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Pyrolysis of Beef Tallow into Liquid Fuel: Temperature and Reaction Time Effects

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ABSTRACT

The increasing demand for energy in Indonesia has led to greater reliance on fossil fuels, causing their reserves to diminish. To address this issue, it is essential to explore alternative energy sources that are renewable and can reduce dependence on conventional liquid fuels. One promising option is liquid fuel derived from beef fat (tallow).

This study focuses on identifying the optimal temperature and reaction time for achieving the highest yield of liquid fuel. The process involves using 500 grams of beef fat (tallow) and a 10% zeolite catalyst in a pyrolysis reaction at temperatures of 310°C, 330°C, 350°C, 370°C, and 390°C, with reaction times of 100, 120, and 140 minutes in a catalytic cracking reactor. The quality of the resulting liquid fuel was assessed based on its density, viscosity, flash point, cetane number, and a detailed composition analysis using Gas Chromatography-Mass Spectrometry (GC-MS). The study found that the highest yield of 12.4718% was obtained at a temperature of 350°C and a reaction time of 140 minutes. The resulting liquid fuel had a density of 785.38 kg/m³, a viscosity of 3.00 mm²/s, and a cetane number of 76.7. GC-MS analysis revealed the composition of the fuel: 28.15% gasoline fraction (C5–C12), 9.01% kerosene fraction (C13–C14), and 41.41% diesel fraction (C15–C19). This highlights the potential of beef fat as a viable raw material for producing renewable liquid fuel. Furthermore, the study discusses methods to improve the flash point for safety compliance and evaluates the environmental implications of the pyrolysis process.

Keywords: pyrolysis; beef fat (tallow); liquid fuel; zeolite catalyst; reactor.

INTRODUCTION

Indonesia has faced a persistent decline in crude oil production since the 1990s, primarily due to insufficient exploration and investment in the oil and gas sector. This trend, coupled with the nation's increasing energy demand driven by industrial growth and population expansion, has resulted in Indonesia becoming a net oil importer since 2004. The reliance on imported fuel oil poses economic and energy security challenges, such as fluctuating global oil prices and vulnerability to supply disruptions (Basu, 2018; Gebremariam & Marchetti, 2018). These issues underscore the urgency of diversifying energy sources and reducing dependence on fossil fuels.

Moreover, the global production of biodiesel is highly adaptable, relying on a diverse array of renewable feedstocks. Alternative feedstocks including microalgae and more recently, waste animal fat, are emerging as viable options. Waste Animal Fats, encompassing by-products like chicken fat, lard, waste beef tallow, and fish oil, offer a cost-effective and environmentally sustainable solution by repurposing biowaste that would otherwise contribute to pollution. Thus, integrating these renewable resources in biodiesel production not only enhances economic feasibility but also advances environmental sustainability and energy security.

In addition to its technically and economic advantages, Beef tallow, a by-product is primarily utilized in the

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soap industry. However, when market demand is saturated, these fats are often incinerated or disposed of in landfills, leading to environmental pollution. By integrating such industrial residues into biodiesel production, it is possible to mitigate these negative impacts, create alternative employment opportunities, and contribute to more sustainable waste management practices.

One potential solution is the development of renewable energy sources, including biofuels derived from readily available and cost-effective feedstocks. Among these, beef fat (tallow) presents a viable option due to its abundance, affordability, and compatibility with existing processing technologies. Tallow, a by-product of the meat processing industry, not only provides an alternative use for waste materials but also contributes to reducing environmental pollution caused by improper disposal (Kosgei & Inambao, 2019).

The production of biofuels from tallow involves the catalytic cracking process, also known as pyrolysis, where unsaturated long-chain hydrocarbons are thermally decomposed into shorter chains, producing liquid fuels such as gasoline, kerosene, and diesel. This process can be optimized using zeolite catalysts, known for their effectiveness in cracking reactions and their abundance in natural reserves. Zeolite's carbon-neutral characteristics further enhance its appeal as a sustainable catalyst (Knothe & Razon, 2017).

Pyrolysis is a cracking process involving the application of heat in conditions with little to no oxygen, aimed at breaking down the organic compounds in a solid material into liquid and gas products while releasing the bonds of bound inorganic substances (Ahmad, Mufrodi, & Muhammad, 2020). Pyrolysis yields three main products: bio-oil (pyrolysis oil), non-condensable gases (e.g., CO, CO_2, H_2, CH_4), and solid residues (char). Bio-oil is the primary focus due to its potential as a liquid fuel or chemical feedstock. The efficiency and composition of bio-oil depend significantly on operating parameters, particularly temperature and reaction time. Temperature influences the decomposition rate of raw materials, breaking down large molecules into smaller ones. Similarly, the reaction time determines the extent to which the material undergoes conversion, impacting the proportion of gas, liquid, and char products (Eldwita & Lestari, 2021).

In Indonesia, efforts to meet national biofuel standards, such as the Indonesian National Standard (SNI) 8968:2021 for diesel biohydrocarbons, demand meticulous research to identify optimal operating conditions. This study investigates the influence of pyrolysis temperature and reaction time on the yield and quality of liquid fuels produced from beef fat, aiming to provide a sustainable energy alternative that aligns with national and global energy strategies.

By addressing these challenges, this research contributes to the development of renewable biofuels as a step toward achieving energy security, reducing carbon emissions, and utilizing waste resources effectively.

MATERIALS AND METHOD

Materials

The primary materials used in this study include beef fat (tallow) and a zeolite catalyst. A total of 500 grams of beef fat served as the feedstock for liquid fuel production, while zeolite, constituting 10% of the raw material weight, acted as the catalyst in the catalytic cracking reactor. Zeolite's role in enhancing the cracking process by breaking long-chain hydrocarbons into shorter, usable fractions like gasoline and diesel has been extensively documented (Eldwita & Lestari, 2021).

Method

Catalytic Cracking Reactor Description

The pyrolysis process was conducted in a catalytic cracking reactor designed to operate under elevated temperatures and controlled conditions for thermal and catalytic decomposition. The reactor consisted of a heat-resistant chamber equipped with: **Heating System:** Capable of maintaining a steady temperature range of 310°C–390°C. **Stirring Mechanism:** Ensuring uniform distribution of heat and catalyst-material interaction. **Condenser Unit:** To condense volatile compounds into liquid fuel fractions. **Gas Outlet:** To release non-condensable gases such as CO, CO_2, H_2, and CH_4.

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The reactor's configuration enabled precise control of reaction parameters, including temperature, reaction time, and catalyst contact, which are crucial for maximizing liquid fuel yield. This setup aligns with systems described in prior studies on catalytic pyrolysis for biofuel production (Kosgei & Inambao, 2019; Basu, 2018).

Process Details

1. **Preparation of Beef Fat**. Beef fat was cut into small pieces and heated at 80°C–100°C to separate oil and dry the fat. The extracted oil was cooled overnight, resulting in a solid fat known as tallow.

2. **Preparation of Zeolite Catalyst**. Zeolite granules were pulverized and sieved using a 60-mesh sieve. The sieved zeolite was treated with 1 N HCl for 80 minutes under stirring to enhance catalytic activity. After washing with distilled water to achieve neutral pH, the zeolite was calcined at 300°C for 2 hours to activate catalytic sites, following established protocols (Knothe & Razon, 2017).

3. **Pyrolysis Procedure**. The reactor was loaded with 500 grams of beef fat and 10% zeolite catalyst. The process was conducted at varying temperatures (310°C, 330°C, 350°C, 370°C, and 390°C) and reaction times (100 minutes, 120 minutes, and 140 minutes). The system ensured continuous monitoring of temperature and reaction time to optimize the breakdown of long-chain hydrocarbons.

4. **Analysis of Products**. The liquid fuel was evaluated for yield percentage, density, viscosity, flash point, and cetane number. GC-MS analysis was conducted to identify the chemical composition and assess the proportions of gasoline, kerosene, and diesel fractions.

The catalytic cracking reactor provided the controlled environment necessary to achieve efficient conversion of beef fat into liquid fuel while maintaining product quality and consistency.

RESULTS AND DISCUSSION (REVISED GRAPHICS AND LEGENDS)

Yield Percentage

Yield percentage is the ratio of the mass of the product produced to the mass of the raw material fed. The percentage yield resulting from the cracking process is shown in **Figure 1**.

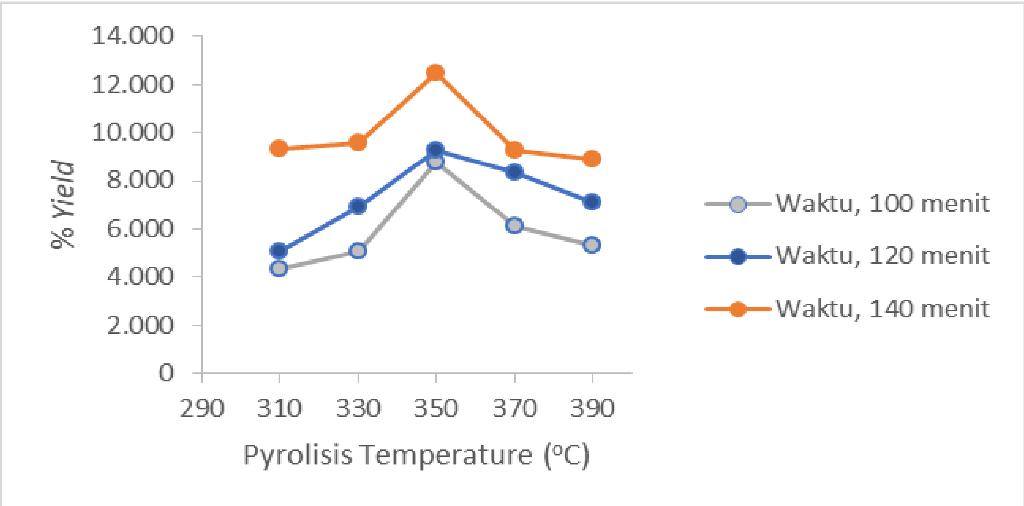

Figure 1. Yield Percentage vs. Pyrolysis Temperature at Different Reaction Times

(Ensure the graph legend uses concise English terms, such as "Reaction Time: 100 min," "120 min," and "140 min.")

The yield of liquid fuel increases with the pyrolysis temperature due to more complete decomposition of raw materials at higher temperatures. According to Arrhenius' theory, higher temperatures increase the reaction rate constant, thereby enhancing product yield.

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The reaction time also affects the yield, as prolonged contact between heat and raw materials improves decomposition efficiency (Maulina et al., 2017).

However, yield decreases at higher temperatures and prolonged times, such as at 370°C and 100 minutes (6.10%) or 390°C and 100 minutes (5.30%), due to over-cracking or secondary reactions leading to gas formation and weight loss (Febriana et al., 2020).

Density

Density, the mass of a material per unit volume, indicates the quality of liquid fuel produced through pyrolysis. The results are shown in **Figure 2**.

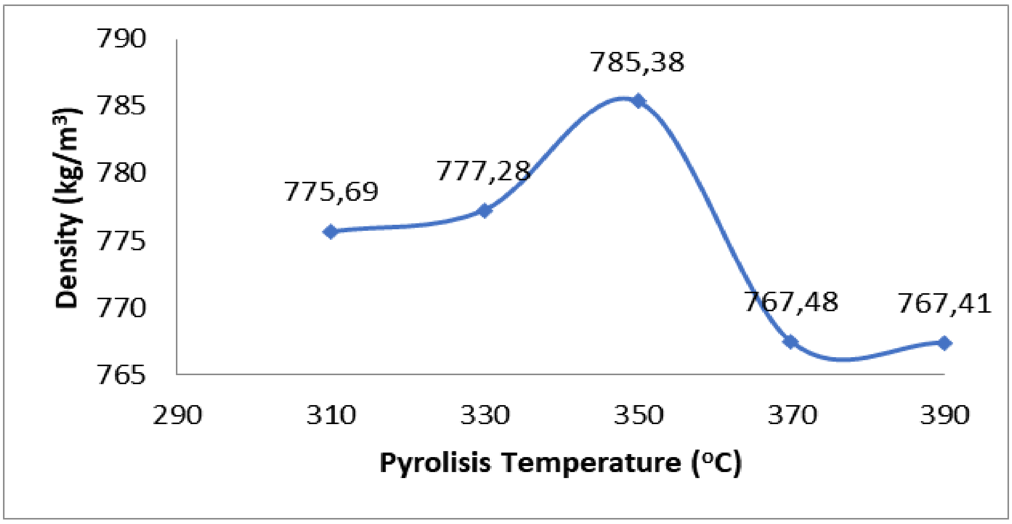

Figure 2. Density vs. Pyrolysis Temperature at Different Reaction Times
(Legend: "Reaction Time: 100 min," "120 min," "140 min.")

The density increases at 350°C (785.38 kg/m³) but decreases at 370°C (767.48 kg/m³) and 390°C (767.41 kg/m³) due to the depletion of decomposable compounds and evaporation of lighter components. Lower densities are associated with shorter hydrocarbon chains (Husein, 2018). The liquid fuel meets the Indonesian National Standard (SNI 8968:2021) density range of 765–800 kg/m³.

Viscosity

Viscosity reflects the fluid's resistance to flow. The results are displayed in **Figure 3**.

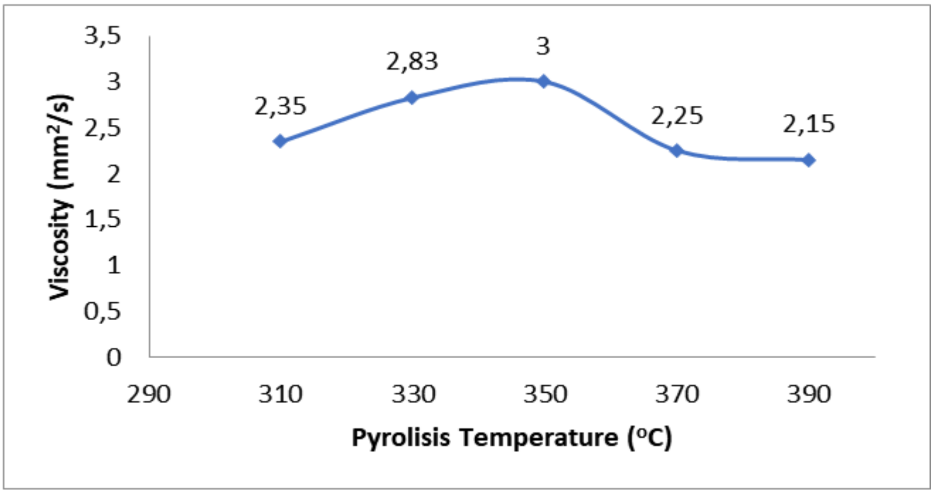

Figure 3. Viscosity vs. Pyrolysis Temperature at Different Reaction Times
(Legend: "Reaction Time: 100 min," "120 min," "140 min.")

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Viscosity increases with temperature up to 350°C (3.00 mm²/s) due to higher molecular cohesion but decreases at 370°C (2.25 mm²/s) and 390°C (2.15 mm²/s) as hydrocarbon chains become shorter. These values fall within the SNI range of 2.0–4.5 mm²/s, indicating suitability as a liquid fuel (Endang, 2017).

Properties of Beef fat tallow (this study) and Palm Oil-FAME (Benjumea et al, 2008) compared to ASTM D6751 and SNI 8968:2021 Standard.

Properties	**Beef Tallow**	**Palm Oil-Fame**	**ASTM D6751**	**SNI 8968:2021**
Cetane number	76,7	57,3	≥40	Min. 70
Density (g/cm^3)	785,38	864	Not specified	850-890
Kinematic viscosity (mm/s)	3,00	4,71	1,9-6	2,5-4,5
Flash point (°C)	38,9	16	-	Min. 55°C

Flash Point

The flash point measures the ease of ignition of the fuel vapor. Results are shown in **Figure 4**.

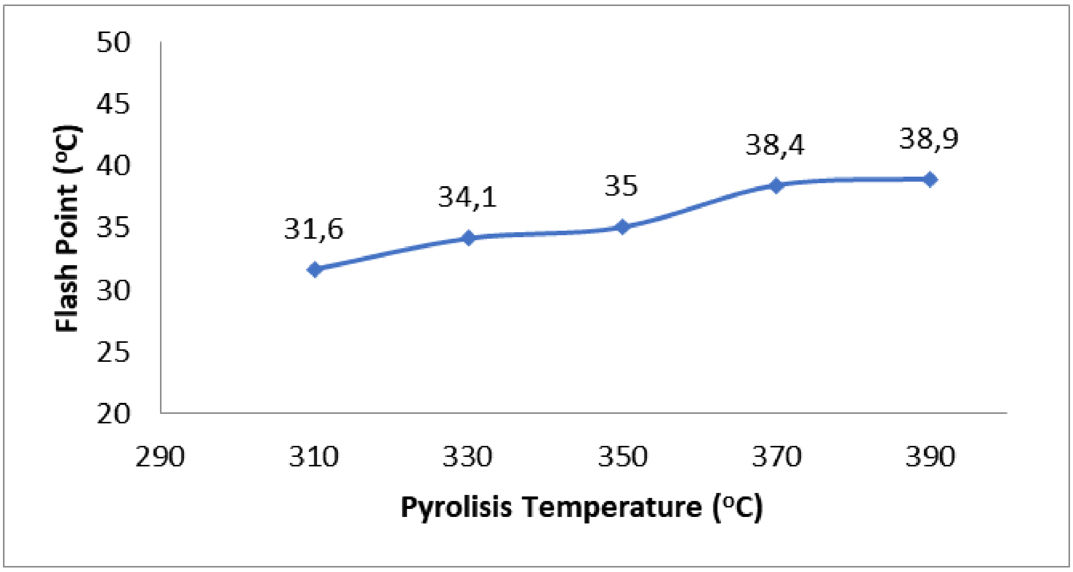

Figure 4. Flash Point vs. Pyrolysis Temperature at Different Reaction Times
(Legend: "Reaction Time: 100 min," "120 min," "140 min.")

The flash point increases with temperature, ranging from 31.6°C at 310°C to 38.9°C at 390°C. These values are below the SNI minimum of 55°C, likely due to volatile compounds in the product. This indicates the need for refining to improve safety standards (Ahmad et al., 2017).

Cetane Number

The cetane number, indicating diesel fuel quality, is measured at 76.7, exceeding the SNI standard of 70. This is attributed to the high saturated fatty acid content in beef fat (89.75%), which contributes to better ignition quality and combustion efficiency (Naimah et al., 2017).

GC-MS Analysis of Beef Fat Raw Material

The GC-MS chromatogram in **Figure 5** reveals that beef fat contains 89.75% saturated fatty acids and 10.25% unsaturated fatty acids, with the most abundant compounds being stearic acid (38.59%) and palmitic acid (22.7%).

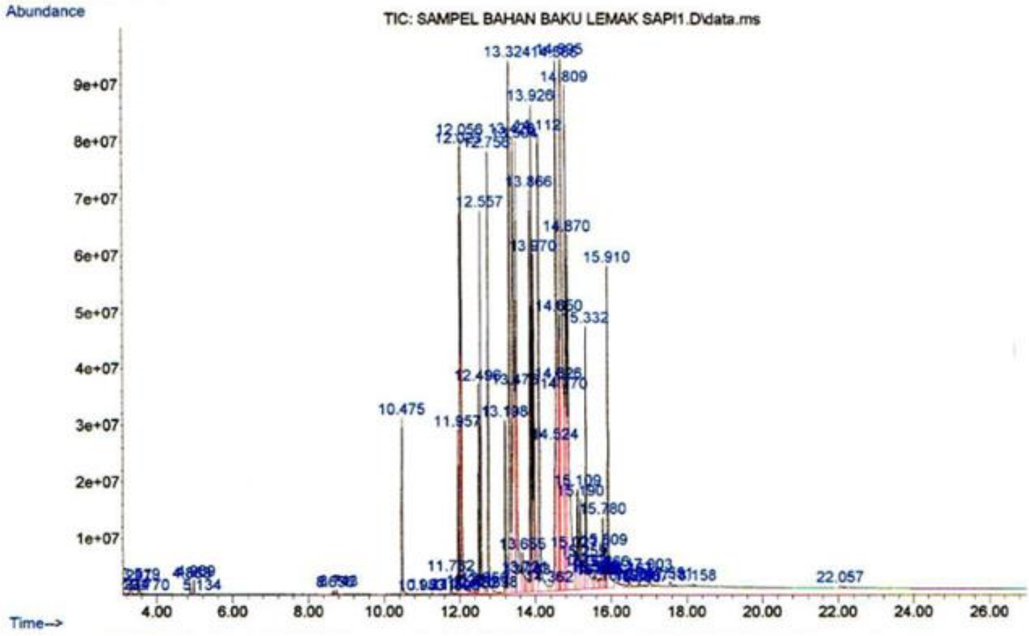

Figure 5. Chromatogram of Beef Fat Raw Material

GC-MS Analysis of Liquid Fuel Products

The GC-MS chromatogram in **Figure 6** identifies the product fractions: gasoline (C5–C12) at 28.15%, kerosene (C13–C14) at 9.01%, and diesel (C15–C19) at 41.41%.

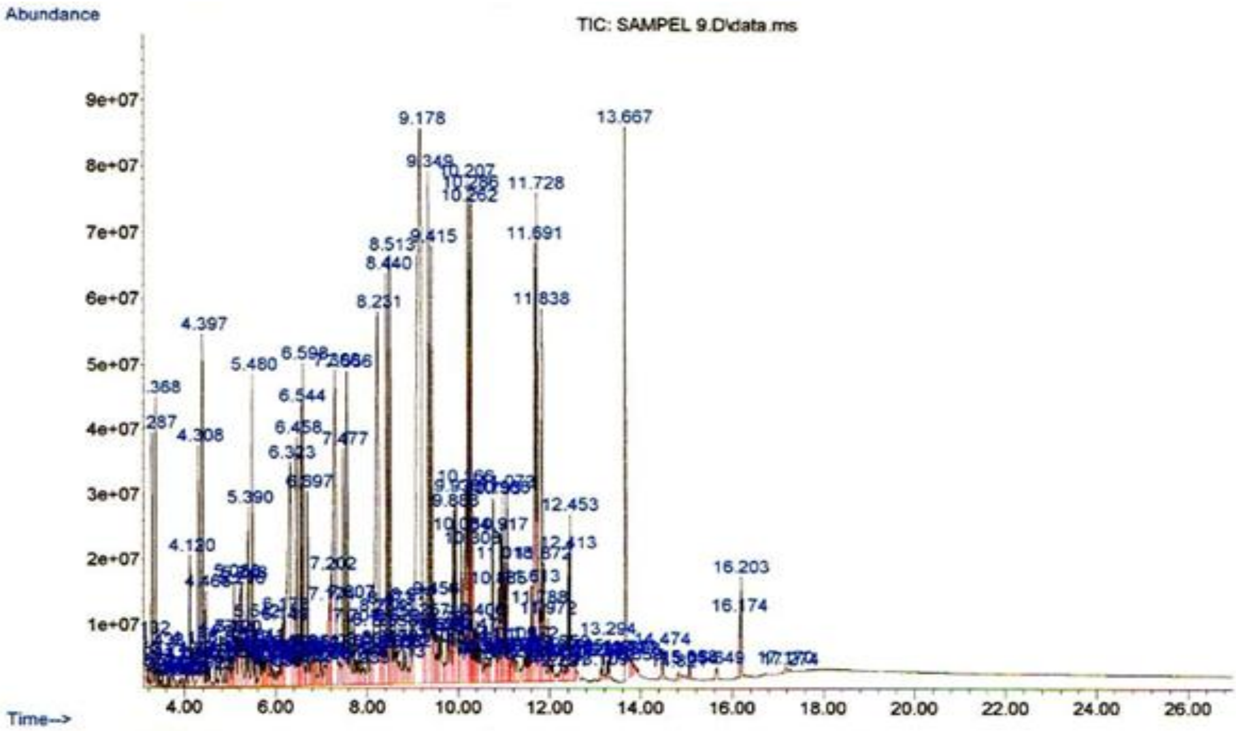

Figure 6. Chromatogram of Liquid Fuel Products at 350°C and 140 min

This composition highlights the suitability of the pyrolysis product as a diesel-equivalent fuel.

CONCLUSION

This study aimed to explore the potential of beef fat (tallow) as a raw material for liquid fuel production through pyrolysis, addressing the challenges of energy dependency and sustainable resource utilization. The

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research focused on identifying optimal operating conditions to maximize yield and improve the quality of the produced fuel, aligning with Indonesian National Standards (SNI) for biofuel specifications.

The findings indicate that the best operating conditions for producing liquid fuel with the highest yield are at a pyrolysis temperature of **350°C** and a reaction time of **140 minutes**. Under these conditions: The highest yield achieved was **12.47%**. The resulting fuel had a density of **785.38 kg/m³**, viscosity of **3.00 mm²/s**, and a cetane number of **76.7**, all meeting the **SNI 8968:2021** standards. GC-MS analysis revealed the composition of the liquid fuel, with **28.15% gasoline fraction (C5–C12)**, **9.01% kerosene fraction (C13–C14)**, and **41.41% diesel fraction (C15–C19)**.

The research demonstrates that beef fat can be effectively converted into a liquid fuel with properties equivalent to diesel, offering a renewable and sustainable alternative to conventional fossil fuels. These findings provide a foundation for further exploration of tallow-based biofuels, emphasizing their potential contribution to energy diversification and sustainability.

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