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Original Research Article

A Green and Sustainable Approach for Converting Laboratory Latex Glove Waste into Liquid Fuel via Microwave-Assisted Pyrolysis

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Abstract

The extensive use of chemical laboratories for experimental and research activities has resulted in the substantial accumulation of latex glove waste, a widely used form of personal protective equipment (PPE). This study presents a novel and sustainable approach for converting laboratory latex glove waste into liquid fuel using microwave-assisted pyrolysis (MAP), which aligns with the principles of green chemistry. Under optimal conditions, including a microwave power of 800 W and an irradiation time of 30 min, the process achieved a liquid product yield of 52.584 wt%, with 41.862 wt% consisting of gasoline-range hydrocarbons (C_5–C_{12}). The primary compound identified in the liquid product was D-limonene ($C_{10}H_{16}$), a valuable monocyclic terpene. Compared to conventional pyrolysis conducted in a semi-batch reactor, the MAP process exhibited superior performance in terms of liquid yield, gasoline-range hydrocarbon content, total hydrocarbon composition, and calorific value. This innovative waste-to-fuel conversion method demonstrates the strong potential of MAP as an efficient and environmentally responsible strategy for waste valorization and resource recovery.

Keywords: Microwave-assisted pyrolysis; latex glove waste; green chemistry; sustainable fuel production; waste valorization

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1. Introduction

Latex gloves, an essential component of personal protective equipment (PPE), are widely used in hospital settings, especially following the COVID-19 pandemic, as well as in research laboratories where they support routine experimental activities. Consequently, a single chemistry laboratory can generate up to 200 kg of latex glove waste annually [1]. High-quality latex gloves are typically manufactured from a blend of synthetic and natural rubber, providing properties such as water resistance, elasticity, mechanical strength, durability, and softness [2,3]. However, their widespread use in high-throughput laboratory environments has led to the significant accumulation of waste that is difficult to manage due to its non-biodegradable nature. These materials can persist in landfills for extended periods before decomposing [4].

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Currently, only approximately 1.5% of total rubber waste is recycled or reused, revealing a critical gap in sustainable waste management practices [5]. Moreover, because latex gloves are designed for single use to prevent cross-contamination and disease transmission [6], their disposal significantly contributes to the growing volume of PPE waste. Therefore, it is essential to develop effective and environmentally responsible strategies to manage and valorize latex glove waste. Sustainable approaches are crucial to minimizing the environmental impact of rubber-based PPE and promoting a circular economy.

Several strategies have been investigated for rubber waste management. Mechanical recycling and cryogenic grinding offer potential for material recovery. These methods, however, are often hindered by contamination, high operational costs, and the limited economic value of the recovered materials [7]. Devulcanization, which involves breaking sulfur cross-links to restore rubber properties, presents another alternative. This process generally requires toxic chemicals and elevated temperatures, which limits its environmental compatibility [8].

Thermal processes, such as incineration and gasification, are also widely used due to their simplicity and capacity for energy recovery. Nevertheless, these methods generally operate at temperatures exceeding 800 °C and result in considerable emissions of carbon monoxide (CO) and carbon dioxide (CO_2) [9]. The excessive release of CO and CO_2 is recognized as a major contributor to climate change and global warming [10], raising significant environmental concerns about the long-term viability of such techniques.

Among existing methods, pyrolysis has emerged as a more promising and sustainable solution for rubber waste conversion. This thermal decomposition process occurs at moderate temperatures and often yields valuable products such as liquid fuels. Pyrolysis is considered one of the most effective thermal-based technologies for transforming polymer waste into usable energy resources [11,12]. Ongoing research continues to explore greener and more energy-efficient alternatives to conventional pyrolysis.

Traditional pyrolysis systems frequently exhibit low energy efficiency and limited control over product selectivity due to non-uniform heat and mass transfer. To overcome these limitations, microwave-assisted pyrolysis (MAP) has been introduced as an advanced technique that enables uniform and volumetric heating by directly coupling microwave energy with reactive molecules [13,14]. This method allows for shorter reaction times and lower operating temperatures, making it more energy-efficient and environmentally friendly. In contrast to conventional conduction-based heating systems, such as semi-batch reactors [15,16], MAP significantly reduces energy consumption while accelerating the pyrolysis process [17]. For example, Cui *et al.* [18] reported that MAP applied to polypropylene plastic at 450 °C with a microwave power of 500 W and a feed mass of 30 g resulted in an optimal oil yield of 0.793 g/g. The resulting oil consisted primarily of cycloalkanes, alkenes, and alkanes, which accounted for approximately 99.6% of the total GC–MS area.

In the present study, the MAP technique was employed to convert laboratory latex glove waste into liquid fuel. Prior research, such as the work by Mishra *et al*. [19], has explored the co-pyrolysis of waste nitrile gloves (WNG), polystyrene (PS), and mahua seeds (MH) using a semi-batch reactor operated at 550 °C with a heating rate of 80 °C/min and a nitrogen flow rate of 100 mL/min. Their study focused on mixed feedstocks rather than single-source laboratory glove waste. The addition of 20 wt% plastic improved the liquid product yield, achieving 44.18 ± 1.2 wt% and 45.89 ± 1.4 wt% for the MH + WNG and MH + PS blends, respectively. However, to the best of our knowledge, no previous study has specifically investigated the direct conversion of laboratory latex glove waste into liquid fuel using MAP. The present work aims to fill this research gap by proposing a sustainable, chemistry-driven approach that addresses both the issue of PPE waste accumulation and the ongoing depletion of fossil fuel resources.

2. Materials and Methods

2.1 Materials

Latex glove waste was collected from the Physical Chemistry Laboratory, Department of Chemistry, Universitas Gadjah Mada. Nitrogen gas (N_2, 99.90% purity) was supplied by PT. Surya Indotim Imex.

2.2. Microwave-Assisted Pyrolysis of Latex Glove Waste

The latex glove waste was first thoroughly washed with distilled water and air-dried under sunlight to remove any surface contaminants. After drying, the gloves were cut and shredded into small pieces, approximately 1 mm in size, and then introduced into the MAP reactor. Prior to pyrolysis, the material was characterized using a simultaneous thermal analyzer (STA, PerkinElmer) under a nitrogen atmosphere. The analysis was conducted from room temperature to 1000 °C, with a nitrogen flow rate of 20 mL/min and a constant heating rate of 10 °C/min.

Figure 1 illustrates the configuration of the MAP reactor used in this study. The system employed a commercial microwave oven operating at a magnetron frequency of 2.45 GHz. A fixed amount of 10 g of latex glove waste was loaded

into the reactor's feed chamber. Pyrolysis was initiated by operating the microwave oven at various power levels and irradiation durations. In this study, the microwave power was varied at 100, 200, 400, 600, and 800 W, while the irradiation time was adjusted to 10, 15, 20, 25, and 30 min to identify the optimal operating conditions. These variations were selected based on the adjustable power and time settings available on the microwave oven. During the pyrolysis process, nitrogen gas was continuously supplied at a flow rate of 20 mL/min to maintain an inert atmosphere. A thermocouple connected to a temperature controller was used to monitor the internal temperature of the reactor. At the maximum applied power of 800 W, the pyrolysis temperature reached 532 °C, which was selected as the optimal temperature for comparison with conventional pyrolysis.

For benchmarking purposes, conventional pyrolysis was conducted using a semi-batch reactor under the same optimal temperature and reaction time determined from the MAP experiments. In this setup, 10 g of latex glove waste was manually loaded into the reactor's feed chamber and sealed prior to heating. The liquid products obtained from both MAP and conventional pyrolysis were analyzed using gas chromatography–mass spectrometer (GC–MS, Shimadzu QP2010S; column length: 30 m, film thickness: 0.25 µm, inner diameter: 0.25 mm). Product conversion and liquid fuel yield were calculated according to Eqs. (1)–(6). The most optimal liquid products from MAP and conventional pyrolysis were further characterized using Fourier-transform infrared spectrometer (FTIR, Shimadzu Prestige-21) over a wavenumber range of 400–4000 cm^{-1}. The calorific values of the resulting liquid fuels were measured using a bomb calorimeter (Parr 6100 Compensated Calorimeter) and compared with commercial RON 90 gasoline (Pertalite) obtained from PT Pertamina.

$$\text{Residue (wt\%)} = \frac{\text{weight of residue (g)}}{\text{weight of feed (g)}} \times 100 \quad (1)$$

$$\text{Liquid product (wt\%)} = \frac{\text{weight of liquid product (g)}}{\text{weight of feed (g)}} \times 100 \quad (2)$$

$$\text{Gas product (wt\%)} = 100 - \text{liquid product} - \text{residue} \quad (3)$$

$$\text{Gasoline yield (wt\%)} = \frac{\text{GC area of } C_5 - C_{12}}{\text{total GC area}} \times \text{liquid product} \quad (4)$$

$$\text{Diesel yield (wt\%)} = \frac{\text{GC area of} > C_{12}}{\text{total GC area}} \times \text{liquid product} \quad (5)$$

$$\text{Non} - \text{hydrocarbon yield (wt\%)} = \text{Liquid product} - \text{gasoline yield} - \text{diesel yield} \quad (6)$$

3. Results and Discussion

3.1. Thermal Behaviour of Laboratory Latex Glove Waste

Figure 2 shows the thermal behavior of laboratory latex glove waste as analyzed by thermogravimetric analysis (TGA) and

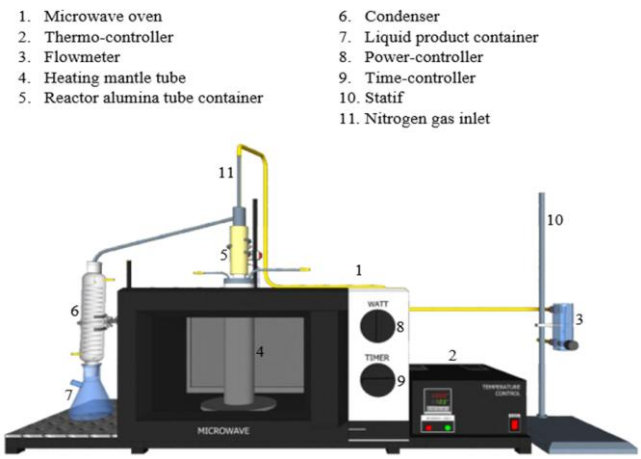

Figure 1. Scheme of the MAP reactor employed in this study.

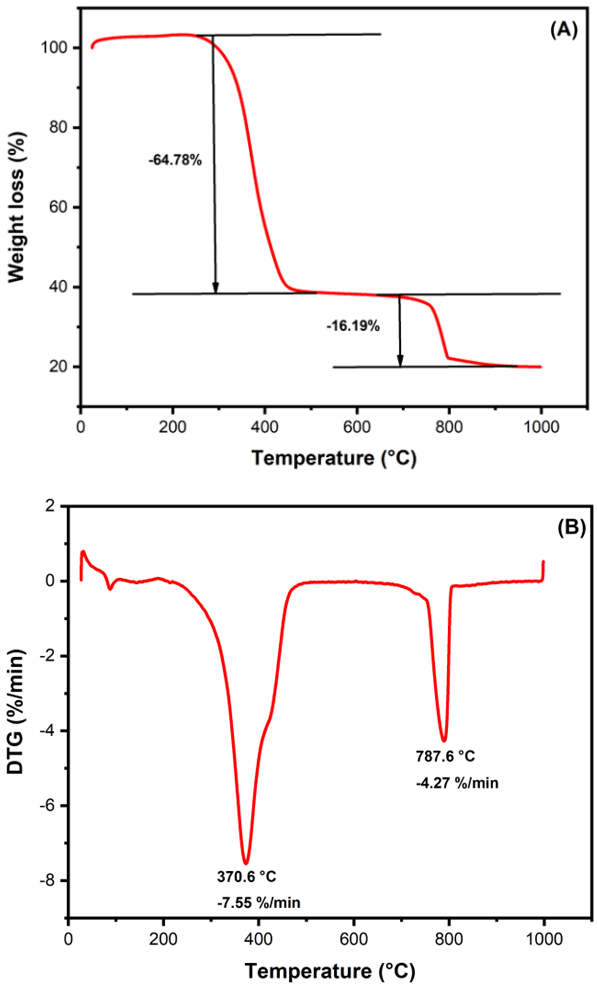

Figure 2. (A) TGA and (B) DTG profiles of laboratory latex glove waste.

differential thermogravimetric analysis (DTG). The curves display distinct mass loss events, indicating that the pyrolysis process proceeds through multiple stages of thermal degradation, each involving specific decomposition mechanisms and weight loss rates.

Two primary degradation stages were identified in both the TGA and DTG profiles, suggesting a two-step pyrolysis process. The first stage occurred between 255.7 °C and 508.2 °C, during which a significant mass loss of 64.78% was observed. The highest decomposition rate in this stage was recorded at 370.6 °C, corresponding to a DTG peak of −7.55 %/min. This major weight loss is mainly attributed to the thermal degradation of polyisoprene rubber, which is the primary component of latex gloves, along with the decomposition of organic additives [20]. The second stage took place between 508.2 °C and 912.5 °C, contributing an additional 16.19% to the overall mass loss. A DTG peak at 787.6 °C, with a maximum degradation rate of −4.27%/min, was observed in this stage. This phase is associated with the secondary cracking of intermediate pyrolysis products and the breakdown of thermally stable residues such as char and ash [21].

Above 900 °C, the TGA curve reached a plateau, indicating that most pyrolytic reactions had concluded with minimal additional mass loss. The total mass loss throughout the heating process was 80.97%, confirming the substantial thermal decomposition of latex glove waste and its strong potential for conversion into liquid pyrolysis products.

3.2. Effect of Microwave Power on MAP Products

Figure 3 illustrates the effect of microwave power on (A) product distribution and (B) the yield of liquid products across different hydrocarbon fractions obtained from MAP of latex glove waste. The experiments were performed under controlled conditions using a nitrogen flow rate of 20 mL/min, a feed mass of 10 g, and an irradiation time of 30 min. These parameters were selected based on the findings of Zhao *et al.* [22], who demonstrated that nitrogen as a carrier gas enhances product yields across a wide range of feed masses (3–30 g).

As shown in Figure 3(A), product distribution varied considerably with increasing microwave power, from 100 to 800 W. At 100 and 200 W, no conversion of the latex glove waste was observed. The feedstock either remained unaltered or only partially melted, indicating insufficient energy to initiate pyrolysis. At 400 W, pyrolysis began, with gas as the dominant product (69.000 wt%). The corresponding yields of liquid and solid products were 18.851 wt% and 12.149 wt%, respectively. These results suggest that although thermal decomposition occurred, the energy primarily favored the formation of non-condensable gases rather than liquid hydrocarbons.

At 600 W, the liquid yield increased significantly to 32.796 wt%, while gas and solid yields decreased to 53.000 wt% and 14.204 wt%, respectively. This shift indicates that the energy level was more favorable for breaking down the rubber matrix into volatile compounds, which subsequently condensed into liquids. The highest liquid yield was obtained at 800 W, reaching 52.584 wt%. At this power, gas yield further decreased to 18.000 wt%, while the solid residue increased to 29.416 wt%. The rise in residue is likely due to the formation of secondary char or the presence of thermally stable components that resisted complete degradation.

Figure 3(B) presents the composition of the liquid products. At 400 W, gasoline-range hydrocarbons (C_5–C_{12}) dominated the liquid

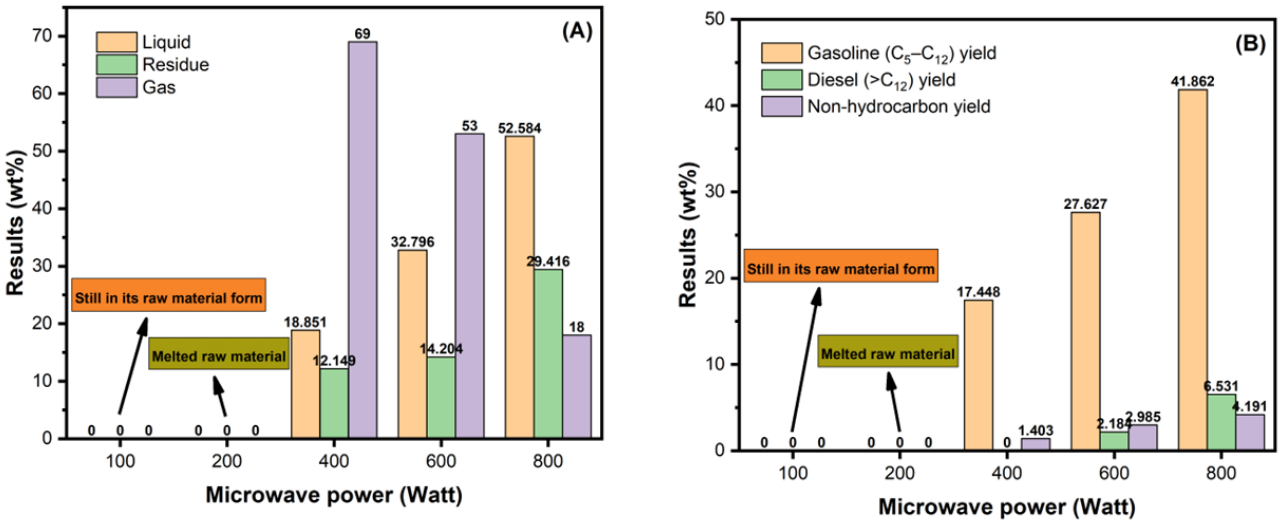

Figure 3. (A) Product distribution and (B) liquid product yield across various hydrocarbon fractions obtained from MAP of latex glove waste at different microwave power levels. Experimental conditions: N_2 flow rate = 20 mL/min, feed mass = 10 g, and irradiation time = 30 min.

phase, contributing 17.448 wt%, with negligible amounts of diesel-range and non-hydrocarbon compounds. Increasing the power to 600 W raised the gasoline yield to 27.627 wt%, while diesel and non-hydrocarbon fractions accounted for 2.184 wt% and 2.985 wt%, respectively. At 800 W, the gasoline fraction peaked at 41.862 wt%, with corresponding increases in diesel (6.531 wt%) and non-hydrocarbon (4.191 wt%) content.

These findings highlight the critical role of microwave power in determining both the quantity and composition of pyrolysis products. A power level of 800 W was found to be optimal for maximizing the liquid fraction, particularly in the gasoline range, while maintaining acceptable levels of gas and solid residues. This enhanced performance is attributed to the higher microwave energy density, which improves energy absorption by the rubber compounds. The resulting molecular friction generates more intense internal heating, accelerating the pyrolytic reactions, increasing the temperature, and promoting the breakdown of complex polymer chains into smaller hydrocarbons [23].

In contrast, no decomposition occurred at 100 W, and only partial melting was observed at 200 W, resulting in a viscous slurry without the formation of liquid or gaseous products. These observations confirm that low microwave power fails to supply sufficient energy to overcome the activation energy barrier for pyrolysis [24]. At such levels, limited energy density results in weak molecular friction and inadequate heating, thereby restricting the extent and rate of thermal degradation.

3.3. Effect of Irradiation Time on MAP Products

Figure 4 shows the effect of varying irradiation times (10 to 30 min) on (A) the distribution of pyrolysis products and (B) the yield of hydrocarbon fractions in the liquid phase during MAP of latex glove waste. All experiments were conducted at a constant microwave power of 800 W, with a nitrogen flow rate of 20 mL/min and a feed mass of 10 g. As illustrated in Figure 4(A), product distribution shifted notably with increasing irradiation time. At 10 min, gas was the dominant product, accounting for 76.000 wt%, while liquid and solid yields were relatively low, at 14.533 wt% and 9.467 wt%, respectively. This outcome suggests that short irradiation durations promote the rapid release of volatiles but do not provide sufficient time for the thermal cracking and condensation needed to form significant amounts of liquid products [25].

Extending the irradiation time to 15 and 20 min resulted in a marked decrease in gas yield, dropping to 50.000 wt% and 35.000 wt%, respectively. Concurrently, the liquid yield increased to 24.239 wt% at 15 min and 40.984 wt% at 20 min. The solid residue remained relatively stable during this interval. These changes indicate that prolonged irradiation facilitates further degradation of the polymer matrix and increases the production of condensable vapors, aligning with typical pyrolysis behavior observed in elastomeric materials [26]. At 25 min, the liquid yield rose to 45.044 wt%, while the gas fraction decreased to 20.000 wt%. The highest liquid yield was recorded at 30 min, reaching 52.584 wt%. During this period, the solid residue declined from 34.956 wt% to 29.416 wt%, indicating progressive decomposition of the feedstock.

Figure 4(B) further details the composition of the liquid products. At 10 min, gasoline-range hydrocarbons (C_5–C_{12}) dominated the liquid phase at 12.654 wt%, with diesel-range and non-hydrocarbon components present at 1.048 wt% and 0.840 wt%, respectively. As irradiation time increased, the gasoline yield rose steadily,

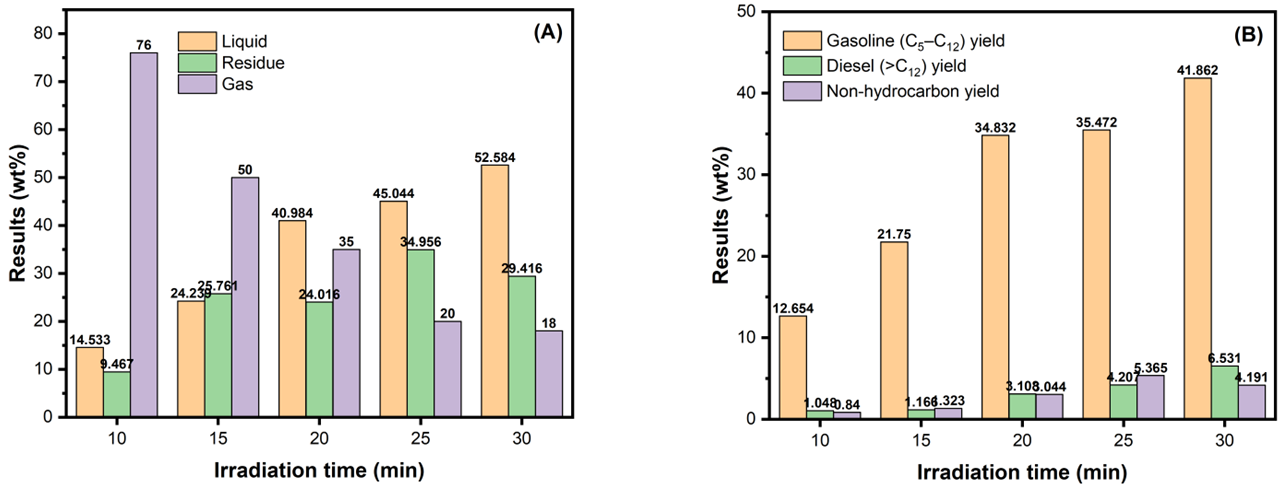

Figure 4. (A) Product distribution and (B) liquid product yield across various hydrocarbon fractions obtained from MAP of latex glove waste at different irradiation times. Experimental conditions: N_2 flow rate = 20 mL/min, feed mass = 10 g, and microwave power level = 800 W.

reaching 21.750 wt% at 15 min and 34.832 wt% at 20 min. Diesel and non-hydrocarbon fractions also increased, indicating continued cracking of larger molecules into a broader range of hydrocarbons.

By 25 min, the gasoline content reached 35.472 wt%, while diesel and non-hydrocarbon yields rose to 4.207 wt% and 5.365 wt%, respectively. The maximum gasoline yield of 41.862 wt% was achieved at 30 min, alongside diesel and non-hydrocarbon yields of 6.531 wt% and 4.191 wt%, respectively. These findings suggest that longer irradiation enhances conversion efficiency and supports the formation of valuable light hydrocarbons.

An irradiation time of 30 min was identified as the optimal condition for maximizing gasoline-range liquid fuel yield while minimizing gas and solid by-products. This performance can be attributed to improved microwave energy absorption and intensified molecular friction within the feedstock, promoting efficient thermal decomposition and the formation of desirable hydrocarbon compounds [27].

3.4. Comparison with Conventional Pyrolysis

Figure 5 compares MAP and conventional pyrolysis of latex glove waste, focusing on (A) product distribution and (B) the composition of hydrocarbon fractions in the liquid phase. Both processes were carried out under identical experimental conditions: a nitrogen flow rate of 20 mL/min, a feed mass of 10 g, and a reaction time of 30 min. The reactor temperature in the MAP system reached 532 °C under optimal power input, which was replicated in the conventional semi-batch pyrolysis setup to ensure a fair comparison.

As shown in Figure 5(A), MAP produced a significantly higher liquid yield of 52.584 wt%, compared to 32.303 wt% from conventional pyrolysis. This improvement is attributed to the volumetric and selective nature of microwave heating, which allows uniform and rapid energy distribution within the feedstock. Efficient energy transfer reduces heat loss, shortens reaction time, and improves energy efficiency, aligning with green chemistry principles.

MAP also resulted in a lower solid residue yield of 29.416 wt%, compared to 44.107 wt% from the conventional method, indicating more complete feedstock decomposition. Gas production was similarly reduced in MAP (18.000 wt%) relative to conventional pyrolysis (23.590 wt%), suggesting a shift in selectivity toward condensable vapors rather than non-condensable gases. These outcomes highlight the sustainability potential of MAP through reduced formation of undesirable by-products.

Figure 5(B) provides further detail on the liquid product composition. Gasoline-range hydrocarbons (C_5–C_{12}) dominated both processes, with MAP yielding a notably higher 41.862 wt% compared to 29.293 wt% from conventional pyrolysis. Diesel-range hydrocarbons (>C_{12}) were also more abundant in MAP (6.531 wt%) versus the conventional method (0.256 wt%). Non-hydrocarbon components were slightly higher in MAP (4.191 wt%) than in conventional pyrolysis (2.754 wt%). These non-hydrocarbon fractions may be reduced or refined further in subsequent upgrading steps.

From a green chemistry perspective, these findings underscore the technical and environmental advantages of MAP. The method enables the recovery of resources from non-biodegradable latex glove waste, a persistent pollutant especially in clinical and laboratory settings. The high yield of energy-rich liquid hydrocarbons provides a promising alternative to fossil-based fuels, supporting circular economy

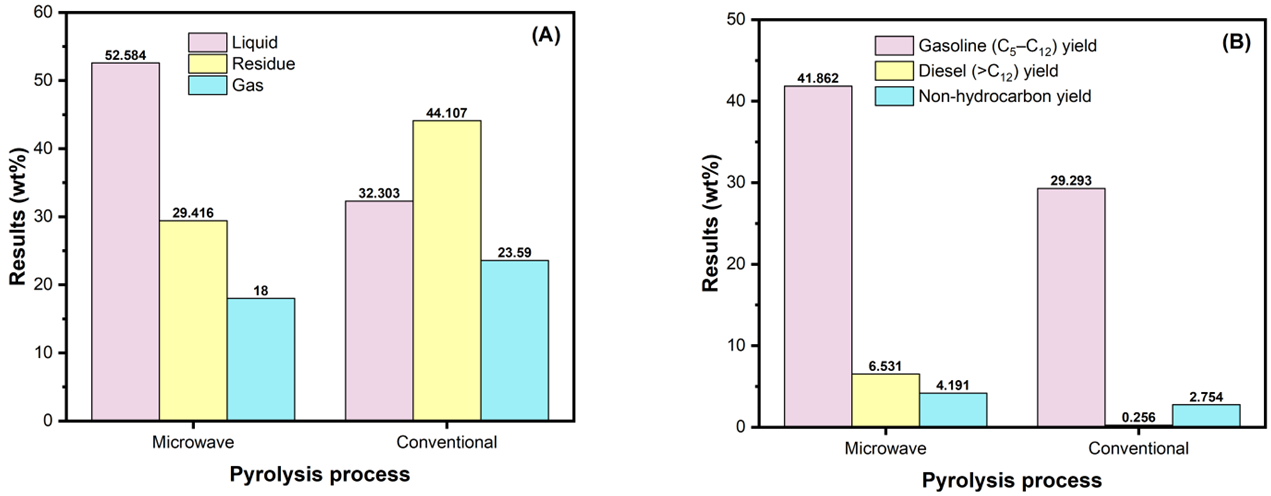

Figure 5. Comparison of (A) product distribution and (B) liquid product yield from microwave-assisted and conventional pyrolysis of latex glove waste at the same temperature of 532 °C. Experimental conditions: N_2 flow rate = 20 mL/min, feed mass = 10 g, and pyrolysis time = 30 min.

efforts. Furthermore, reduced formation of char and non-condensable gases simplifies waste handling and lowers environmental impact.

MAP also enhances process sustainability by decreasing reaction time and reducing external energy input compared to conventional pyrolysis. Unlike conduction-based heating, microwave energy interacts directly with polar molecules in the rubber matrix, generating heat through rapid molecular motion. This direct energy conversion accelerates thermal decomposition and minimizes heat loss, improving overall energy efficiency [28,29]. Microwave heating also ensures more uniform temperature distribution throughout the reaction medium, promoting consistent feedstock breakdown and selective formation of desirable products [30,31].

The environmental relevance of MAP is further supported by Wu *et al.* [32], who reported that microwave pyrolysis of biomass yields less char than conventional methods due to more effective thermal degradation. This observation is consistent with the current study, where MAP of latex glove waste produced a significantly lower solid residue. Overall, the reduced waste generation and efficient production of high-quality liquid fuels illustrate the strong potential of MAP as a sustainable and environmentally responsible approach to waste valorization.

3.5. Liquid Product Evaluation

Figure 6 provides a comprehensive comparison of the hydrocarbon distribution and molecular structure of liquid fuels obtained from MAP, conventional pyrolysis, and commercial RON 90 gasoline. As shown in Figure 6(A), the MAP-derived fuel is predominantly composed of C_{10} hydrocarbons, with D-limonene ($C_{10}H_{16}$) as the major compound, along with a significant proportion of hydrocarbons above C_{12}. The total hydrocarbon content in the MAP product reaches 92.04%. In contrast, the conventional pyrolysis product exhibits a broader range of hydrocarbons from C_7 to C_{10}, with a slightly lower total hydrocarbon content of 91.47%. Commercial RON 90 gasoline contains mainly lighter hydrocarbons in the C_6 to C_8 range, with ethylbenzene (C_8H_{10}), a stable aromatic, as the dominant component.

These findings indicate that MAP favors the preservation of heavier hydrocarbons due to its rapid and volumetric heating, which limits

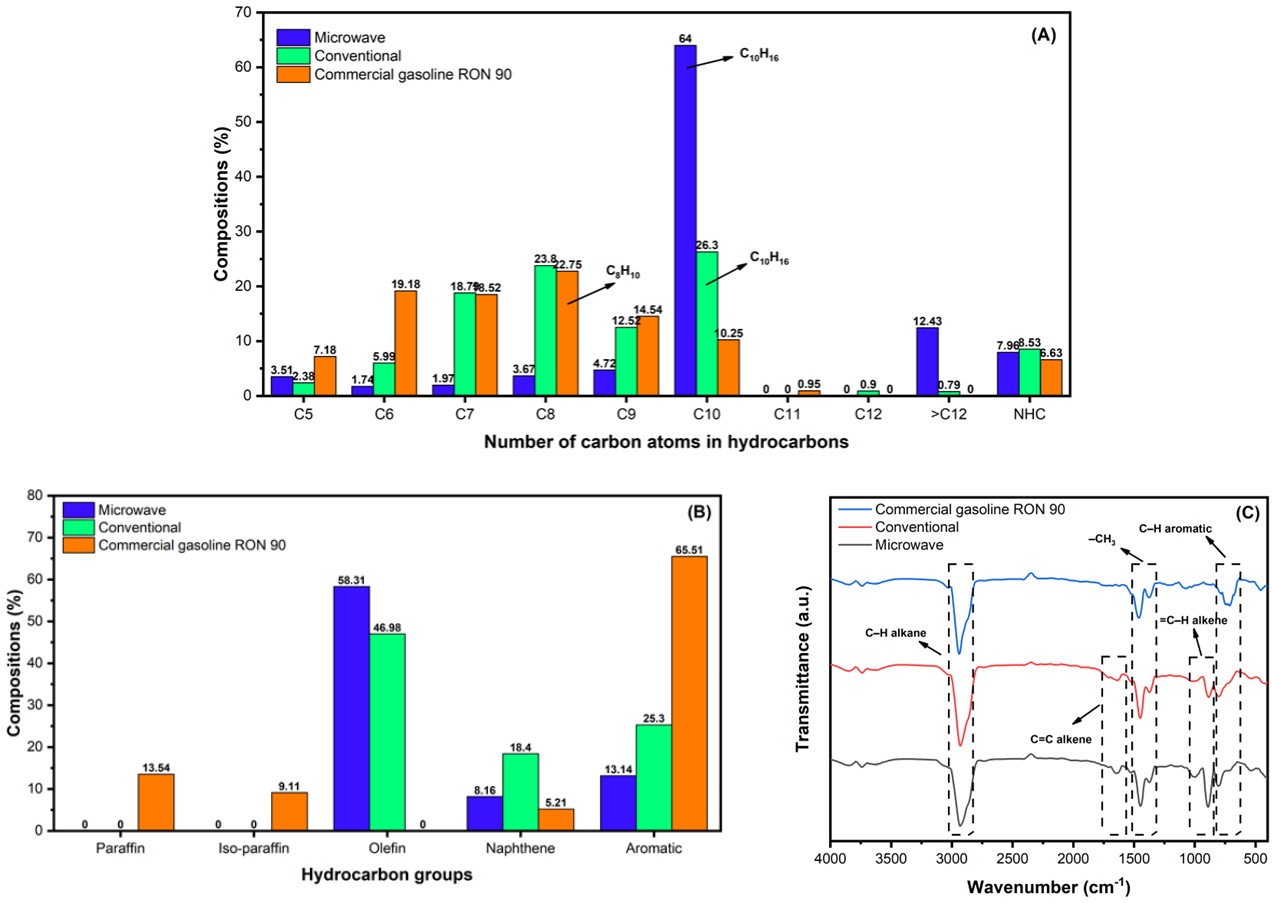

Figure 6. Comparison of (A) the number of carbon atoms in hydrocarbons, (B) hydrocarbon group composition, and (C) FTIR spectra of liquid fuels produced by MAP and conventional pyrolysis, in comparison with commercial RON 90 gasoline.

secondary cracking. In comparison, the slower and less uniform heating of conventional pyrolysis promotes the breakdown of larger molecules, resulting in a wider distribution of hydrocarbon products [33].

Figure 6(B) further highlights differences in hydrocarbon group composition. The MAP-derived fuel contains a high proportion of olefins, along with smaller amounts of aromatics and naphthenes. Commercial gasoline, in contrast, consists primarily of aromatics, paraffins, and iso-paraffins, with no detectable olefins. While olefins enhance energy content and serve as important feedstocks for petrochemical applications, their presence can negatively affect fuel stability, increase gum formation, and raise combustion reactivity [34]. Conversely, aromatics and iso-paraffins improve knock resistance and increase octane ratings, which are important for efficient engine performance [35].

However, the environmental implications of aromatics must also be considered. Aromatic hydrocarbons are known to produce higher yields of soot during combustion, contributing significantly to particulate emissions and degraded air quality [36]. For this reason, many regulatory frameworks limit aromatic content in fuels. In this context, MAP-derived fuels, which contain lower aromatic levels, may offer cleaner combustion and reduced particulate emissions.

Further confirmation of compositional differences is provided by FTIR spectra in Figure 6(C). Fuels produced via MAP and conventional pyrolysis show strong absorption bands corresponding to aliphatic C–H stretching and =C–H bending, characteristic of olefins. Aromatic signals are weak in both pyrolysis fuels. In contrast, RON 90 gasoline exhibits strong aromatic C–H stretching bands, reflecting its higher aromatic content.

Another advantage of MAP-derived fuel is its higher calorific value compared to both conventional pyrolysis fuel and RON 90 gasoline, as shown in Table 1. This increased energy content is primarily due to a higher proportion of long-chain hydrocarbons and olefins, which release more heat during combustion [37]. Although aromatics contribute to higher octane ratings, they provide less energy per unit mass, making MAP fuels potentially more efficient in terms of energy output.

Table 1. Calorific value test results.

Sample	Calorific value (MJ/kg)
Microwave	42.392
Conventional	41.756
Commercial RON 90 gasoline	38.526

Despite these benefits, some limitations must be addressed before MAP fuels can be used directly in internal combustion engines. The high olefin content may lead to reduced oxidative stability, increased gum formation, and starting difficulties at low temperatures. To overcome these challenges, upgrading processes such as hydrotreating is necessary to improve the fuel's physicochemical properties and eliminate problematic components. These treatments increase the concentration of saturated hydrocarbons and aromatics, making the composition more comparable to commercial gasoline.

This study demonstrates the potential for producing sustainable liquid fuels from latex glove waste. Future research should focus on catalytic upgrading of MAP fuels using advanced hydrotreating catalysts to enrich lighter hydrocarbons and enhance combustion properties. It will also be essential to evaluate key fuel parameters such as density, viscosity, boiling point range, and research octane number (RON) to ensure compliance with automotive fuel standards. With further development, MAP represents a viable and environmentally responsible strategy for converting non-biodegradable laboratory waste into valuable liquid fuels for practical energy applications.

3.6. Reaction Pathway of Gasoline-Range Hydrocarbons Formation from MAP of Laboratory Latex Glove Waste

The proposed reaction pathways for converting laboratory latex glove waste into gasoline-range hydrocarbons is shown in Fig. 7, based on the hydrocarbon compounds identified by GC–MS analysis. Table 2 summarizes the major hydrocarbon components present in the liquid product obtained from MAP of latex glove waste under optimal conditions of microwave power and irradiation time.

The transformation of polyisoprene into D-limonene during MAP involves a series of radical-driven thermal degradation reactions. The process begins with ß-scission of the polyisoprene backbone, resulting in carbon–carbon bond cleavage and the formation of alkyl and allylic radicals. These reactive intermediates follow various pathways depending on their structure and energy state. One primary route involves depropagation, where polymer fragments degrade into monomer units, particularly isoprene (2-methyl-1,3-butadiene), a fundamental component of polyisoprene. The liberated isoprene may undergo a Diels–Alder cycloaddition reaction to form six-membered cyclic compounds, which act as intermediates in the generation of aromatic hydrocarbons [38,39].

Concurrently, other radical species can undergo molecular rearrangement and intramolecular cyclization, leading to the formation of D-limonene, a prominent monocyclic monoterpene commonly observed in the pyrolysis of rubber-based materials. This pathway also underscores the thermal instability of D-limonene at elevated temperatures, which can result in its further degradation into benzene, toluene, ethylbenzene, and xylene (BTEX) compounds [40]. Additionally, the high energy input from microwave irradiation promotes extensive thermal cracking, yielding low-carbon olefins as secondary products. These olefins serve as key intermediates in petrochemical processes and synthetic fuel production. Overall, the proposed reaction mechanism highlights the efficiency of MAP in converting rubber-based laboratory waste into energy-dense, gasoline-like hydrocarbons.

4. Conclusion

This study demonstrated the effective conversion of laboratory latex glove waste into liquid fuel using microwave-assisted pyrolysis (MAP), offering a sustainable method for fuel production and waste management. Under optimal conditions of 800 W of microwave power and 30 min of irradiation, the process yielded 52.584 wt% liquid product with a total hydrocarbon content of 92.04%, comprising 41.862 wt% gasoline-range hydrocarbons (C_5–C_{12}) and 6.531 wt% diesel-range hydrocarbons (greater than C_{12}). These values significantly exceeded those from conventional pyrolysis, where the process yielded 32.303 wt% liquid product with a total hydrocarbon content of 91.47%, comprising gasoline- and diesel-range hydrocarbons of 29.293 wt% and 0.256 wt%, respectively.

The MAP-derived fuel exhibited a high calorific value of 42.392 MJ/kg, mainly due to its olefin-rich composition. To enhance fuel quality, future research should focus on upgrading techniques such as hydrotreating with suitable catalysts to reduce olefin content and increase the proportions of aromatics and paraffins. A comprehensive evaluation of physicochemical properties, including density, viscosity, flash point, boiling point range, and research octane number, is essential. Analytical methods such as proton nuclear magnetic resonance (^{1}H-NMR) should also be employed to assess fuel composition and its suitability for use in internal combustion engines. This work highlights MAP as a promising and environmentally responsible method for converting non-biodegradable laboratory waste into valuable liquid fuel.

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CRedit Author Statement

Author Contributions: *W. Wangsa*: Conceptualization, Methodology, Investigation, Data Curation, Writing – Original Draft. *A.J. Saviola*: Visualization, Validation, Formal Analysis, Supervision, Writing – Review and Editing. *L. Hauli*: Validation, Formal Analysis, Supervision, Writing – Review and Editing. *W. Trisunaryanti*: Validation, Formal Analysis, Supervision, Writing – Review and Editing. *P. Chandra*: Data Curation, Writing – Original Draft. *R.A. Fitria*: Data Curation, Writing – Original Draft. *P.N. Mahayuwati*: Data Curation,

Table 2. Five dominant hydrocarbon compounds identified by GC–MS in the liquid product from MAP of latex glove waste under optimal microwave power and irradiation time.

Compound name	Molecular formula	GC area (%)
2-methyl-1,3-butadiene	C_5H_8	3.51
Xylene	C_8H_{10}	2.19
1,2,4-trimethyl-benzene	C_9H_{12}	2.63
D-limonene	$C_{10}H_{16}$	42.46
1-methyl-4-(1-methylethyl)-cyclohexene	$C_{10}H_{18}$	2.95

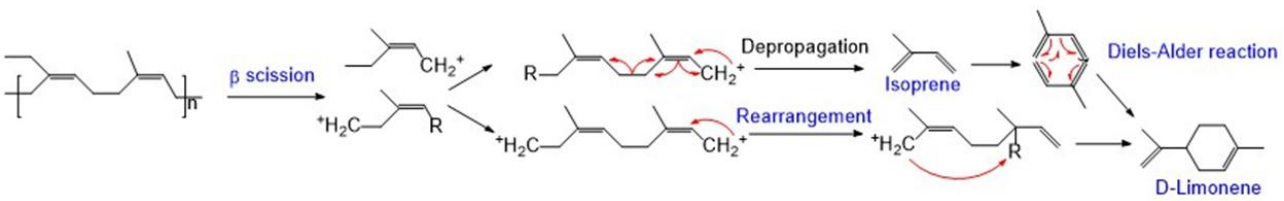

Figure 7. Proposed schematic reaction pathway for the formation of D-limonene from polyisoprene degradation.

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