	2,2,2-Trichloro-1-(2-nitrophenylthioamino)ethanol	C8H7Cl3N2O3S	Aromatic
2	2.466	94848661	0.22	70437791	0.64	44.00	1,3,2-Dioxaborolane, 2-ethyl-, 2-Epoxy-nonane	C4H9BO2	Alkane
3	2.699	264514619	0.61	128459535	1.16	71.15	Cyclopentane, 1,1,3-trimethyl-	C9H18O	Alkane
4	3.026	76491653	0.18	42935574	0.39	83.05	Cyclobutane, 1-butyl-2-ethyl-	C8H16	Alkane
5	3.273	329313599	0.76	107564058	0.97	71.00	Bicyclo[4.1.0]heptan-2-ol, (1.alpha.,2.beta.,6.alpha.)-	C10H20	Alkane
6	3.445	193073657	0.45	109024264	0.99	58.00	trans-2,3-Epoxyoctane	C7H12O	Alkane
7	3.544	843779348	1.95	249587596	2.26	72.00	Urea, 1-phenyl-3-phenylaminosulfonyl)	C8H16O	Alkane
8	3.77	1437846224	3.33	92951217	0.84	92.90	4-Azaspiro[2.6]nonan-5-one	C13H13N3O3S	Aromatic
9	3.85	258898505	0.6	140392699	1.27	43.85	Cyclooctane	C8H16	Alkane
10	3.941	107088926	0.25	60559149	0.55	97.95	1,2-Epoxy-nonane	C9H18O	Alkane
11	4.08	446732146	1.03	161154783	1.46	58.00	2-Tridecane	C13H24	Olefin
12	4.17	96128789	0.22	60313088	0.55	95.05	Cyclooctane	C8H16	Alkane
13	4.212	-2035998	0	30496682	0.28	55.95	2(1H)-Naphthalene, 3,4,4a,5,8,8a-hexahydro-4a-methyl-, trans-	C11H16O	Aromatic
14	4.308	871662307	2.02	278996248	2.53	94.00	1,1-Dimethyl-4-methylenecyclohexane	C9H16	Olefin
15	4.426	172666800	0.4	64265798	0.58	67.05			

Table 4. (Continous)
Complete GC-MS peak
report of PET-derived
pyrolysis oil yield from
95% PET:5% EZAC

Peak	R,Time	Area	Area (%)	Height	Peak Report Height (%)	Base m/z	Name	Formula	Hydrocarbon class
16	4.503	177975271	0.41	94772232	0.86	97.15	Bis(1-methylheptyl) methylphosphonate	C17H37O3P	Alkane
17	4.583	1100499739	2.55	259804662	2.35	127.05	trans-2,3-Epoxyoctane	C8H16O	Alkane
18	4.982	125175537	0.29	58774157	0.53	95.95	1-Methylcyclooctene	C9H16	Olefin
19	5.126	1726586667	4	236003306	2.14	127.85	Oxirane, octyl-	C10H20O	Alkane
20	5.479	3506602274	8.12	309825007	2.81	59.15	5-Methoxy-cyclooctene	C9H16O	Olefin
21	5.648	334120941	0.77	90186265	0.82	112.05	1,2,2-Trimethyl-1-aza-spiro[2.3]hexane	C8H15N	Alkane
22	5.77	1241385715	2.87	335179215	3.04	127.60	5-Ethoxy-cyclooctene	C10H18O	Olefin
23	5.871	100580713	0.23	54727359	0.5	109.10	Cyclopentanecarboxaldehyde, 2-methyl-3-methylene-	C8H12O	Olefin
24	5.923	156127398	0.36	87481458	0.79	91.05	2-(4-Benzyl-1,2,5-trimethylpiperidin-4-yl)acetonitrile	C17H24N2	Aromatic
25	6.188	1336895220	3.1	98873687	0.9	85.05	2- Chloropropionic acid, decyl ester	C13H25ClO2	Alkane
26	6.387	596435801	1.38	217280593	1.97	125.00	2(3H)-Benzofuranone, hexahydro-3-methylene-	C9H12O2	Aromatic
27	6.524	410582987	0.95	123722882	1.12	57.95	1-Heptene, 2-isohexyl-6-methyl-	C14H28	Olefin
28	6.758	791212513	1.83	237011612	2.15	44.90	trans-2,3-Epoxyoctane	C8H16O	Alkane
29	6.912	676705958	1.57	202816315	1.84	138.15	2-Oxatricyclo[4.3.1.0(3,8)]decane	C9H14O	Alkane
30	7.015	274221359	0.63	94507578	0.86	123.95	Cyclopropane, 1,1,2-trimethyl-3-(2-methyl-1-propenyl)-	C10H18	Olefin
31	7.088	227775954	0.53	101283006	0.92	84.75	3-Octyn-1-ol	C8H14O	Olefin
32	7.355	809560198	1.87	257835334	2.33	66.55	2(3H)-Benzofuranone, hexahydro-3-methylene-	C9H12O2	Aromatic
33	7.44	108829123	0.25	45678802	0.41	96.00	2-n-Butyl-2-cyclopentenone	C9H14O	Olefin
34	7.578	179118149	0.41	81472302	0.74	83.05	Bicyclo[3.1.1]heptane, 2,6,6-trimethyl-	C10H18	Alkane
35	7.641	152770599	0.35	51730606	0.47	96.00	2-Dodecyne	C12H22	Olefin
36	7.733	73780242	0.17	38209812	0.35	82.05	Hexane, 1-(isopropylidenecyclopropyl)-	C12H22	Alkane
37	7.798	60973978	0.14	35649497	0.32	69.05	Cyclohexane, 1,1,2,3-tetramethyl-	C10H20	Alkane
38	7.869	23214778	0.05	17897408	0.16	43.05	1-Undecene, 8-methyl-	C12H24	Olefin
39	7.94	131872540	0.31	55357039	0.5	97.05	Cyclooctanone, 2-methyl-	C9H16O	Alkane
40	8.037	392835627	0.91	101277524	0.92	44.10	Octanal	C8H16O	Alkane
41	8.098	154749632	0.36	72492651	0.66	56.00	Hexahydro-1,4-dioxo-cyclopropa[a]pentalen-3-one	C7H8O3	Alkane
42	8.33	458909837	1.06	95440750	0.86	84.05	Cyclobutane, 1-butyl-2-ethyl-	C10H20	Alkane
43	8.484	110368844	0.26	37554195	0.34	83.05	Cyclopentane, 1,3-dimethyl-2-(1-methylethenyl)-, (1.alpha.,2.alpha.,3.beta.)-	C10H18	Olefin
44	8.603	373517798	0.86	118979005	1.08	44.00	Hexahydro-1,4-dioxo-cyclopropa[a]pentalen-3-one	C7H8O3	Alkane
45	8.761	244575124	0.57	90968236	0.82	58.00	1,4,5,8-Tetraazadecalin	C6H14N4	Alkane
46	9.028	319969128	0.74	107705381	0.98	120.15	Bicyclo[6.1.0]non-4-ene-9-carbaldehyde	C10H14O	Olefin
47	9.096	164429525	0.38	84183296	0.76	109.05	Naphthalene, decahydro-, trans-	C10H18	Aromatic
48	9.26	192725612	0.45	72771918	0.66	82.05	Bicyclo[3.1.1]heptane, 2,6,6-trimethyl-	C10H18	Alkane
49	9.498	288659812	0.67	92570551	0.84	81.05	Cyclooctene, 1,2-dimethyl-	C10H18	Olefin
50	9.605	408942480	0.95	92430490	0.84	82.05	7-Octadecyne, 2-methyl-	C19H36	Olefin
51	9.683	86200898	0.2	42666018	0.39	56.00	1-Decene	C10H20	Olefin
52	9.8	1331033123	3.08	232658942	2.11	71.95	1,2-Epoxy-nonane	C9H18O	Alkane
53	10.02	164519694	0.38	74165762	0.67	43.95	5-Hydroxycyclooctane-1,2-dione	C8H12O3	Alkane
54	10.108	168287626	0.39	73318391	0.66	57.05	Decanal	C10H20O	Alkane
55	10.365	774744443	1.79	214801102	1.95	114.10	trans-2,3-Epoxyoctane	C8H16O	Alkane
56	10.784	85591205	0.2	36212411	0.33	69.10	Cyclohexane, 1,2-diethyl-1-methyl-	C11H22	Alkane
57	11.02	349867652	0.81	118271445	1.07	98.05	1-Tetradecene	C14H28	Olefin
58	11.325	150722235	0.35	68943115	0.62	84.00	1-Undecene	C11H22	Olefin
59	11.463	239919938	0.56	70880066	0.64	69.15	Pentadec-7-ene, 7-bromomethyl-	C16H31Br	Olefin
60	11.571	197394496	0.46	78350690	0.71	43.05	Oxirane, tetradecyl-	C16H32O	Alkane
61	11.765	494711401	1.15	94730131	0.86	95.05	Bicyclo[3.1.1]heptane, 2,6,6-trimethyl-	C10H18	Alkane
62	11.895	643515264	1.49	95794801	0.87	85.05	7-Octyloxepan-2-one	C14H26O2	Alkane
63	11.97	354271297	0.82	91669646	0.83	84.00	Oleyl alcohol, trifluoroacetate	C20H35F3O2	Olefin
64	12.193	634771351	1.47	98922409	0.9	125.05	s-2-Dodecen-1-ol, trifluoroacetate	C14H23F3O2	Olefin
65	12.438	1637912085	3.79	352316557	3.19	58.95	trans-2,3-Epoxyoctane	C8H16O	Alkane
66	12.563	1145573933	2.65	314252905	2.85	86.00	Oxirane, octyl-	C10H20O	Alkane
67	12.877	30158196	0.07	19812725	0.18	57.05	1-Octanol, 2-methyl-	C9H20O	Alkane
68	13.024	70153461	0.16	34884912	0.32	43.05	1-Nonene, 4,6,8-trimethyl-	C12H24	Olefin
69	13.206	29334285	0.07	14410477	0.13	69.05	Cyclopentane, 1,1,3-trimethyl-3-(2-methyl-2-propenyl)-	C12H22	Olefin
70	13.474	90958868	0.21	38179333	0.35	125.10	Cyclohexane, 1,3,5-trimethyl-2-octadecyl-	C27H54	Alkane
71	13.544	77444970	0.18	39499578	0.36	55.00	E-11-Tetradecen-1-ol trifluoroacetate	C16H27F3O2	Olefin
72	13.603	36479191	0.08	21240610	0.19	83.05	2-Hexyl-2-cyclopenten-1-one	C11H18O	Olefin
73	13.779	113745381	0.26	52788109	0.48	83.10	Cyclohexane, (cyclopentylmethyl)-	C12H22	Alkane
74	14.033	477554790	1.11	104681627	0.91	57.15	Trichloroacetic acid, tridecyl ester	C15H27Cl3O2	Alkane
75	14.152	144533878	0.33	44730323	0.41	83.00	1,1'-Bicyclohexyl, 2-(1-methylethyl)-, trans-	C15H28	Alkane
76	14.342	150134024	0.35	65207168	0.59	56.05	3-Undecene, 8-methyl-	C12H24	Olefin
77	14.589	867956916	2.01	262634589	2.38	70.95	3,7-Diazabicyclo[3.3.1]nonane, 9,9-dimethyl-	C9H18N2	Alkane
78	14.92	410604740	0.95	107441759	0.97	69.95	1,1'-Bicyclohexyl, 2-propyl-, trans	C15H28	Alkane
79	15.186	111491184	0.26	49244943	0.45	43.00	-Undecene, 7-methyl-	C12H24	Olefin
80	16.124	271980284	0.63	98633799	0.89	70.00	1,1'-Bicyclohexyl, 2-propyl-, trans	C15H28	Alkane
81	16.466	262745671	0.61	101806491	0.92	71.00	1-Tetradecene	C14H28	Olefin
82	16.642	92910915	0.22	46513493	0.42	43.00	2-Undecene, 2,5-dimethyl-	C13H26	Olefin
83	16.781	147910937	0.34	50753024	0.46	41.00	Citronellyl butyrate	C14H26O2	Olefin
84	16.911	82782109	0.19	36719139	0.33	43.05	1-Nonene, 4,6,8-trimethyl-	C12H24	Olefin
85	17.017	238191951	0.55	63390158	0.57	57.15	Octadecane, 5-methyl-	C19H40	Alkane
86	17.246	193225098	0.45	67870022	0.61	71.15	3-Ethyl-3-methylheptane	C10H22	Alkane
87	17.449	245297479	0.57	95069285	0.86	71.15	Oxirane, dodecyl-	C14H28O	Alkane
88	17.679	182387757	0.42	73857056	0.67	69.05	Cyclododecanemethanol	C13H26O	Alkane
89	17.891	89099175	0.21	37216460	0.34	69.05	11-Methyldodecanol	C13H28O	Alkane
90	18.176	71948471	0.17	32484165	0.29	83.00	2-Octene, 2,3,7-trimethyl-	C11H22	Olefin
91	18.42	315924074	0.73	106230975	0.96	41.05	Acetic acid, chloro-, hexadecyl ester	C18H35ClO2	Alkane
92	18.62	82642049	0.19	38511335	0.35	69.05	(2,4,6-Trimethylcyclohexyl) methanol	C10H20O	Alkane
93	19.003	1444919064	3.35	111171555	1.01	111.15	1,2-Epoxy-nonane	C9H18O	Alkane
94	19.228	1113896930	2.58	113970199	1.03	84.10	1-Nonadecene	C19H38	Olefin
95	19.458	1297276086	3	115701065	1.05	84.05	trans-2,3-Epoxydecane	C10H20O	Alkane
96	20.16	337733367	0.78	102556870	0.93	57.05	1-Tetracosene	C24H48	Olefin
97	20.736	141255154	0.33	60246337	0.55	43.00	Pentadecafluorooctanoic acid, tetradecyl ester	C22H29F15O2	Alkane

Table 4. (Continous)
Complete GC-MS peak
report of PET-derived
pyrolysis oil yield from
95% PET:5% EZAC

Peak	R,Time	Area	Area (%)	Height	Peak Report Height (%)	Base m/z	Name	Formula	Hydrocarbon class
98	20.833	549625509	1.27	113689645	1.03	82.05	trans-2-Dodecen-1-ol, trifluoroacetate	C14H23F3O2	Olefin
99	21.059	116546750	0.27	45697878	0.41	69.05	(2,4-Dimethylcyclohexyl)methanol (isomer 2)	C9H18O	Alkane
100	21.307	174967560	0.41	66079095	0.6	69.05	Cyclododecanemethanol	C13H26O	Alkane
101	22.281	118379792	0.27	48055829	0.44	69.05	11-Methyldodecanol	C13H28O	Alkane
102	24.051	55409714	0.13	25228983	0.23	69.05	10-Dodecen-1-ol, 7,11-dimethyl-	C14H28O	Olefin
103	25.151	295878050	0.69	94288065	0.85	71.05	1-Tetracosene	C24H48	Olefin
104	25.4	110568544	0.26	47774287	0.43	69.05	1-Decanol, 2-hexyl-	C16H34O	Alkane
105	25.526	62101788	0.14	27838684	0.25	69.05	1-Dodecanol, 2-hexyl-	C18H38O	Alkane
106	26.198	271816901	0.63	105747193	0.96	109.05	Oleyl alcohol, trifluoroacetate	C20H35F3O2	Olefin
107	26.807	59578459	0.14	24517387	0.22	69.05	(2,4,6-Trimethylcyclohexyl) methanol	C10H20O	Alkane
108	29.354	224753373	0.53	86548515	0.74	69.10	Nonadecyl trifluoroacetate	C21H39F3O2	Alkane
109	29.961	220410050	0.51	69464917	0.63	69.00	1-Decanol, 2-hexyl-	C16H34O	Alkane
110	30.9	134067102	0.31	51516621	0.47	69.00	11-Dodecen-1-ol, 2,4,6-trimethyl-, (R,R,R)-	C15H30O	Olefin
111	31.475	14560309	0.03	7348239	0.07	69.05	Cyclooctane, 1-methyl-3-propyl-	C12H24	Alkane
112	33.702	46769073	0.11	19401396	0.18	69.05	1-Decanol, 2-hexyl-	C16H34O	Alkane
113	35.121	66788203	0.15	26016740	0.24	69.05	Cyclooctane, 1-methyl-3-propyl-	C12H24	Alkane

Table 5.
Complete GC-MS peak
report of PET-derived
pyrolysis oil yield from
90% PET : 10% EZAC

Peak	R,Time	Area	Area (%)	Height	Peak Report Height (%)	Base m/z	Name	Formula	Hydrocarbon class
1	1.675	1000421697	2.52	107357972	1.1	70.15	Nickel, bis(1,1-dimethyl-pi.-allyl)-bis(ethoxy)bis	C14H28NiO2	Olefin
2	2.393	324661174	0.82	157608303	1.62	52.05	2,2,2-Trichloro-1-(2-nitrophenylthioamino)ethanol	C8H7Cl3N2O3S	Aromatic
3	2.498	44956656	0.11	41654530	0.43	67.05	Bicyclo[4.1.0]heptane	C7H12	Alkane
4	2.583	523989884	1.32	154941688	1.59	57.95	1,2-Epoxy-nonane	C9H18O	Alkane
5	2.703	290384815	0.73	99501726	1.02	71.15	1,2-Epoxy-nonane	C9H18O	Alkane
6	2.785	750227936	1.89	103829659	1.07	55.05	Cyclopropane, 1-(1'-propenyl)-2-hydroxymethyl-	C7H12O	Olefin
7	3.019	74858425	0.19	41275213	0.42	55.05	Cyclopentane, 1,1,3-trimethyl-	C8H16	Alkane
8	3.135	158009535	0.4	97048123	1	82.00	3-Heptyne	C7H12	Olefin
9	3.243	201712988	0.51	86780517	0.89	71.10	Cyclobutane, 1-butyl-2-ethyl-	C10H20	Alkane
10	3.388	60271641	0.15	37457816	0.38	69.15	Cyclopentane, 1,1,3,4-tetramethyl-, cis-	C9H18	Alkane
11	3.435	187449977	0.47	104980557	1.08	58.10	Bicyclo[4.1.0]heptan-2-ol, (1.alpha.,2.beta.,6.alpha.)-	C7H12O	Alkane
12	3.565	870466520	2.19	93578632	0.96	70.15	Cyclobutane, 1-butyl-2-ethyl-	C10H20	Alkane
13	3.692	1192556147	3	235197929	2.42	99.15	trans-2,3-Epoxyoctane	C8H16O	Alkane
14	3.839	799149872	2.01	230238337	2.36	82.00	Cyclopropane, 1-(1'-propenyl)-2-hydroxymethyl-	C7H12O	Olefin
15	3.93	102317642	0.26	59030717	0.61	98.05	Cyclooctane	C8H16	Alkane
16	4.067	372592614	0.94	143825582	1.48	58.05	1,2-Epoxy-nonane	C9H18O	Alkane
17	4.157	56790543	0.14	43898137	0.45	95.05	2-Tridecyne	C13H24	Olefin
18	4.268	925370892	2.33	105665547	1.09	109.15	2-Allyl-2-methyl-1,3-cyclopentanediol	C9H12O2	Olefin
19	4.414	157127197	0.4	58947016	0.61	109.10	1,1-Dimethyl-4-methylenecyclohexane	C9H16	Olefin
20	4.489	185689360	0.47	93181545	0.96	97.15	Bis(1-methylheptyl) methylphosphonate	C17H37O3P	Alkane
21	4.569	1132360700	2.85	271730649	2.79	58.10	trans-2,3-Epoxyoctane	C8H16O	Alkane
22	4.803	699531830	1.76	104485289	1.07	207.95	Di-n-decylsulfone	C20H42O2S	Alkane
23	5.113	1654377325	4.16	236173957	2.43	127.95	Oxirane, octyl-	C10H20O	Alkane
24	5.463	2630203834	6.62	239544340	2.46	59.10	5-Thiatricyclo[4.1.0.0(2,4)]heptane	C6H8S	Alkane
25	5.755	1257737987	3.16	328766828	3.38	127.80	Oxirane, octyl-	C10H20O	Alkane
26	5.92	289845093	0.73	90789807	0.93	91.05	Benzeneacetic acid, 2-tridecyl ester	C21H34O2	Aromatic
27	6.168	1233434050	3.1	103461195	1.06	85.10	3-Methyl-4-(phenylthio)-2-prop-2-enyl-2,5-dihydrothiophene 1,1-dioxide	C14H16O2S2	Aromatic
28	6.373	574323929	1.44	208630028	2.14	125.10	2(3H)-Benzofuranone, hexahydro-3-methylene-	C9H12O2	Aromatic
29	6.739	746990425	1.88	236138543	2.43	86.00	trans-2,3-Epoxyoctane	C8H16O	Alkane
30	6.898	417095678	1.05	155402754	1.6	138.10	Cyclopentanol, 1-(1-methylene-2-propenyl)-	C9H14O	Olefin
31	7.074	246296840	0.62	102156149	1.05	84.00	3-Octyn-1-ol	C8H14O	Olefin
32	7.338	659468975	1.66	222507552	2.29	110.10	2(3H)-Benzofuranone, hexahydro-3-methylene-	C9H12O2	Aromatic
33	7.998	329468794	0.83	104128743	1.07	84.15	Cyclobutane, 1-butyl-2-ethyl-	C10H20	Alkane
34	8.31	389803703	0.98	101826314	1.05	84.15	Cyclobutane, 1-butyl-2-ethyl-	C10H20	Alkane
35	8.605	365311149	0.92	93576624	0.96	71.05	Cyclodecane	C10H20	Alkane
36	8.76	386894715	0.97	91714851	0.94	71.15	N-Cyclohexyl-4-methyl-1-piperazinecarboxamide	C12H23N3O	Alkane
37	8.998	333176795	0.84	89698821	0.92	82.10	Cyclopentanol, 1-(1-methylene-2-propenyl)-	C9H14O	Olefin
38	9.083	235030627	0.59	94497545	0.97	82.10	Cyclopentane, 1,2-dimethyl-3-(1-methylethenyl)-	C10H18	Olefin
39	9.249	149601881	0.38	61821819	0.63	82.05	Bicyclo[3.1.1]heptane, 2,6,6-trimethyl-	C10H18	Alkane
40	9.498	215973482	0.54	86684769	0.89	81.10	Bicyclo[8.2.0]dodecane, 11,11-dimethyl-	C14H26	Alkane
41	9.563	311556383	0.78	103353414	1.06	82.15	Cyclooctene, 1,2-dimethyl-	C10H18	Olefin
42	9.935	306055921	0.77	131140010	1.35	42.00	trans-2,3-Epoxydecane	C10H20O	Alkane
43	10.188	722375263	1.82	93552372	0.96	71.15	3-Ethyl-3-methylheptane	C10H22	Alkane
44	10.373	712355033	1.79	107846179	1.11	72.10	trans-2,3-Epoxyoctane	C8H16O	Alkane
45	11.01	220056710	0.55	87567608	0.9	57.15	1-Undecene	C11H22	Olefin
46	11.314	136368218	0.34	62955210	0.65	56.15	Cyclopropane, 1-methyl-2-octyl-	C12H24	Alkane
47	11.451	153870022	0.39	49858476	0.51	69.10	11-Methyldodecanol	C13H28O	Alkane
48	11.561	115008178	0.29	47961594	0.49	43.10	1,1'-Bicyclopentyl, 2-hexadecyl-	C26H50	Alkane
49	11.733	351679925	0.88	97698092	1	69.15	Oxirane, decyl-	C12H24O	Alkane
50	11.84	528924359	1.33	100081334	1.03	84.00	3-Dodecene, (E)-	C12H24	Olefin
51	11.945	232957907	0.59	89435534	0.92	84.05	trans-Undec-4-enal	C11H20O	Olefin
52	12.22	388057986	0.98	95699866	0.98	70.05	9-Octadecen-1-ol, (Z)-	C18H36O	Olefin
53	12.417	1414041401	3.56	330198414	3.39	86.10	trans-2,3-Epoxyoctane	C8H16O	Alkane
54	12.546	1096879466	2.76	302786791	3.11	86.10	1,2-Epoxy-nonane	C9H18O	Alkane
55	13.466	73711658	0.19	32396165	0.33	125.15	Cyclohexane, 1,3,5-trimethyl-2-octadecyl-	C27H54	Alkane
56	13.88	540150155	1.36	111635459	1.15	57.15	Trichloroacetic acid, tridecyl ester	C15H27Cl3O2	Alkane
57	14.055	360246446	0.91	112497577	1.16	57.15	Trichloroacetic acid, tridecyl ester	C15H27Cl3O2	Alkane
58	14.333	105560162	0.27	50553106	0.52	56.05	3-Undecene, 8-methyl-	C12H24	Olefin
59	14.602	779119561	1.96	100011775	1.03	70.05	7-Octadecyne, 2-methyl-	C19H36	Olefin
60	14.675	440302062	1.11	101767777	1.05	70.05	Dichloroacetic acid, undec-2-enyl ester	C13H22Cl2O2	Olefin
61	14.905	354169681	0.89	107212594	1.1	70.05	1,1'-Bicyclohexyl, 2-propyl-, trans	C15H28	Alkane
62	15.178	104017760	0.26	43021584	0.44	43.05	1-Undecene, 8-methyl-	C12H24	Olefin

Table 5. (Continous)
Complete GC-MS peak
report of PET-derived
pyrolysis oil yield from
90% PET : 10% EZAC

Peak	R,Time	Area	Area (%)	Height	Peak Report Height (%)	Base m/z	Name	Formula	Hydrocarbon class
63	15.384	228553112	0.57	76275725	0.78	70.05	1,1'-Bicyclohexyl, 2-propyl-, trans	C15H28	Alkane
64	16.116	237699892	0.6	86633105	0.89	70.05	1,1'-Bicyclohexyl, 2-propyl-, trans	C15H28	Alkane
65	16.46	181786761	0.46	77133725	0.79	70.05	2-Undecene, 4,5-dimethyl-, [R*,S*-(Z)]-	C13H26	Olefin
66	17.238	156392153	0.39	57036273	0.59	71.15	Dodecane, 2,6,11-trimethyl-	C15H32	Alkane
67	17.44	204801569	0.52	80640352	0.83	71.15	Phytol	C20H40O	Alkane
68	17.67	117778065	0.3	51433543	0.53	69.10	Cyclododecanemethanol	C13H26O	Alkane
69	18.413	250395134	0.63	83481817	0.86	69.10	1-Hexadecanol	C16H34O	Alkane
70	18.964	1044582841	2.63	297895678	3.06	86.10	Oxirane, octyl-	C10H20O	Alkane
71	19.217	985184512	2.48	115579341	1.19	111.15	1-Nonadecene	C19H38	Olefin
72	19.447	1110500975	2.79	115480037	1.19	85.15	trans-2,3-Epoxydecane	C10H20O	Alkane
73	20.142	223580698	0.56	88167830	0.91	83.10	1-Tetracosene	C24H48	Olefin
74	20.731	86060044	0.22	39785360	0.41	43.05	1-Heptanol, 2,4-diethyl-	C11H24O	Alkane
75	20.868	469636672	1.18	97456431	0.99	82.25	trans-2-Dodecen-1-ol, trifluoroacetate	C14H23F3O2	Olefin
76	21.055	92001909	0.23	37525311	0.39	69.10	(2,4-Dimethylcyclohexyl)methanol (isomer 2)	C9H18O	Alkane
77	21.301	133050914	0.33	54242450	0.56	69.05	Cyclododecanemethanol	C13H26O	Alkane
78	22.276	74808763	0.19	32933906	0.34	69.10	11-Methyldodecanol	C13H28O	Alkane
79	22.483	42510915	0.11	18231977	0.19	69.10	11-Methyldodecanol	C13H28O	Alkane
80	23.237	213056064	0.54	48357602	0.5	69.10	1,22-Docosanediol	C22H46O2	Alkane
81	24.488	337882676	0.85	112639081	1.16	71.15	1-Tetracosene	C24H48	Olefin
82	24.725	192919824	0.49	74541958	0.77	71.10	Heptacos-1-ene	C27H54	Olefin
83	25.149	255026591	0.64	82697044	0.85	69.10	1-Tetracosene	C24H48	Olefin
84	25.399	105605391	0.27	42893153	0.44	69.10	1-Decanol, 2-hexyl-	C16H34O	Alkane
85	26.194	217494322	0.55	88428750	0.91	83.10	Cyclododecanemethanol	C13H26O	Alkane
86	26.803	42459960	0.11	19526049	0.2	69.10	(2,4,6-Trimethylcyclohexyl) methanol	C10H20O	Alkane
87	28.284	170904325	0.43	57303746	0.59	69.05	1-Decanol, 2-hexyl-	C16H34O	Alkane
88	29.08	156671954	0.35	42203972	0.41	69.05	Pentacosyl trifluoroacetate	C27H51F3O2	Alkane
89	29.351	185376787	0.43	73582168	0.76	69.10	1-Decanol, 2-hexyl-	C16H34O	Alkane
90	29.952	242247654	0.61	75955713	0.74	69.10	Nonadecyl trifluoroacetate	C21H39F3O2	Alkane
91	30.216	90117430	0.23	35380026	0.36	69.10	Cyclooctane, 1-methyl-3-propyl-	C12H24	Alkane
92	30.651	59001290	0.15	26401266	0.27	69.10	1-Decanol, 2-hexyl-	C16H34O	Alkane
93	30.897	130511371	0.33	49242337	0.51	69.05	11-Dodecen-1-ol, 2,4,6-trimethyl-, (R,R,R)-	C15H30O	Olefin
94	34.925	46839926	0.12	18530360	0.19	69.10	Cyclohexane, 1,2,3,5-tetraisopropyl-	C18H36	Alkane

Table 6.
Complete GC-MS peak
report of PET-derived
pyrolysis oil yield from
85% PET : 15% EZAC

Peak	R,Time	Area	Area (%)	Height	Peak Report Height (%)	Base m/z	Name	Formula	Hydrocarbon class
1	2.397	276394424	0.76	140921489	1.57	77.05	2,2,2-Trichloro-1-(2-nitrophenylthioamino)ethanol	C8H7Cl3N2O3S	Aromatic
2	2.466	93707365	0.26	70695635	0.79	70.15	3-Buten-1-amine, n-butyl-N-methyl-	C9H19N	Olefin
3	2.589	481669685	1.32	148869142	1.66	57.95	1,4-Cyclohexanediol, trans-	C6H12O2	Alkane
4	2.708	974939345	2.68	97671586	1.09	71.10	1,2-Epoxynonane	C9H18O	Alkane
5	3.026	57036161	0.16	35732582	0.4	55.05	Cyclopentane, 1,1,3-trimethyl-	C8H16	Alkane
6	3.143	142271243	0.39	86543559	0.96	82.00	3-Heptyne	C7H12	Olefin
7	3.397	85472626	0.23	42692647	0.47	55.10	Cyclobutane, 1-butyl-2-ethyl-	C10H20	Alkane
8	3.264	200040127	0.55	106109906	1.18	71.10	Cyclobutane, 1-butyl-2-ethyl-	C10H20	Alkane
9	3.445	272907135	0.75	138565173	1.54	58.10	Bicyclo[4.1.0]heptan-2-ol,(1.alpha.,2.beta.,6.alpha.)-	C7H12O	Alkane
10	3.544	844555439	2.32	263833985	2.93	72.00	trans-2,3-Epoxyoctane	C8H16O	Alkane
11	3.77	1239905561	3.41	95998441	1.07	93.00	1,5-Heptadien-3-yne	C7H8	Olefin
12	3.818	948822592	2.61	88355805	0.98	68.05	11-Tridecyn-1-ol	C13H24O	Olefin
13	3.941	110833390	0.3	62139904	0.69	98.00	Cyclooctane	C8H16	Alkane
14	4.08	285822713	0.79	132586991	1.47	58.00	Cyclobutane, 1-butyl-2-ethyl-	C10H20	Alkane
15	4.17	90369543	0.25	57725809	0.64	95.10	2-Tridecyne	C13H24	Olefin
16	4.308	835961580	2.3	271818031	3.02	111.10	2(1H)-Naphthalenone, 3,4,4a,5,8,8a-hexahydro-4a-methyl-, trans-	C11H16O	Aromatic
17	4.503	188373798	0.52	97000176	1.08	112.10	Cyclobutane, 1-butyl-2-ethyl-	C10H20	Alkane
18	4.584	1215291817	3.34	271851758	3.02	127.05	Oxirane, octyl-	C10H20O	Alkane
19	4.877	786889001	2.16	110527572	1.23	71.15	trans-2,3-Epoxyoctane	C8H16O	Alkane
20	4.981	166746824	0.46	63443332	0.71	96.05	Thujone	C10H16O	Alkane
21	5.13	1642912363	4.51	220430395	2.45	112.60	Cyclopropane, 1-(1'-propenyl)-2-hydroxymethyl-	C7H12O	Olefin
22	5.773	1208833859	3.32	323120681	3.59	127.85	Oxirane, octyl-	C10H20O	Alkane
23	5.94	321544759	0.88	88699311	0.99	91.05	Benzeneacetic acid, 4-tridecyl ester	C21H34O2	Aromatic
24	6.188	1311704814	3.6	100602445	1.12	85.10	C21H34O2	C11H22O	Alkane
25	6.388	573343736	1.58	208430370	2.32	125.10	2(3H)-Benzofuranone, hexahydro-3-methylene-	C9H12O2	Aromatic
26	6.523	370200171	1.02	114813905	1.28	70.95	1-Heptene, 2-isohexyl-6-methyl-	C14H28	Olefin
27	6.759	763256106	2.1	230740839	2.57	45.00	trans-2,3-Epoxyoctane	C8H16O	Alkane
28	6.912	634273457	1.74	191418118	2.13	138.10	2-Oxatricyclo[4.3.1.0(3,8)]decane	C9H14O	Alkane
29	7.088	214511550	0.59	94718710	1.05	56.00	3-Octyn-1-ol	C8H14O	Olefin
30	7.355	747352123	2.05	245987973	2.74	110.10	2(3H)-Benzofuranone, hexahydro-3-methylene-	C9H12O2	Aromatic
31	8.04	376144844	1.03	106519444	1.18	84.15	Octanal	C8H16O	Alkane
32	8.325	411915440	1.13	103032297	1.15	84.15	Cyclobutane, 1-butyl-2-ethyl-	C10H20	Alkane
33	8.62	387459852	1.06	92090957	1.02	71.05	Cyclodecane	C10H20	Alkane
34	8.77	414382627	1.14	102698030	1.14	57.95	1,4,5,8-Tetraazadecalin	C6H14N4	Alkane
35	9.045	419962791	1.15	92610175	1.03	105.95	2,8-Decadiyne	C10H14	Olefin
36	9.095	236473279	0.65	97135689	1.08	82.10	Cyclopentane, 1,2-dimethyl-3-(1-methylethenyl)-	C10H18	Olefin
37	9.509	218069966	0.6	87421100	0.97	81.10	Cyclooctene, 1,2-dimethyl-	C10H18	Olefin
38	9.6	357879710	0.98	95565254	1.06	82.10	Bicyclo[3.1.1]heptane, 2,6,6-trimethyl-	C10H18	Alkane
39	10.198	725947725	1.99	87715222	0.98	71.15	3-Ethyl-3-methylheptane	C10H22	Alkane
40	10.39	717948257	1.97	99453083	1.11	57.15	trans-2,3-Epoxydecane	C10H20O	Alkane
41	11.03	245495938	0.67	88859215	0.99	57.15	1-Undecen	C11H22	Olefin
42	11.728	443320839	1.22	108782554	1.21	85.10	Undecanal	C11H22O	Alkane
43	11.845	597026081	1.64	98316805	1.09	84.00	1-Dodecene	C12H24	Olefin
44	11.965	274185686	0.75	93775217	1.04	84.00	trans-Undec-4-enal	C11H20O	Olefin
45	12.233	497072968	1.37	99956158	1.11	70.00	9-Eicosyne	C20H38	Olefin
46	13.895	676624092	1.86	106015604	1.18	57.15	Trichloroacetic acid, tridecyl ester	C15H27Cl3O2	Alkane
47	14.343	130501190	0.36	59047393	0.66	56.10	3-Undecene, 8-methyl-	C12H24	Olefin
48	14.589	791857568	2.18	250186663	2.78	70.95	3,7-Diazabicyclo[3.3.1]nonane, 9,9-dimethyl-	C9H18N2	Alkane

Table 6. (Continous)
Complete GC-MS peak
report of PET-derived
pyrolysis oil yield from
85% PET : 15% EZAC

Peak	R,Time	Area	Area (%)	Height	Peak Report Height (%)	Base m/z	Name	Formula	Hydrocarbon class
49	14.667	351093320	0.96	147352096	1.64	56.00	3,7,11,15-Tetramethyl-2-hexadecen-1-ol	C20H40O	Olefin
50	14.888	389107915	1.07	110657296	1.23	70.00	1,1'-Bicyclohexyl, 2-propyl-, trans	C15H28	Alkane
51	15.186	97946641	0.27	47628453	0.53	43.05	1-Undecene, 7-methyl-	C12H24	Olefin
52	15.393	266581781	0.73	81825647	0.91	70.05	3-Hexene, 2,2,5,5-tetramethyl-, (Z)-	C10H20	Olefin
53	16.123	264975152	0.73	94214489	1.05	70.05	1,1'-Bicyclohexyl, 2-propyl-, trans	C15H28	Alkane
54	16.467	267806887	0.74	104358111	1.16	71.05	1-Tetradecene	C14H28	Olefin
55	16.644	106784725	0.29	50291615	0.56	43.05	2-Undecene, 2,5-dimethyl-	C13H26	Olefin
56	16.781	144408632	0.4	51397518	0.57	41.05	1-Octadecyne	C18H34	Olefin
57	17.246	190475951	0.52	68370578	0.76	71.15	3-Ethyl-3-methylheptane	C10H22	Alkane
58	17.449	248503118	0.68	97034709	1.08	71.25	Oxirane, dodecyl-	C14H28O	Alkane
59	17.679	188541323	0.52	78899095	0.88	69.10	Oleyl alcohol, trifluoroacetate	C20H35F3O2	Olefin
60	17.892	99630692	0.27	39531933	0.44	69.10	11-Methyldodecanol	C13H28O	Alkane
61	18.091	51905055	0.14	23611130	0.26	69.10	Acetic acid, trifluoro-, dodecyl ester	C14H25F3O2	Alkane
62	18.43	340565884	0.94	103154320	1.15	84.05	Acetic acid, chloro-, hexadecyl ester	C18H35ClO2	Alkane
63	18.621	92823436	0.26	42223575	0.47	69.05	10-Dodecen-1-ol, 7,11-dimethyl-	C14H28O	Olefin
64	19.008	1463802951	4.02	108670877	1.21	85.10	trans-2,3-Epoxydecane	C10H20O	Alkane
65	19.228	1141530533	3.14	112558580	1.25	84.15	1-Nonadecene	C19H38	Olefin
66	19.458	1314001283	3.61	114160864	1.27	111.25	trans-2,3-Epoxydecane	C10H20O	Alkane
67	20.063	61254210	0.17	27143142	0.3	83.10	1,6-Octadiene, 5,7-dimethyl-, (R)-	C10H18	Olefin
68	20.16	368553673	1.01	114213640	1.27	57.15	1-Tetracosene	C24H48	Olefin
69	20.497	60353007	0.17	29107609	0.32	69.10	1-Heptanol, 2,4-diethyl-	C11H24O	Alkane
70	20.737	176017716	0.48	70477547	0.78	43.10	2-Isopropyl-5-methyl-1-heptanol	C11H24O	Alkane
71	20.88	593422904	1.63	111743329	1.24	82.15	trans-2-Dodecen-1-ol, trifluoroacetate	C14H23F3O2	Olefin
72	21.061	119950477	0.33	50171277	0.56	69.05	(2,4,6-Trimethylcyclohexyl) methanol	C10H20O	Alkane
73	21.308	193678072	0.53	73840164	0.82	69.15	Cyclododecanemethanol	C13H26O	Alkane
74	22.283	131231153	0.36	53438880	0.59	69.10	11-Methyldodecanol	C13H28O	Alkane
75	22.986	60378094	0.17	20897577	0.23	71.10	Dodecane, 4,6-dimethyl-	C14H30	Alkane
76	24.051	78959441	0.22	32646037	0.36	69.10	10-Dodecen-1-ol, 7,11-dimethyl-	C14H28O	Olefin
77	24.517	473410259	1.3	117391065	1.31	70.10	1-Nonadecene	C19H38	Olefin
78	25.152	346621257	0.95	108006458	1.2	71.15	1-Tetracosene	C24H48	Olefin
79	25.402	136144748	0.37	57879198	0.64	69.10	1-Decanol, 2-hexyl-	C16H34O	Alkane
80	25.528	79892789	0.22	35340455	0.39	69.05	1-Dodecanol, 2-hexyl-	C18H38O	Alkane
81	26.214	330166705	0.91	96750690	1.08	83.15	Oleyl alcohol, trifluoroacetate	C20H35F3O2	Olefin
82	26.409	38404272	0.11	14610287	0.16	69.10	10-Dodecen-1-ol, 7,11-dimethyl-	C14H28O	Olefin
83	26.809	68498553	0.19	30818702	0.34	69.10	(2,4,6-Trimethylcyclohexyl) methanol	C10H20O	Alkane
84	27.36	27080537	0.07	11238708	0.13	69.10	11-Methyldodecanol	C13H28O	Alkane
85	28.962	34234429	0.09	13857993	0.15	69.10	6-Octenoic acid, 3,7-dimethyl-, 3,7-dimethyl-6-octenyl ester	C20H36O2	Olefin
86	29.355	252043826	0.69	97335093	1.08	71.10	Heptacos-1-ene	C27H54	Olefin
87	29.553	59479986	0.16	21784874	0.24	69.10	1-Decanol, 2-hexyl-	C16H34O	Alkane
88	29.726	29328038	0.08	13117644	0.15	69.10	Tetradecanoic acid, 2-hexyl-, 2-hexyl-1-tetradecanoate	C38H69F7O2	Alkane
89	29.961	272341754	0.75	83238701	0.93	69.10	1-Decanol, 2-hexyl-	C16H34O	Alkane
90	30.9	160992462	0.44	66884793	0.74	69.15	11-Dodecen-1-ol, 2,4,6-trimethyl-, (R,R,R)-	C15H30O	Olefin
91	31.478	27158591	0.07	11413276	0.13	69.10	Cyclooctane, 1-methyl-3-propyl-	C12H24	Alkane
92	33.702	57825827	0.16	24359892	0.27	69.10	1-Decanol, 2-hexyl-	C16H34O	Alkane
93	35.123	79371008	0.22	31866111	0.35	69.10	Cyclohexane, 1,2,3,5-tetraisopropyl-	C18H36	Alkane
94	37.643	20111114	0.06	8652012	0.14	69.10	1-Decanol, 2-hexyl-	C16H34O	Alkane
95	38.953	34587296	0.1	14240213	0.16	69.10	Cyclohexane, 1,2,3,5-tetraisopropyl-	C18H36	Alkane

Table 7.
Complete GC-MS peak
report of PET-derived
pyrolysis oil yield from
80% PET : 20% EZAC

Peak	R,Time	Area	Area (%)	Height	Peak Report Height (%)	Base m/z	Name	Formula	Hydrocarbon class
1	2.313	381882664	1.03	198164734	1.99	95.05	2,2,2-Trichloro-1-(2-nitrophenylthioamino)ethanol	C8H7Cl3N2O3S	Aromatic
2	2.398	340456252	0.92	163759137	1.65	52.15	2,2,2-Trichloro-1-(2-nitrophenylthioamino)ethanol	C8H7Cl3N2O3S	Aromatic
3	2.466	94222189	0.25	70170223	0.71	72.10	2-Pentene, 2-methoxy-	C6H12O	Olefin
4	2.61	517957003	1.4	96429356	0.97	70.15	Cycloheptane	C7H14	Alkane
5	2.7	238420826	0.65	122572482	1.23	71.15	Oxirane, octyl-	C10H20O	Alkane
6	2.762	525128607	1.42	217303249	2.19	80.00	Cyclopropane, 1-(1'-propenyl)-2-hydroxymethyl-	C7H12O	Olefin
7	3.027	81718913	0.22	44988983	0.45	55.05	Cyclopentane, 1,1,3-trimethyl-	C8H16	Alkane
8	3.144	172427680	0.47	99356167	1	82.00	3-Heptyne	C7H12	Olefin
9	3.28	333954718	0.9	97656091	0.98	69.05	Cyclobutane, 1-butyl-2-ethyl-	C10H20	Alkane
10	3.344	64988470	0.18	40968556	0.41	83.10	2-Hexene, 2,3-dimethyl-	C8H16	Olefin
11	3.447	197022260	0.53	111118515	1.12	58.00	Cyclopropane, 1-(1'-propenyl)-2-hydroxymethyl-	C7H12O	Olefin
12	3.545	831031609	2.25	245738285	2.47	85.00	Trans-2,3-Epoxyoctane	C8H16O	Alkane
13	3.852	278853983	0.75	145743524	1.47	70.90	4-Azaspiro[2.6]nonan-5-one	C8H13NO	Alkane
14	4.098	592737867	1.6	108879662	1.1	57.10	Bicyclo[4.1.0]heptan-2-ol, (1.alpha.,2.beta.,6.alpha.)-	C7H12O	Alkane
15	4.175	257011551	0.7	109363475	1.1	68.05	Cyclohexanol, 2,3-dimethyl-	C8H16O	Alkane
16	4.22	201807361	0.55	95862560	0.96	112.10	Cyclooctane	C8H16	Alkane
17	4.35	960050705	2.6	107583920	1.08	85.15	6-Methyl-2-heptanol, chlorodifluoroacetate	C10H17ClF2O2	Alkane
18	4.435	330806343	0.9	89476990	0.9	109.10	1,1-Dimethyl-4-methylenecyclohexane	C9H16	Olefin
19	4.515	224281688	0.61	86958689	0.87	97.15	Bis(1-methylheptyl) methylphosphonate	C17H37O3P	Alkane
20	4.586	1052795260	2.85	249217868	2.51	72.05	Oxirane, octyl-	C10H20O	Alkane
21	4.818	856102558	2.32	108729006	1.09	207.90	Di-n-decylsulfone	C20H42O2S	Alkane
22	5.779	1222397761	3.31	324207404	3.26	113.00	Oxirane, octyl-	C10H20O	Alkane
23	5.929	249710231	0.68	116526189	1.17	85.15	trans-2,3-Epoxyoctane	C8H16O	Alkane
24	6.198	1505649288	4.07	95135987	0.96	85.15	2-Chloropropionic acid, decyl ester	C13H25ClO2	Alkane
25	6.285	99866738	0.27	53678613	0.54	111.10	Cyclohexane, 1,2,4-trimethyl-	C9H18	Alkane
26	6.391	632016746	1.71	224708841	2.26	125.00	2(3H)-Benzofuranone, hexahydro-3-methylene-	C9H12O2	Aromatic
27	6.765	811391996	2.2	223713966	2.25	141.05	trans-2,3-Epoxyoctane	C8H16O	Alkane
28	6.917	673529172	1.82	204681995	2.06	138.15	2-Oxatricyclo[4.3.1.0(3,8)]decane	C9H14O	Alkane
29	7.063	834469071	2.26	91196795	0.92	83.05	2-Cyclohexen-1-ol, 2-methyl-5-(1-methylethenyl)-, cis-	C10H16O	Olefin
30	7.362	850940497	2.3	260203875	2.62	110.00	2(3H)-Benzofuranone, hexahydro-3-methylene-	C9H12O2	Aromatic
31	7.581	214659673	0.58	88611163	0.89	83.15	Bicyclo[3.1.1]heptane, 2,6,6-trimethyl-	C10H18	Alkane
32	7.943	135140699	0.37	56553059	0.57	97.10	4-Nonene, 5-butyl-	C13H26	Olefin

Table 7. (Continous)
Complete GC-MS peak
report of PET-derived
pyrolysis oil yield from
80% PET : 20% EZAC

Peak	R,Time	Area	Area (%)	Height	Peak Report Height (%)	Base m/z	Name	Formula	Hydrocarbon class
33	8.043	444011528	1.2	104725311	1.05	84.15	Octanal	C8H16O	Alkane
34	8.327	476082231	1.29	101088756	1.02	84.05	Hexahydro-1,4-dioxo-cyclopropa[a]pentalen-3-one	C7H8O3	Alkane
35	8.386	201493130	0.55	79010679	0.79	57.05	1-Decene	C10H20	Olefin
36	8.603	341002301	0.92	116388130	1.17	84.05	Hexahydro-1,4-dioxo-cyclopropa[a]pentalen-3-one	C7H8O3	Alkane
37	8.763	94998199	0.26	70089709	0.71	57.95	1,4,5,8-Tetraazadecalin	C6H14N4	Alkane
38	9.032	415117977	1.12	142234603	1.43	106.00	Bicyclo[6.1.0]non-4-ene-9-carbaldehyde	C10H14O	Olefin
39	9.11	270202720	0.73	92006222	0.93	109.10	11-Tetradecen-1-ol, (E)-	C14H28O	Olefin
40	9.262	185724588	0.5	70467210	0.71	82.05	Cyclooctane, ethenyl-	C10H18	Olefin
41	9.512	185093774	0.5	83144692	0.84	68.05	Cyclooctene, 1,2-dimethyl-	C10H18	Olefin
42	9.589	399890529	1.08	126478075	1.27	83.05	7-Octadecyne, 2-methyl-	C19H36	Olefin
43	9.803	523601195	1.42	162912017	1.64	105.10	5-Ethoxy-cyclooctene	C10H18O	Olefin
44	9.95	337410712	0.91	143672556	1.45	86.10	trans-2,3-Epoxyoctane	C8H16O	Alkane
45	10.022	186479498	0.5	81549191	0.82	72.05	3-Piperidinamine, 1-ethyl-	C7H16N2	Alkane
46	10.111	142373210	0.39	72115944	0.73	111.10	Decanal	C10H20O	Alkane
47	10.395	755422623	2.04	98331035	0.99	57.15	trans-2,3-Epoxyoctane	C8H16O	Alkane
48	11.023	306429550	0.83	117869951	1.19	98.15	1-Tetradecene	C14H28	Olefin
49	11.465	282897866	0.77	81757188	0.82	69.15	trans-2-Dodecen-1-ol, trifluoroacetate	C14H23F3O2	Olefin
50	11.573	231443640	0.63	92437932	0.93	43.10	Oxirane, tetradecyl-	C16H32O	Alkane
51	11.745	475930974	1.29	139868507	1.41	109.15	3,7,11,15-Tetramethyl-2-hexadecen-1-ol	C20H40O	Olefin
52	11.958	224413918	0.61	99978637	1.01	70.05	trans-2-Dodecen-1-ol, trifluoroacetate	C14H23F3O2	Olefin
53	12.25	724140299	1.96	97853759	0.98	70.05	3-Tridecene	C13H24	Olefin
54	12.567	1162141136	3.14	306908059	3.09	44.95	Oxirane, octyl-	C10H20O	Alkane
55	13.782	134805843	0.36	61889514	0.62	83.15	(-)-trans-Pinane	C10H18	Alkane
56	13.898	794612405	2.15	103490495	1.04	71.05	Oxirane, octyl-	C10H20O	Alkane
57	14.08	541233805	1.46	101607584	1.02	57.15	Trichloroacetic acid, tridecyl ester	C15H27Cl3O2	Alkane
58	14.595	766645803	2.07	247456595	2.49	84.95	7-Hexadecyn-1-ol	C16H30O	Olefin
59	14.671	403473734	1.09	158267442	1.59	84.05	3,7,11,15-Tetramethyl-2-hexadecen-1-ol	C20H40O	Olefin
60	14.888	441820868	1.2	105756906	1.06	125.15	1,1'-Bicyclohexyl, 2-propyl-, trans	C15H28	Alkane
61	15.187	149394901	0.4	63690104	0.64	43.15	n-Heptadecanol-1	C17H36O	Alkane
62	15.392	303455399	0.82	89641996	0.9	126.05	3-Hexene, 2,2,5,5-tetramethyl-, (Z)-	C10H20	Olefin
63	16.124	299812512	0.81	106055030	1.07	70.00	1,1'-Bicyclohexyl, 2-propyl-, trans	C15H28	Alkane
64	16.453	340499931	0.92	97559057	0.98	70.10	1-Tetradecene	C14H28	Olefin
65	16.645	133473231	0.36	61751187	0.62	71.10	2-Ethyl-1-dodecanol	C14H30O	Alkane
66	16.782	192457737	0.52	64966304	0.65	82.05	Pentadecanal-	C15H30O	Alkane
67	17.246	221390786	0.6	77733159	0.78	57.15	Octadecane, 5-methyl-	C19H40	Alkane
68	17.46	293085718	0.79	95177778	0.96	71.15	Oxirane, hexadecyl-	C18H36O	Alkane
69	17.68	233593885	0.63	96535764	0.97	55.05	trans-2-Dodecen-1-ol, trifluoroacetate	C14H23F3O2	Olefin
70	17.892	128131945	0.35	51461047	0.52	69.05	Pentadecafluorooctanoic acid, dodecyl ester	C20H25F15O2	Alkane
71	18.178	79066706	0.21	36972913	0.37	83.10	3-Decene, 2,2-dimethyl-, (E)-	C12H24	Olefin
72	18.433	443508937	1.2	108575153	1.09	84.10	1,2-Oxathiane, 6-dodecyl-, 2,2-dioxide	C16H32O3S	Alkane
73	18.622	123893455	0.34	56653743	0.57	41.05	Cyclododecanemethanol	C13H26O	Alkane
74	18.928	1560643891	4.22	106723462	1.07	43.15	1-Nonadecene	C19H38	Olefin
75	19.462	1413089993	3.82	113474353	1.14	111.15	trans-2,3-Epoxydecane	C10H20O	Alkane
76	20.165	444836684	1.2	118218768	1.19	57.15	1-Tetracosene	C24H48	Olefin
77	20.878	684484508	1.85	110527425	1.11	82.05	trans-2-Dodecen-1-ol, heptafluorobutyrate	C16H23F7O2	Olefin
78	21.307	223458712	0.6	85933424	0.86	55.05	Cyclododecanemethanol	C13H26O	Alkane
79	24.525	508910775	1.38	108868602	1.1	71.15	1-Nonadecene	C19H38	Olefin
80	25.154	363636088	0.98	111534665	1.12	71.15	1-Tetracosene	C24H48	Olefin
81	26.215	387613285	1.05	110010813	1.11	109.15	Oleyl alcohol, trifluoroacetate	C20H35F3O2	Olefin
82	26.809	83016108	0.22	33986737	0.34	69.10	(2,4,6-Trimethylcyclohexyl) methanol	C10H20O	Alkane
83	28.963	39666794	0.11	18328609	0.18	69.10	Cyclohexane, 1-ethyl-2-propyl-	C11H22	Alkane
84	29.356	293179517	0.79	108974130	1.1	71.10	1-Tetracosene	C24H48	Olefin
85	29.551	63304827	0.17	23414708	0.24	69.10	1-Decanol, 2-hexyl-	C16H34O	Alkane
86	29.962	550049093	0.68	81521720	0.82	69.10	Nonadecyl trifluoroacetate	C21H39F3O2	Alkane
87	30.656	89189430	0.24	35758360	0.36	69.05	1-Decanol, 2-hexyl-	C16H34O	Alkane
88	30.901	202654377	0.55	79317898	0.81	69.15	Oleyl alcohol, trifluoroacetate	C20H35F3O2	Olefin
89	33.702	65979705	0.18	26647589	0.27	69.10	1-Decanol, 2-hexyl-	C16H34O	Alkane
90	35.123	92211816	0.25	35888450	0.36	69.10	Cyclooctane, 1-methyl-3-propyl-	C12H24	Alkane
91	38.955	36428999	0.12	15297107	0.15	69.10	(1,2,4-Trimethylcyclohexyl)methanol, acetate (isomer 2)	C12H22O2	Alkane

3.3.2. Gas product

It should be noted that the gas profiles were obtained using MQ-series sensors. Therefore, the H₂, CH₄, CO, and CO₂ data are interpreted mainly as time-resolved comparative trends rather than fully calibrated gas compositions. Absolute gas quantification and mass-based gas yields should be confirmed in future work using calibrated GC or micro-GC analysis.

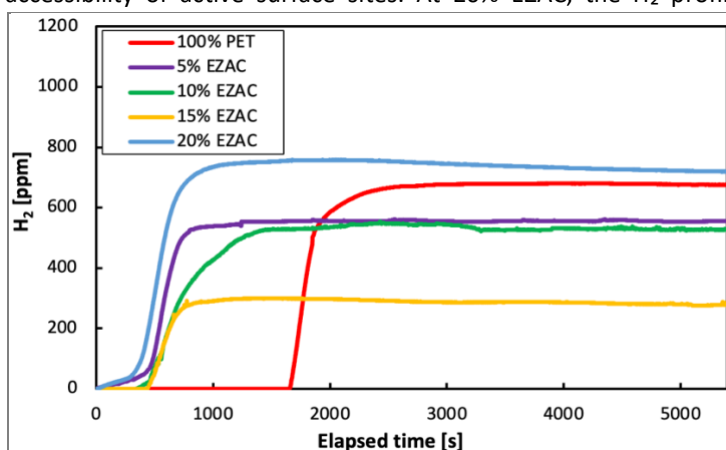
3.3.2.1. Hydrogen (H₂)

Figure 15 shows that EZAC addition not only accelerated the onset of H₂ formation but also changed the quasi-steady H₂ profile and its overall response to catalyst loading. Under non-catalytic PET pyrolysis (0% EZAC), H₂ exhibited a long induction period: the concentration remained near zero until 1700 s, then increased sharply and stabilized at approximately 677 ppm. This behavior suggests that, under the operating conditions of this study, measurable H₂ generation in the absence of EZAC is largely associated with secondary reactions that become more prominent in the later stages of devolatilization. With EZAC addition, H₂ was detected substantially earlier (300–700 s), indicating that EZAC accelerated secondary cracking, dehydrogenation, and hydrogen-transfer reactions. Despite the earlier onset, the quasi-steady H₂ levels at low-to-moderate EZAC

loadings were lower than those under non-catalytic conditions, reaching 556 ppm (5% EZAC) and 544 ppm (10% EZAC). This indicates that earlier H₂ appearance does not necessarily translate into higher net H₂ production; rather, EZAC may redirect reaction pathways toward condensable liquids and/or retain reactive intermediates within pores, thereby reducing net measurable H₂ during certain stages.

At higher EZAC loadings, the H₂ response became non-monotonic, implying competing mechanisms. At 15% EZAC, H₂ reached the lowest level (288 ppm) and gradually declined with time, which may be associated with increased carbon deposition (coke) and/or pore blockage that limits accessibility of active surface sites. At 20% EZAC, the H₂ profile showed the highest sensor response (745 ppm) and approached a quasi-steady level more rapidly, suggesting enhanced H₂-forming pathways under the tested conditions. The slight decrease in the 10% EZAC profile at 3200–3600 s may reflect changes in vapor composition and dominant reaction pathways during the final stage of pyrolysis.

Figure 15.
H₂ of gas yields
produced in elapsed
time

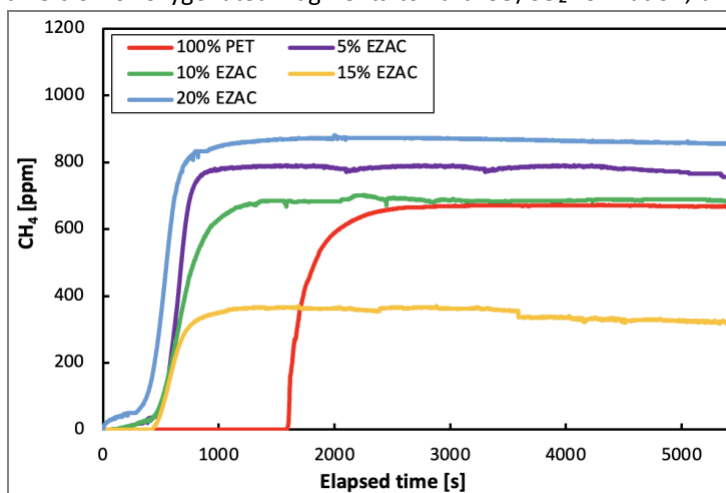


3.3.2.2. Methane (CH₄)

Figure 16 shows the time-resolved CH₄ concentration profiles during PET pyrolysis (room temperature to 350 °C) and highlights distinct kinetic behavior between neat PET and PET–EZAC mixtures. Under non-catalytic conditions (0% EZAC), CH₄ exhibited a relatively long induction period, remaining near zero until 1500 s before increasing to a quasi-steady level of approximately 669 ppm. This trend indicates that, at the operating conditions applied here, CH₄ formation is dominated by secondary reactions that become significant only after sufficient devolatilization and accumulation of reactive intermediates. With EZAC addition, CH₄ appeared earlier and the quasi-steady concentration changed substantially. At 5% EZAC, the quasi-steady CH₄ level increased to 789 ppm, suggesting that the porous carbon surface enhances vapor solid interactions, retains heavier volatiles, and promotes secondary cracking and hydrogen-transfer reactions that generate CH₄. However, at 10% EZAC, the quasi-steady CH₄ level decreased to 687 ppm, indicating that increasing EZAC loading does not linearly intensify CH₄ formation. Instead, EZAC likely alters the balance between CH₄-producing pathways and competing processes, such as increased conversion of reactive fragments into condensable liquids and/or adsorption/retention of gas precursors within pores.

At higher EZAC loadings, the nonlinearity became more pronounced. At 15% EZAC, CH₄ decreased markedly to 362 ppm and gradually declined at longer times, which may reflect dominant competing mechanisms, including stronger adsorption of light-hydrocarbon precursors, diversion of oxygenated fragments toward CO/CO₂ formation, and/or reduced effective surface activity due to coke deposition and pore blockage. In contrast, at 20% EZAC, CH₄ reached the highest quasi-steady level (871 ppm) and showed the fastest rise, consistent with sufficiently high surface availability and adsorption capacity to retain heavier volatiles and facilitate subsequent reactions that favor CH₄ formation.

Figure 16.
CH₄ of gas yields
produced in elapsed
time



3.3.2.3. Carbon monoxide (CO)

The CO sensor-response profiles (Figure 17) indicate that EZAC addition accelerated the onset of CO formation and influenced the stability of CO levels during the later stage of pyrolysis. Under non-catalytic PET pyrolysis (0% EZAC), CO exhibited a relatively long induction period, remaining near zero until 1600 s before rising sharply to a high plateau (810–830 ppm) and then slightly declining toward the end of the run. This trend suggests that CO is generated predominantly through secondary reactions of oxygen-containing species that become more prominent during the later stages of heating and devolatilization.

In contrast, all PET–EZAC mixtures showed an earlier CO onset (500–800 s). This earlier appearance is consistent with activated carbon enhancing vapor–solid contact, adsorbing oxygenated volatiles, and promoting secondary cracking/deoxygenation reactions, thereby producing CO at earlier times.

At higher EZAC loadings particularly 20% the CO profile showed a more pronounced gradual decline after the initial plateau. This behavior may reflect increased competition from CO-consuming surface reactions and/or progressive conversion of CO to CO₂ via reactions facilitated on the carbon surface (e.g., in association with carbon deposition and/or interactions with water vapor generated during transformations of oxygenated fragments). Quantitatively, at 3000 s the highest CO sensor response was observed for non-catalytic PET (826 ppm), followed by 5% EZAC (775 ppm), whereas 20% EZAC was lower (719 ppm) and exhibited a sustained downward trend. Overall, these results indicate that EZAC affects CO not only by accelerating early formation, but also by altering the balance between CO formation and consumption during the later reaction stage.

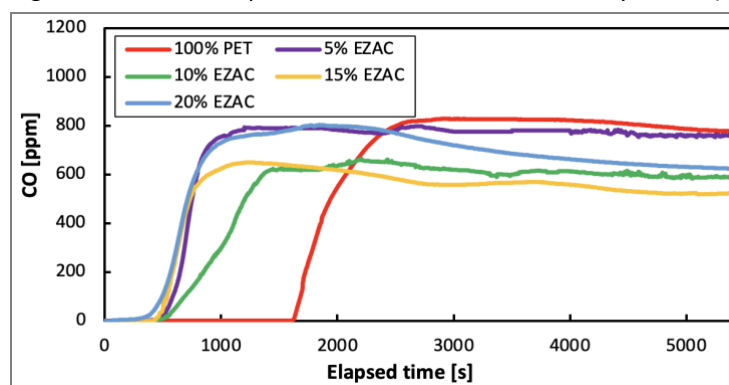


Figure 17.
CO of gas yields
produced in elapsed
time

3.3.2.4. Carbon dioxide (CO₂)

The CO₂ sensor-response profiles (Figure 18) show that EZAC addition substantially affected both the onset of CO₂ formation and the quasi-steady CO₂ level during PET pyrolysis. Under non-catalytic conditions (0% EZAC), CO₂ exhibited a long induction period, remaining near zero until 1700 s before increasing sharply to the highest plateau (590–610 ppm). This behavior suggests that CO₂ formation under the present conditions is dominated by late-stage secondary reactions of oxygen-containing species originating from PET ester functionalities, likely via deoxygenation pathways such as decarboxylation and/or decarbonylation.

In contrast, all PET–EZAC mixtures showed an earlier CO₂ onset (400–700 s), consistent with activated carbon enhancing vapor–solid contact, adsorbing oxygenated intermediates, and accelerating secondary transformations on surfaces and within pores. However, the quasi-steady CO₂ level did not increase monotonically with EZAC loading, indicating competing pathways for carbon and oxygen partitioning among CO₂, CO, condensable oxygenates, and solid residue. At 3000 s, the highest CO₂ concentration remained that of non-catalytic PET (598 ppm), followed by 20% EZAC (501 ppm), whereas 10% EZAC produced the lowest CO₂ concentration (252 ppm). This non-monotonic response implies that, at intermediate EZAC loading (e.g., 10%), oxygenated

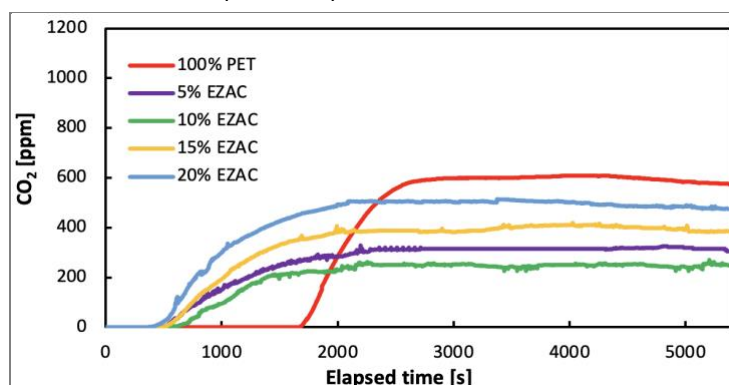


Figure 18.
CO₂ of gas yields
produced in elapsed
time

fragments may be preferentially routed toward condensable products and/or CO rather than CO₂, while at higher loading (20%) additional surface-mediated reactions may favor greater CO₂ generation.

At high EZAC loading (particularly 20%), the gradual downward drift

after the initial plateau may reflect depletion of oxygenated precursors and/or progressive loss of effective activity due to pore coverage by carbon deposition. A local decrease observed for the 10% EZAC profile at intermediate times may similarly indicate changes in vapor composition as devolatilization proceeds and oxygenated species become less available, coupled with adsorption and surface deactivation effects. Overall, these trends highlight that EZAC influences CO₂ formation through both acceleration of early deoxygenation and modification of late-stage competition between formation and consumption/redistribution pathways.

3.4. Mechanistic Role of EZAC in PET Pyrolysis

In PET pyrolysis, the addition of Euxideroxylon zwageri-derived activated carbon (EZAC) can both accelerate polymer-fragment breakdown and redirect secondary reactions so that a greater fraction of PET-derived carbon is recovered as condensable volatiles (oil). The mechanistic that EZAC provides a porous surface and abundant sites that temporarily retain pyrolysis vapors, increase collision frequency, and prolong the residence time of reactive intermediates near/within the solid as following **Figure 19**. In non-catalytic pyrolysis, primary PET volatiles may (i) leave the hot zone too rapidly, limiting opportunities for vapor-phase upgrading toward condensable products, or (ii) undergo recombination/condensation to form oligomers and heavy tar, which increases kinematic viscosity and degrades oil quality. EZAC can modulate both pathways through adsorption and confinement effects, resulting in an “optimum window” of catalyst loading: at moderate dosages, vapor upgrading increases oil formation; at excessive dosages, intensified vapor–solid contact promotes carbon deposition (coke), increases the solid fraction, and diminishes effective activity.

At the molecular level, several EZAC roles likely occur simultaneously. First, selective adsorption: heavy or reactive intermediates can be retained on the carbon surface and within pores, preventing immediate escape from the reactor. Second, a microreactor (confinement) effect: the pore network provides confined spaces that enhance the probability of secondary reactions (e.g., mild cracking and rearrangement) by increasing the frequency of interactions between vapor molecules and pore walls. Third, surface-mediated reactions: the large surface area and porous structure increase vapor–solid contact and residence time, thereby increasing the likelihood of secondary transformations on the carbon surface [47]. Fourth, surface functional groups: oxygen-containing functionalities on activated carbon can act as reactive sites that assist transformation of polymer fragments into smaller and relatively more stable molecules [48]. Collectively, these effects can alter reaction kinetics and product selectivity, steering distributions toward more desirable fractions [38].

The observed increase in oil yield at moderate EZAC loading can therefore be explained by retention of heavy intermediates within EZAC pores, which provides sufficient time and contact for “appropriate” secondary reactions that convert tar/oligomers into condensable molecules. Conversely, at excessive EZAC loading, overly intense vapor–solid contact can promote further cracking toward permanent gases and/or facilitate condensation of reactive unsaturated/Aromatic species as coke on the carbon surface. Coke deposition can block pores and mask active sites, such that adding more EZAC no longer increases oil yield and instead diverts carbon toward the solid and gas fractions.

Improvements in oil quality are also consistent with these mechanisms. More controlled cracking and suppression of heavy tar/oligomer formation tend to produce a lighter and more

homogeneous oil, consistent with the measured decrease in kinematic viscosity and the slight reduction in density. Enrichment in lighter fractions increases volatility, which can lower the flash point under the optimum condition; however, at higher EZAC dosages, the flash point may increase again if the product distribution shifts

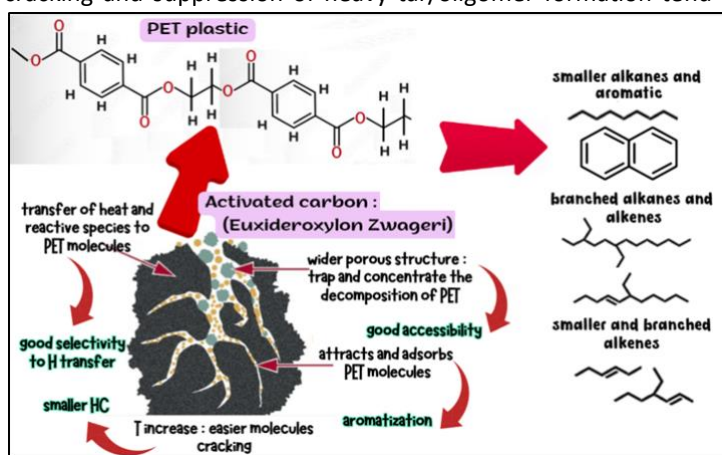


Figure 19.
The role of EZAC in the
mechanism of
carbon chain
breakdown in PET
plastics pyrolysis

toward less volatile fractions and/or if coke deposition modifies the spectrum of volatiles produced.

Finally, the increases in octane number and HHV can be attributed to shifts in hydrocarbon composition, including enrichment in gasoline-range fractions and changes in hydrocarbon classes induced by secondary reactions on/within EZAC. Moderate levels of Olefin and Aromatics can enhance knock resistance, consistent with the measured RON. In addition, π - π interactions between the Aromatic carbon surface and Aromatic intermediates may favor aromatization under specific conditions; activated carbon has been reported to influence Aromatic formation through complex secondary catalytic pathways [49]. A higher HHV may reflect enrichment in energy-dense hydrocarbons and/or a reduced contribution of certain oxygenated species, although this interpretation should ideally be supported by detailed compositional analysis (GC-MS) and/or elemental characterization.

3.5. Challenges, Limitations, and Future Outlook

Several challenges remain before the PET-EZAC process can be considered technically validated. First, because each PET:EZAC ratio was evaluated in a single reactor run, replicate experiments are needed to establish uncertainty, reproducibility, and statistical confidence in the observed yield trends. Second, long-term liquid stability, possible wax/oligomer crystallization, and the presence of terephthalic-, benzoic-acid, and other oxygenated Aromatic derivatives should be evaluated using detailed compound-level GC-MS/GC-FID, elemental analysis, acid number, and storage tests. Third, catalyst characterization should be expanded to include BET surface area, pore-size distribution, SEM/TEM morphology, FTIR/XPS surface chemistry, ash/mineral content, and spent-catalyst coke analysis. Fourth, because the MQ-series sensors provide trend-based gas monitoring rather than fully calibrated gas composition, gas analysis should be upgraded to calibrated GC or micro-GC measurements to obtain absolute concentrations and mass-based gas yields. Fifth, a complete mass and energy balance, including LPG consumption and heat loss, is required to support efficiency or scale-up claims. Therefore, the present findings should be interpreted as preliminary evidence of improved product distribution and fuel-relevant properties, rather than direct evidence of process-level energy savings. Finally, the feedstock rationale should be refined toward contaminated, degraded, colored, multilayered, or recycling-rejected PET fractions rather than clean PET streams that are better suited to mechanical recycling.

4. Conclusion

Euxideroxylon zwageri-derived activated carbon improved low-temperature PET pyrolysis by increasing oil yield and enhancing preliminary fuel-relevant properties. An optimum window was identified at PET:EZAC = 90:10 (w/w), which produced the highest oil yield (543 mL; 404 g; 80.8%) and favorable fuel-property indicators, including RON 97, HHV 47.88 MJ/kg, density 0.772 g/mL, kinematic viscosity 2.384 cSt, and flash point 13 °C.

Chemical characterization further indicated that the 90:10 condition most closely approached gasoline-like characteristics, as reflected by the highest C7–C10 fraction (62.95%) and a relatively balanced hydrocarbon-class distribution (Alkanes 64.64%, Olefin 27.61%, and Aromatics 7.75%). Increasing EZAC beyond 10% led to a more pronounced rise in the solid fraction (up to 20.6%) and a shift in oil composition toward more reactive fractions (higher Olefin/Aromatics), highlighting a practical upper limit for catalyst loading when the objective is to maximize liquid yield while maintaining product quality.

In the gas phase, EZAC accelerated the onset of H₂ and CH₄ formation, although their concentration profiles varied non-monotonically with EZAC loading. These trends support the interpretation that EZAC influences PET pyrolysis through competing secondary pathways and progressive carbon deposition on the catalyst surface, which can reduce effective activity at certain dosages. Accordingly, the present findings should be interpreted as preliminary comparative evidence because each PET ratio was evaluated in a single run and the gas profiles were obtained using MQ-series sensors, while process-level efficiency and energy-saving potential require further verification through a complete mass and energy balance, including LPG consumption, heat loss, and energy recovery from the products.

Future work should include (i) replicate experiments with uncertainty reporting, (ii) calibration and normalization of gas-sensor outputs to obtain absolute concentrations and mass-based gas yields, (iii) evaluation of additional fuel-relevant parameters (e.g., distillation curve, stability, and impurity profiling), and (iv) more comprehensive EZAC characterization (e.g., surface

area, pore structure, and surface functional groups) to strengthen structure–activity relationships and mechanistic interpretation.

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Authors' Declaration

Authors' contributions and responsibilities – Ahmad Yani: Conceptualization, Methodology, Investigation, Data curation, Formal analysis, Validation, Visualization, Writing – original draft, Writing – review & editing. Widya Wijayanti: Conceptualization, Methodology, Validation, Visualization, Supervision, Resources, Project administration, Formal analysis, Writing – review & editing. Mega Nur Sasongko: Methodology, Validation, Supervision, Resources, Writing – review & editing. Slamet Wahyudi: Methodology, Validation, Supervision, Writing – review & editing. Dwi Irawan: Investigation.

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Availability of data and materials – All data is available from the authors.

Competing interests – The authors declare no competing interests.

Additional information – No additional information from the authors.

Generative AI statement – The author used ChatGPT to enhance the clarity of the writing. After using the ChatGPT, the authors reviewed and edited the content as needed and take full responsibility for the publication's content.

References

- [1] H. L. Chen, T. K. Nath, S. Chong, V. Foo, C. Gibbins, and A. M. Lechner, "The plastic waste problem in Malaysia: management, recycling and disposal of local and global plastic waste," *SN Applied Sciences*, vol. 3, no. 4, p. 437, Apr. 2021, doi: 10.1007/s42452-021-04234-y.
- [2] K. P. Muthee, N. P. Mwangi, and O. F. Xavier, "Conversion of Solid Wastes to Fuel Energy Resources through Normal and Catalytic Pyrolysis Process Conditions: A Renewable Resources Strategy," *Energy and Power Engineering*, vol. 17, no. 02, pp. 13–34, 2025, doi: 10.4236/epe.2025.172002.
- [3] C. C. Seah et al., "Co-pyrolysis of biomass and plastic: Circularity of wastes and comprehensive review of synergistic mechanism," *Results in Engineering*, vol. 17, no. October 2022, p. 100989, Mar. 2023, doi: 10.1016/j.rineng.2023.100989.
- [4] W. N. Cahyo, A. Munang, H. Purnomo, and I. D. Widodo, "Perspective and modeling requirement on household solid waste management," *Mechanical Engineering for Society and Industry*, vol. 6, no. 1, May 2026, doi: 10.31603/mesi.14267.
- [5] M. Setiyo, S. Sunaryo, and M. L. Rochman, "Pyrolysis for plastic waste: Environmental goals vs business interests, which is more realistic?," *Mechanical Engineering for Society and Industry*, vol. 5, no. 1, pp. 1–4, Jul. 2025, doi: 10.31603/mesi.14149.
- [6] T. Xayachak et al., "Pyrolysis for plastic waste management: An engineering perspective," *Journal of Environmental Chemical Engineering*, vol. 10, no. 6, p. 108865, Dec. 2022, doi: 10.1016/j.jece.2022.108865.
- [7] S. Armenise et al., "Plastic waste recycling via pyrolysis: A bibliometric survey and literature

- review,” *Journal of Analytical and Applied Pyrolysis*, vol. 158, p. 105265, Sep. 2021, doi: 10.1016/j.jaap.2021.105265.
- [8] L. M. Rios Mendoza and M. Balcer, “Microplastics in freshwater environments: A review of quantification assessment,” *TrAC Trends in Analytical Chemistry*, vol. 113, no. 113, pp. 402–408, Apr. 2019, doi: 10.1016/j.trac.2018.10.020.
 - [9] S. Sunaryo, S. Sutoyo, S. Suyitno, Z. Arifin, T. Kivevele, and A. I. Petrov, “Characteristics of briquettes from plastic pyrolysis by-products,” *Mechanical Engineering for Society and Industry*, vol. 3, no. 2, pp. 57–65, Jun. 2023, doi: 10.31603/mesi.9114.
 - [10] D. B. Aji, M. Effendy, and N. Ngafwan, “Combustion characteristics of pyrolysis oil droplets from pyrolysis of polyethylene (PE) plastic waste,” *Mechanical Engineering for Society and Industry*, vol. 5, no. 1, pp. 125–132, Mar. 2025, doi: 10.31603/mesi.12763.
 - [11] Z. C. Mibei, A. Kumar, and S. M. Talai, “Catalytic Pyrolysis of Plastic Waste to Liquid Fuel Using Local Clay Catalyst,” *Journal of Energy*, vol. 2023, no. 1, pp. 1–11, Jun. 2023, doi: 10.1155/2023/7862293.
 - [12] A. Nawaz and S. A. Razzak, “Synergism, pyrolysis performance, product distribution and characteristics in the co-pyrolysis of date palm waste and polyethylene foam: Harnessing the potential of plastics and biomass valorization,” *Carbon Resources Conversion*, vol. 8, no. 3, p. 100312, Sep. 2025, doi: 10.1016/j.crcon.2025.100312.
 - [13] H. Hsu et al., “Toward sustainability of Waste-to-Energy: An overview,” *Energy Conversion and Management*, vol. 321, no. April, p. 119063, Dec. 2024, doi: 10.1016/j.enconman.2024.119063.
 - [14] N. Pannucharoenwong, K. Duanguppama, S. Echaroj, C. Turakarn, K. Chaiphet, and P. Rattanadecho, “Improving fuel quality from plastic bag waste pyrolysis by controlling condensation temperature,” *Energy Reports*, vol. 9, no. February, pp. 125–138, Sep. 2023, doi: 10.1016/j.egyr.2023.05.231.
 - [15] H. Jeswani et al., “Life cycle environmental impacts of chemical recycling via pyrolysis of mixed plastic waste in comparison with mechanical recycling and energy recovery,” *Science of The Total Environment*, vol. 769, p. 144483, May 2021, doi: 10.1016/j.scitotenv.2020.144483.
 - [16] S. Das, C. Liang, and J. B. Dunn, “Plastics to fuel or plastics: Life cycle assessment-based evaluation of different options for pyrolysis at end-of-life,” *Waste Management*, vol. 153, pp. 81–88, Nov. 2022, doi: 10.1016/j.wasman.2022.08.015.
 - [17] R. A. A. Nugroho, A. F. Alhikami, and W. Wang, “Thermal decomposition of polypropylene plastics through vacuum pyrolysis,” *Energy*, vol. 277, no. February, p. 127707, Aug. 2023, doi: 10.1016/j.energy.2023.127707.
 - [18] F. Hidiyanto et al., “Integrating Synthetic Data with Deep Learning for Predictive Modelling and Optimization of Diesel Engine Performance on Waste Plastic Oil Blends,” *Automotive Experiences*, vol. 9, no. 1, pp. 9–26, 2026, doi: 10.31603/ae.14360.
 - [19] S. Sobri, W. Wijayanti, N. Hamidi, Purnami, W. S. Nugroho, and I. N. G. Wardana, “Engineered seabed sediment via microwave-assisted Ni²⁺ substitution as a catalyst for double-stage pyrolysis of plastic waste: A novel approach to methane reforming and enhanced hydrogen production,” *Results in Engineering*, vol. 27, no. July, p. 106488, Sep. 2025, doi: 10.1016/j.rineng.2025.106488.
 - [20] T. T. Tran, H. Q. Tran, D. H. Tran, T. N. Nguyen, T. K. Phung, and T. C. Do, “The effect of reaction conditions and catalysts on the pyrolysis of polyethylene,” *Science & Technology Development Journal*, vol. 27, no. 2, pp. 3375–3384, 2024, doi: 10.32508/stdj.v27i2.4251.
 - [21] A. Yani, W. Wijayanti, M. N. Sasongko, and S. Wahyudi, “Trash to Treasure: Co-Pyrolysis of PET Plastic and Hibiscus Rosa-Sinensis for Sustainable Syngas Production,” in *Lecture Notes in Mechanical Engineering*, vol. 01, no. ICE-SEAM 2024, Surakarta, Indonesia, W. P. Raharjo, F. Imaduddin, and D. F. Smaradhana, Eds., in *Lecture Notes in Mechanical Engineering*, vol. 01, Singapore: Springer Nature Singapore, 2025, pp. 61–75. doi: 10.1007/978-981-96-5063-7_6.
 - [22] M. M. Hasan, R. Haque, M. I. Jahirul, and M. G. Rasul, “Pyrolysis of plastic waste for sustainable energy Recovery: Technological advancements and environmental impacts,” *Energy Conversion and Management*, vol. 326, p. 119511, Feb. 2025, doi: 10.1016/j.enconman.2025.119511.

- [23] S. Saxena, "Pyrolysis and beyond: Sustainable valorization of plastic waste," *Applications in Energy and Combustion Science*, vol. 21, p. 100311, Mar. 2025, doi: 10.1016/j.jaecs.2024.100311.
- [24] S. Sobri, I. N. G. Wardana, W. Wijayanti, and N. Hamidi, "Clove (*Syzygium aromaticum*) for greener plastic catalytic pyrolysis: A novel catalyst for enhanced hydrogen production and carbon capture," *International Journal of Hydrogen Energy*, vol. 99, no. December 2024, pp. 312–327, Jan. 2025, doi: 10.1016/j.ijhydene.2024.12.227.
- [25] E. Daryanto et al., "Potential of Grocery Bags Plastic Waste as a Fuel Substitute for Fossil-Based Fuels: A Characterization Study on the Non-Catalytic Low-Temperature Pyrolysis Process," *Automotive Experiences*, vol. 7, no. 3, pp. 450–459, Dec. 2024, doi: 10.31603/ae.12099.
- [26] V. Aswie, L. Qadariah, and M. Mahfud, "Pyrolysis of Microalgae *Chlorella* sp. using Activated Carbon as Catalyst for Biofuel Production," *Bulletin of Chemical Reaction Engineering & Catalysis*, vol. 16, no. 1, pp. 205–213, Mar. 2021, doi: 10.9767/bcrec.16.1.10316.205-213.
- [27] Z. Zhou, H. Liu, X. Liu, and C. Chin, "Oxygenated polycyclic aromatic hydrocarbons as key coke precursors in coke formation during zeolite-catalyzed furfural pyrolysis," *Applications in Energy and Combustion Science*, vol. 24, no. August, p. 100389, Dec. 2025, doi: 10.1016/j.jaecs.2025.100389.
- [28] H. Juwono et al., "Catalytic cracking polystyrene waste by co-reactant biodiesel waste coconut oil and its performance at gasoline engine," in *AIP Publishing*, 2021, p. 020070. doi: 10.1063/5.0051809.
- [29] F. Zhao, Z. Yang, L. Zhang, C. Zhang, T. Wang, and H. Zhang, "The effect of temperature on pyrolysis products during oil shale thermal decomposition," *Scientific Reports*, vol. 15, no. 1, p. 26135, Jul. 2025, doi: 10.1038/s41598-025-11050-6.
- [30] A. Mlonka-Mędrala, P. Evangelopoulos, M. Sieradzka, M. Zajemska, and A. Magdziarz, "Pyrolysis of agricultural waste biomass towards production of gas fuel and high-quality char: Experimental and numerical investigations," *Fuel*, vol. 296, no. March, p. 120611, Jul. 2021, doi: 10.1016/j.fuel.2021.120611.
- [31] J. Moško, M. Pohořelý, S. Skoblia, Z. Beňo, and M. Jeremiáš, "Detailed Analysis of Sewage Sludge Pyrolysis Gas: Effect of Pyrolysis Temperature," *Energies*, vol. 13, no. 16, p. 4087, Aug. 2020, doi: 10.3390/en13164087.
- [32] W. Wijayanti, M. Musyaroh, and M. N. Sasongko, "Low-Density Polyethylene Plastic Waste to Liquid Fuel Using Pyrolysis Method: An Effect of Temperatures on the Oil Yields Physicochemical Properties," *Journal of Sustainable Development of Energy, Water and Environment Systems*, vol. 10, no. 3, pp. 1–18, Sep. 2022, doi: 10.13044/j.sdewes.d9.0402.
- [33] A. Yani, W. Wijayanti, M. N. Sasongko, S. Wahyudi, P. Suwandono, and M. Musyaroh, "Synergistic co-pyrolysis of polyethylene terephthalate and hibiscus rosa-sinensis: Catalytic mechanisms for optimizing pyrolysis yields," *South African Journal of Chemical Engineering*, vol. 53, no. June, pp. 281–302, Jul. 2025, doi: 10.1016/j.sajce.2025.05.008.
- [34] A. Koti, P. Khongprom, and S. Ratanawilai, "Catalytic Pyrolysis Oil from Landfilled Plastics through Ni/HZSM-5 and Co/HZSM-5 Catalysts," *ACS Omega*, vol. 10, no. 6, pp. 5744–5755, Feb. 2025, doi: 10.1021/acsomega.4c09247.
- [35] M. F. Paucar-Sánchez, M. Calero, G. Blázquez, R. R. Solís, M. J. Muñoz-Batista, and M. Á. Martín-Lara, "Impact of Metal Impregnation of Commercial Zeolites in the Catalytic Pyrolysis of Real Mixture of Post-Consumer Plastic Waste," *Catalysts*, vol. 14, no. 3, p. 168, Feb. 2024, doi: 10.3390/catal14030168.
- [36] B. Fekhar, L. Gombor, and N. Miskolczi, "Pyrolysis of chlorine contaminated municipal plastic waste: In-situ upgrading of pyrolysis oils by Ni/ZSM-5, Ni/SAPO-11, red mud and Ca(OH)₂ containing catalysts," *Journal of the Energy Institute*, vol. 92, no. 5, pp. 1270–1283, Oct. 2019, doi: 10.1016/j.joei.2018.10.007.
- [37] B. Saha, S. Vedachalam, A. K. Dalai, S. Saxena, B. Dally, and W. L. Roberts, "Review on production of liquid fuel from plastic wastes through thermal and catalytic degradation," *Journal of the Energy Institute*, vol. 114, no. October 2023, p. 101661, Jun. 2024, doi: 10.1016/j.joei.2024.101661.
- [38] K. Qian, W. Tian, W. Li, S. Wu, D. Chen, and Y. Feng, "Catalytic Pyrolysis of Waste Plastics over Industrial Organic Solid-Waste-Derived Activated Carbon: Impacts of Activation Agents,"

- Processes*, vol. 10, no. 12, p. 2668, Dec. 2022, doi: 10.3390/pr10122668.
- [39] F. M. Jais, C. Y. Chee, Z. Ismail, and S. Ibrahim, "Experimental design via NaOH activation process and statistical analysis for activated sugarcane bagasse hydrochar for removal of dye and antibiotic," *Journal of Environmental Chemical Engineering*, vol. 9, no. 1, p. 104829, Feb. 2021, doi: 10.1016/j.jece.2020.104829.
 - [40] D. Irawan, W. Wijayanti, S. Wahyudi, and I. N. G. Wardana, "Modification effects of Na-bentonite catalyst with organic compounds increasing hydrogen production from biomass pyrolysis," *Case Studies in Chemical and Environmental Engineering*, vol. 11, no. January, p. 101206, Jun. 2025, doi: 10.1016/j.cscee.2025.101206.
 - [41] D. Irawan, W. Wijayanti, S. Wahyudi, H. N. R. A. Kusumo, A. Yani, and I. N. G. Wardana, "Enhanced Hydrogen Production from Biomass Pyrolysis using Surfactant-Modified Na-Bentonite Catalyst," *ASEAN Journal of Science and Engineering*, vol. 5, no. 3, pp. 539–558, Aug. 2025, doi: 10.17509/ajse.v5i3.88898.
 - [42] F. I. Septi, W. S. Nugroho, P. Purnami, D. J. D. H. Santjojo, and I. N. G. Wardana, "The role of aromatic rings, heterocyclic rings, and hydroxyl groups in increasing hydrogen production using activated carbon-based photocatalysts," *Mechanical Engineering for Society and Industry*, vol. 6, no. 1, pp. 21–39, Feb. 2026, doi: 10.31603/mesi.15190.
 - [43] T. Gong, Q. Cai, and S. Zhang, "Production of liquid aromatics by two-stage co-pyrolysis of sawdust and low-density polyethylene," *Journal of Fuel Chemistry and Technology*, vol. 52, no. 11, pp. 1604–1616, Nov. 2024, doi: 10.3724/2097-213X.2024.JFCT.0006.
 - [44] B. Hegedüs, Á. B. Palotás, G. Muránszky, and Z. Dobó, "Investigation of gasoline-like transportation fuel obtained by plastic waste pyrolysis and distillation," *Journal of Cleaner Production*, vol. 447, no. February, p. 141500, Apr. 2024, doi: 10.1016/j.jclepro.2024.141500.
 - [45] P. Vozka et al., "Jet fuel density via GC × GC-FID," *Fuel*, vol. 235, pp. 1052–1060, Jan. 2019, doi: 10.1016/j.fuel.2018.08.110.
 - [46] E. Marlina, A. F. Alhikami, S. A. Mardiyani, T. Trismawati, and C. Yazirin, "Catalytic Pyrolysis of Plastic Waste using Red Mud and Limestone: Pyrolytic Oil Production and Ignition characteristics," *Automotive Experiences*, vol. 7, no. 3, pp. 579–591, Dec. 2024, doi: 10.31603/ae.12830.
 - [47] M. M. Harussani, S. M. Sapuan, U. Rashid, A. Khalina, and R. A. Ilyas, "Pyrolysis of polypropylene plastic waste into carbonaceous char: Priority of plastic waste management amidst COVID-19 pandemic," *Science of The Total Environment*, vol. 803, no. January, p. 149911, Jan. 2022, doi: 10.1016/j.scitotenv.2021.149911.
 - [48] K. Sun, Q. Huang, X. Meng, Y. Chi, and J. Yan, "Catalytic Pyrolysis of Waste Polyethylene into Aromatics by H₃PO₄-Activated Carbon," *Energy & Fuels*, vol. 32, no. 9, pp. 9772–9781, Sep. 2018, doi: 10.1021/acs.energyfuels.8b02091.
 - [49] A. Ligeró, M. Calero, A. Pérez, R. R. Solís, M. J. Muñoz-Batista, and M. Á. Martín-Lara, "Low-cost activated carbon from the pyrolysis of post-consumer plastic waste and the application in CO₂ capture," *Process Safety and Environmental Protection*, vol. 173, no. February, pp. 558–566, May 2023, doi: 10.1016/j.psep.2023.03.041.