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C_9 Studying the Temperature Effect of Pyrolysis Distillate Rectification for the Extraction of Hydrocarbons

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ABSTRACT: This study examines the influence of temperature on the rectification of pyrolysis distillate to extract the fraction of hydrocarbons C_9, which is a valuable component for fuel and chemical synthesis. Pyrolysis distillate obtained from organic waste was dry distilled at a temperature from 150°C to 170°C, the fractions were analyzed using infrared (IR) spectroscopy. The results show that at a temperature of 152°C, the highest purity and C_9 aliphatic hydrocarbons were obtained, which are characterized by strong C-H waves and bending lines, with minimal aromatic and oxygen-containing impurities. At 159°C, a decrease in carbonyl inclusions and an increase in unsaturated hydrocarbons were observed, which indicates partial oxidation. At a temperature of 170°C, thermal cracking and aromatization prevail, enriching the fraction with aromatic compounds and reducing the necessary C_9 hydrocarbons. Comparative IR spectral analysis confirmed 152°C as the optimal temperature, which ensures the best balance of efficiency and product integrity. This data provides important information for optimizing rectification processes in sustainable hydrocarbon production.

KEYWORDS: Pyrolysis distillate, C_9 hydrocarbons, rectification, temperature exposure, IR spectroscopy, dry distillation.

I. INTRODUCTION

Pyrolysis, a thermochemical decomposition process, is widely used in the conversion of organic materials into valuable hydrocarbons, especially in the process of processing biomass and waste [1]. The distillate obtained as a result of pyrolysis, often called pyrolysis oil or bio-oil, is a complex mixture of hydrocarbons, oxygenates, and other organic compounds [2]. Among them, the inclusion of alkanes, alkenes, and aromatic substances - octane, nonane, and their derivatives - in the C_9 hydrocarbon fraction is important due to its use in fuel production, chemical synthesis, and as raw materials for subsequent refining processes. However, separating this specific hydrocarbon range from the pyrolysis distillate is difficult due to the complexity of the mixture and the influence of various process parameters, and temperature is one of the most important factors [3].

Temperature plays a decisive role both in the pyrolysis process and in the subsequent rectification of the distillate [4]. During pyrolysis, temperature affects the yield and composition of the distillate, determining the relative ratios of light and heavy hydrocarbons, as well as the formation of unwanted by-products, such as resins or oxygen compounds [5]. At the rectification stage, precise temperature control is necessary to achieve effective separation of the C_9 fraction by dry distillation or appropriate methods [6]. Temperature changes can significantly affect the volatility, phase state, and chemical stability of hydrocarbons, which affects the purity and yield of the desired fraction [7].

The rectification process involves separating the pyrolysis distillate into separate fractions based on differences in boiling points [8]. It is important to maintain optimal temperature conditions for C_9 hydrocarbons, the boiling point of which is usually in the range of 125-175°C, ensuring their effective separation without thermal decomposition and mutual contamination with other fractions [9]. In addition, temperature affects the thermodynamic properties of the distillate, including the vapor-liquid equilibrium, which regulates the efficiency of the rectification process [10]. Excessive temperature can lead to decomposition or polymerization of hydrocarbons, and insufficient temperature can lead to low separation efficiency, which increases impurities in the target fraction [11].

This study is aimed at studying the influence of temperature on the rectification of pyrolysis distillate, with a particular focus on optimizing the extraction of C_9 hydrocarbons [12]. By conducting a systematic analysis of the influence of temperature change on the yield, purity, and composition of the C_9 fraction, this study is aimed at providing insights into the design of effective rectification processes for industrial application [13]. The results are expected to contribute to the development of sustainable and cost-effective methods for producing high-value hydrocarbons from pyrolysis feedstock [14], which will support advances in renewable energy and chemical production [15].

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II. MATERIALS AND METHODS

Materials

The pyrolysis distillate used in this study was mainly obtained from the residual part of the oil fraction. The distillate was pre-filtered to remove solid impurities and water content, which provides a homogeneous liquid raw material for rectification. Analytical grade standards for C_9 hydrocarbons (e.g., octane, nonane, and their isomers) were purchased from a commercial supplier for calibration and comparison. To reduce interference during the analysis process, all chemicals and solvents used in the analysis processes had high purity (≥99%).

Rectification process

Rectification of pyrolysis distillate was carried out using a laboratory-scale dry distillation unit equipped with a packed column (20 theoretical plates) to increase the efficiency of separation. The discharge unit includes a heating mantle, a reverse cooler, and a temperature-controlled assembly system. The distillate was heated at a controlled rate and the temperature was systematically changed from 150°C to 170°C to achieve the boiling range of C_9 hydrocarbons (approximately 125-175°C). The temperature was controlled using a calibrated thermocouple with an accuracy of ±0.5°C. To ensure precise separation of C_9 hydrocarbons, the fractions were collected in a temperature range of 5°C. To ensure reproduction, each fraction was assembled in three copies, and the yield of each fraction was calculated as a percentage of the total distillate mass.

Analysis methods

The collected fractions were analyzed using infrared (IR) spectroscopy.

Infrared (IR) spectroscopy

To identify functional groups and confirm the presence of C_9 hydrocarbons, IR spectroscopy was performed using a Fourier infrared (FTIR) spectrometer. Each sample was scanned in the range of 4000-400 cm-1 with an accuracy of 4 cm^{-1}. Liquid samples were analyzed using the thin film method in the KBr element. By comparing the spectra with the reference spectra of pure C_9 hydrocarbons, characteristic absorption bands were identified, such as C-H elongation (2800-3000 cm−1) and C-H deflection (1350-1470 cm−1), indicating alkanes and alkenes in the target fraction.

Experimental design

Rectification experiments are designed to assess the influence of temperature on the yield and purity of the C8-C9 hydrocarbon fraction. A total of 3 temperature points (152°C, 159°C, and 170°C) were selected for the distillation process. Each temperature condition was checked in three copies, and the obtained fractions were subjected to IR analysis. To determine the significance of the influence of temperature on the yield and composition of C9 hydrocarbons, the data were statistically analyzed using dispersion analysis (ANOVA) with a 95% confidence level ($p < 0.05$).

III. RESULTS AND DISCUSSION

C_9 to extract the hydrocarbon fraction, rectification of the pyrolysis distillate was carried out at various temperatures (from 150°C to 170°C), and the obtained fractions were analyzed using IR spectroscopy to assess the influence of temperature on yield, purity, and composition. The results provide insight into the optimal temperature conditions for effective separation of target hydrocarbons and the effect of temperature on the chemical properties of the distillate.

IR analysis of the sample obtained at a temperature of 152°C is shown in Figure 1, which shows characteristic absorption bands associated with the hydrocarbons $_{C9.}$

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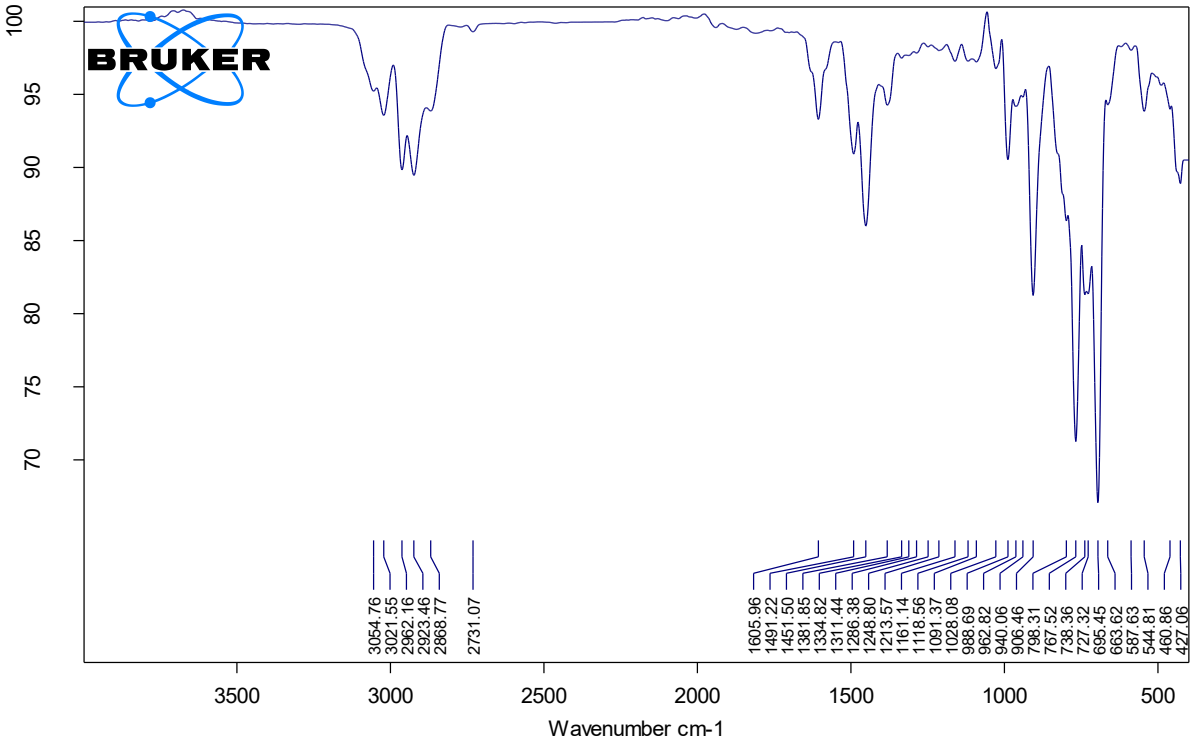

Figure 1. IR spectrum of the pyrolysis distillate fraction at 152°C

The IR spectrum shown in Figure 1 highlights several main absorption bands that provide information about the chemical composition of the 152°C fraction. O-H and N-H stretching lines (around 3300-3500 cm-1) indicate the presence of small hydroxyl or amine groups as additives to the pyrolysis process. The C=O line (approximately 1700 cm-1) shows a small amount of carbonyl compounds, which may occur due to incomplete decomposition or oxidation during pyrolysis. The strong C-H elongation (2800-3000 cm-1) and C-H deflection (1350-1470 cm-1) lines confirm the predominance of aliphatic hydrocarbons corresponding to the target fraction C9. In addition, the presence of C=C elongation (around 1650 cm-1) and =C-H vinyl elongation (around 3000-3100 cm-1) indicates the presence of unsaturated hydrocarbons, while the presence of C-H aromatic elongation (around 3000-3100 cm-1) and the C-Cl line (around 600-800 cm-1) indicate traces of aromatic and chloride compounds in the raw material, possibly from components obtained from plastics. The Me-O line (around 1000-1200 cm-1) also shows a small proportion of methoxy groups. This analysis shows that while the 152°C fraction $_{C9}$ is rich in hydrocarbons, it contains detectable impurities that may require additional purification to meet industry standards.

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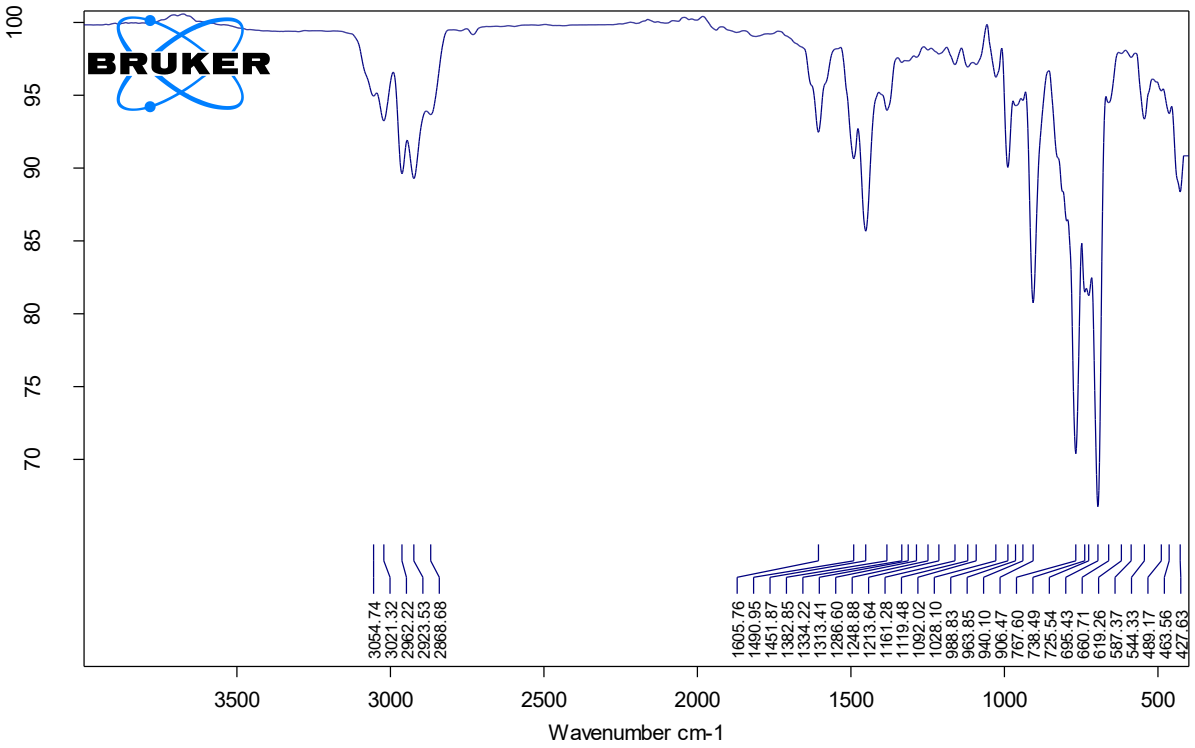

Figure 2. IR spectrum of the pyrolysis distillate fraction at 159°C

As shown in Figure 2, the IR spectra of the 159oC fraction exhibit absorption patterns similar to those of the 159oC fraction, with significant differences in intensity and additional properties. The O-H and N-H stretching lines (3300-3500 $^{cm-1)}$ are preserved, but appear slightly shortened, which indicates a decrease in hydroxyl and amine impurities with increasing temperature. The C=O line (around 1700 cm-1) is less pronounced, indicating a possible decrease in carbonyl compounds, possibly the result of strong evaporation or decomposition at 159°C. C-H elongation (2800-3000 $^{cm-1)}$ and C-H deflection (1350-1470 $^{cm-1)}$ dominate, which enhances the distribution of aliphatic hydrocarbons in the C8-C9 range. The C=C stretching (1650 $^{cm-1)}$ and =C-H vinyl stretching (3000-3100 $^{cm-1)}$ lines are more intense, indicating an increase in unsaturated hydrocarbons at this temperature. C-H aromatic elongation (3000-3100 $^{cm-1)}$ and C-Cl alkyl halides line (600-800 $^{cm-1)}$ show moderate intensity, indicating persistent aromatic and chloride mixtures. In addition to the =C-H plane, bending (around 900-1000 $^{cm-1)}$ and the Me-O line (1000-1200 $^{cm-1)}$ are also determined, the latter slightly increases due to increased stability of the methoxy group at a temperature of 159°C. The curvature outside the C-H plane (around 700-900 $^{cm-1)}$ and the carbonic acid C-O-H line (around 1200-1300 $^{cm-1)}$ indicate the presence of additional oxygenated substances, which may indicate partial oxidation at this temperature. This analysis shows that the 159°C fraction retains a high content of $_{C9}$ hydrocarbons, but there is a shift in the mixture profile relative to the 152°C fraction

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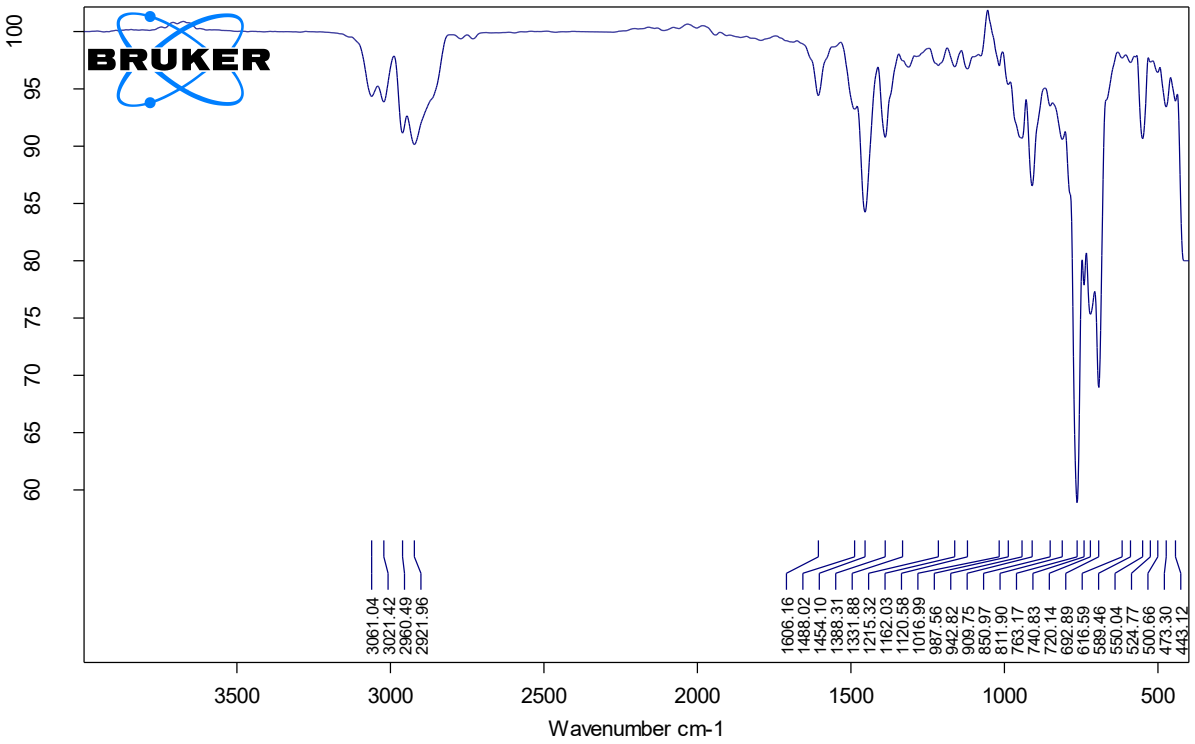

Figure 3. IR spectrum of the pyrolysis distillate fraction at 170°C

The IR spectrum for the 170°C fraction shown in Fig. 3 shows a clear profile compared to low-temperature fractions. The C-H elongation (aromatic) line (around 3000-3100 cm-1) is more pronounced, indicating a higher concentration of aromatic hydrocarbons due to thermal cracking or enhanced aromatization at this temperature. C=O elongation (around 1700 cm-1) significantly decreases, which indicates that carbonyl compounds mainly volatilize or decompose at 170°C. The C-H aldehyde line (around 2700-2800 cm-1) is weak, indicating a minimal amount of aldehyde, the O-H carboxylic acid line (around 2500-3300 cm-1) is practically absent, reflecting a significant decrease in carboxylic acid inclusions. C=C elongation (around 1650 cm-1) is visible, but not very intense, which indicates a possible decrease in unsaturated hydrocarbons due to thermostability limits. The C-H 1,2,3-triple benzene band (around 700-900 cm-1) indicates the presence of substituted aromatic compounds that can be formed during high-temperature treatment. The Me-O band (1000-1200 cm-1) has medium intensity, indicating the stability of methoxy groups, the C-Cl alkyl halides band (600-800 cm-1) is weak, indicating a decrease in chlorine inclusions. This analysis shows that the 170°C fraction is enriched with aromatic hydrocarbons, but may have undergone partial decomposition of other components, which affects the overall yield and purity of the $_{C9}$ fraction.

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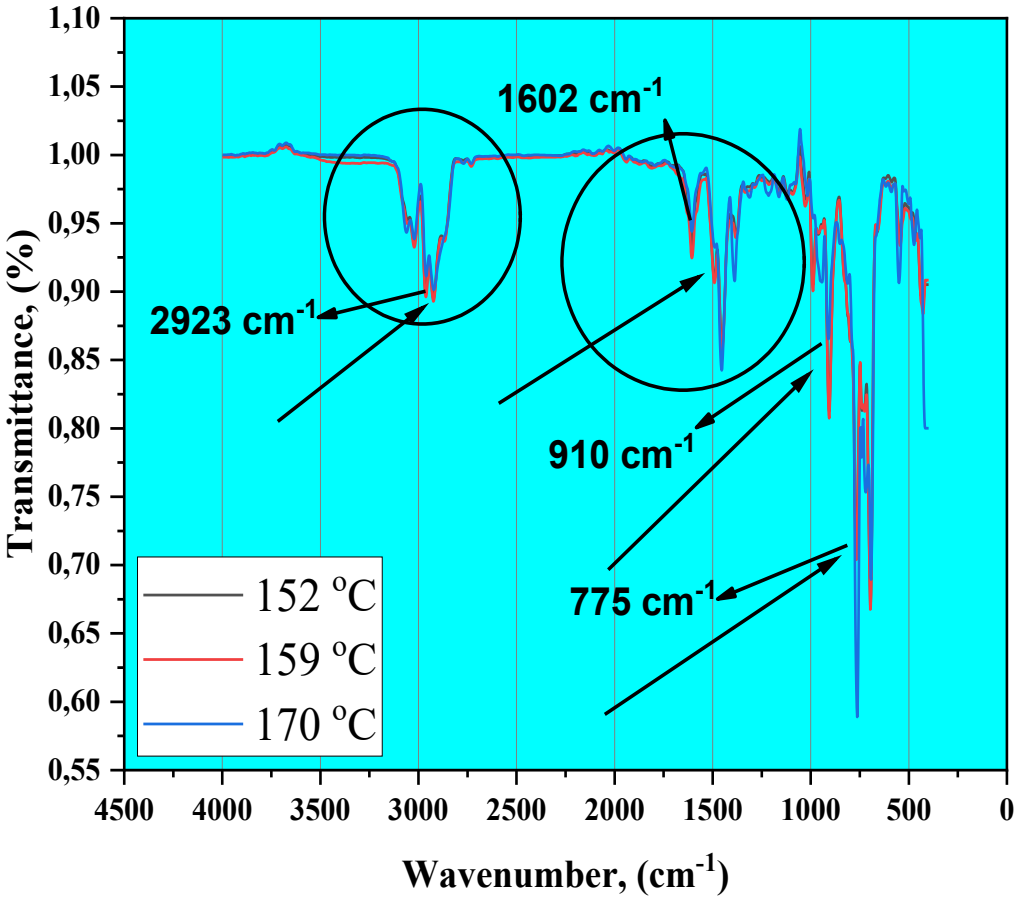

Figure 4. Overlapping IR spectra of pyrolysis distillate fractions at temperatures of 152°C, 159°C, and 170°C

The overlapping IR spectra in Figure 4 show the main differences in peak intensities and profiles for the three temperatures, emphasizing the influence of temperature on the rectification process. At 2923 $^{cm-1,}$ corresponding to aliphatic C-H stretching vibrations, the peak intensity is highest at 152°C (black line), which indicates a predominance of saturated hydrocarbons characteristic of $_{the\ C9}$ fraction. When the temperature rises to 159°C (red line) and 170°C (blue line), the intensity in this wave number decreases, indicating that these compounds can undergo thermal decomposition or evaporation. The line at 1602 $^{cm-1}$ associated with C=C elongation or aromatic rings shows average intensity at all temperatures, but slightly increases at 170°C, which indicates increased aromatization at higher temperatures, which can introduce unwanted aromatic impurities into $_{the\ C9}$ aliphatic target. The 910 $^{cm-1}$ peak, indicating the non-planar bending of vinyl C-H, is most pronounced at 152°C and decreases at higher temperatures, which means a decrease in unsaturated hydrocarbons due to polymerization or cracking with increasing temperature. Similarly, the 775 $^{cm-1}$ line associated with aromatic C-H bending is weakest at 152°C and stronger at 170°C, which once again confirms the shift towards aromatic compounds at high temperatures. In general, the coating shows that low temperatures maintain the integrity of aliphatic $_{C9}$ hydrocarbons with minimal impurities, while high temperatures stimulate secondary reactions leading to aromatization and degradation. Based on these observations, it was found that the optimal temperature for the rectification process, which ensures the best balance of yield and purity for the extraction of C9hydrocarbons, is 152°C.

IV. RESULT

C_9 showed that temperature significantly affects the yield, purity, and composition of the target fraction. IR spectroscopy of the obtained fractions at temperatures of 152, 159, and 170°C revealed specific trends in the chemical profiles. The fraction at a temperature of 152°C C_9 exhibited the highest concentration of aliphatic hydrocarbons, C-H stretching and bending lines, minimal aromatic and oxygen-containing impurities, which makes it most suitable for

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industrial application. With an increase in temperature to 159 °C, a decrease in some impurities (for example, carbonyl compounds) and an increase in unsaturated hydrocarbons and oxygen-saturated substances, i.e., partial oxidation, were observed. At a temperature of 170°C, the fraction showed a significant increase in aromatic compounds due to thermal cracking and aromatization, along with a decrease in impurities of unsaturated hydrocarbons and carboxylic acids, which indicates the degradation of the desired C_9 fraction. Comparative overlapping of IR spectra confirmed that at 152°C, an optimal balance of purity and yield is ensured, which preserves the integrity of aliphatic hydrocarbons while minimizing secondary reactions. These results emphasize the importance of precise temperature control during the rectification process and indicate that 152°C should be taken as the optimal operating conditions for maximum extraction of high-purity C_9 hydrocarbons from pyrolysis distillate, which contributes to the development of effective and stable purification technologies.

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