# COMBUSTION CHARACTERISTICS OF SINGLE BIODIESEL DROPLET FROM SOYBEAN OIL PRODUCED USING PAPAYA LEAF AND ANIMAL BONE CATALYSTS

**Thesis**

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# ABSTRAK

Konsumsi bahan bakar minyak di Indonesia mengalami peningkatan, sedangkan produksi minyak bumi semakin menurun tiap tahunnya, sehingga diperlukan energi alternatif terbarukan seperti biodeisel. Biodiesel dapat driproduksi menggunakan reaksi transesterifikasi dengan katalis heterogen. Penelitian ini menganalisis karakteristik pembakaran biodiesel minyak kedelai yang diproduksi dengan katalis daun pepaya dan tulang hewan menggunakan uji *Single Droplet*. Sampel yang diuji terdiri dari dua macam, yaitu prosentase katalis 2wt% dan 6wt%. Data pendukung dari peneltian ini menggunakan hasil pengujian GC-MS, Piknometer, dan perhitungan *Lower heating Value* (LHV). Hasil *Selectivy* kandungan FAME pada biodiesel menunjukan 2wt% memiliki kandungan sebanyak 45,66% dan 6wt% sebanyak 98%. Sampel 2wt% juga memiliki densitas dan LHV yang lebih tinggi dibanding 6wt%. Hasil uji *Single Droplet menunjukan* 2wt% mengalami banyak fenomena *weak microexplosion* yang menyebabkan fluktuasi diameter droplet, dan menurunkan kestabilan pembakaran. Pada fase *Burning* 2wt% terdapat *microexplosion,* namun pada 6wt% tidak ditemukan fenomena tersebut. *Evaporation Rate* dan *Flame Lifetime* 6wt% lebih singkat dibandingkan 2wt%. Prosentase FAME yang lebih banyak pada 6wt% menyebabkan karakteristik pembakaran yang lebih stabil dibandingkan 2wt%.

***Kata kunci: Biodiesel, droplet, karakteristik pembakaran, minyak kedelai.***

## ABSTRACT

The consumption of petroleum fuel in Indonesia is increasing, while crude oil production continues to decline each year, thus requiring a renewable alternative energy source such as biodiesel. Biodiesel can be produced through a transesterification reaction using a heterogeneous catalyst. This study analyzes the combustion characteristics of soybean oil-based biodiesel produced using papaya leaf and animal bone catalysts through a single droplet combustion test. Two types of catalyst concentrations were tested: 2 wt% and 6 wt%. Supporting data for this research include GC-MS analysis, pycnometer measurements, and Lower Heating Value (LHV) calculations. The FAME selectivity results show that the 2 wt% sample contains 45.66% FAME, while the 6 wt% sample contains 98%. The 2 wt% sample also has a higher density and LHV compared to the 6 wt% sample. Single droplet test results show that the 2 wt% sample undergoes frequent weak microexplosions, which lead to droplet diameter fluctuations and reduced combustion stability. During the burning phase, microexplosions were observed in the 2 wt% sample, but not in the 6 wt% sample. The 6 wt% sample had a shorter evaporation rate and flame lifetime than the 2 wt% sample. The higher FAME content in the 6 wt% sample results in more stable combustion characteristics compared to the 2 wt% sample.


***Keywords: Biodiesel, droplet, combustion characteristics, soybean oil.***

# BAB I
# INTRODUCTION

## 1.1. Background

Indonesia's fuel consumption has shown an increasing trend each year, while the country's crude oil production has been steadily decreasing (Sa'adah, Fauzi, & Juanda, 2017). Fossil fuels (petroleum-based energy) have high heating values and favorable combustion characteristics; however, their reserves are being depleted day by day (Hassan & Kalam, 2013). In light of these challenges, there is an urgent need for innovation in alternative energy sources that are renewable and environmentally friendly (Surjana, 2012). As part of efforts to find more sustainable solutions, numerous studies have been conducted on biodiesel production as a more eco-friendly alternative energy source (Dos Passos et al., 2024) (Aleman-Ramirez, Okoye, Pal, & Sebastian, 2024) (Arifin, Marlina, & Raharjo, 2023) .

Conventionally, biodiesel is produced through the transesterification reaction of natural oil triglycerides (animal fats or vegetable oils) with short-chain alcohols (such as methanol) using a homogeneous catalyst (Fernando, Karra, Hernandez, & Jha, 2007). Soybean oil is one of the vegetable oils that can be utilized for triglyceride transesterification (Sitorus, Ariani, & Lubis, 2018). According to a study by Imwinkelried et al. (2025), the use of soybean oil-based biodiesel in diesel engines (B100, B50, and B25) shows no significant differences in terms of torque, power output, and fuel consumption compared to pure diesel. This indicates that soybean biodiesel can serve as a viable alternative or blend to replace petroleum-based diesel fuel.

Arifin et al. (2023) conducted a study on the effect of using a heterogeneous catalyst derived from a mixture of animal bones and papaya leaves on the yield, density, and kinematic viscosity of soybean biodiesel produced through transesterification. According to Arifin et al. (2023), homogeneous catalysts have drawbacks, including the production of high water content, which can reduce biodiesel yield, their corrosive nature, and their inability to be reused, thereby contributing to waste. Therefore, in their study, a heterogeneous catalyst made from organic waste, specifically a mixture of animal bones and papaya leaves, was used as a more environmentally friendly and sustainable alternative.

According to Law (1982), research on gasification, oxidation, and droplet dynamics of fuels has both practical and fundamental importance for energy and combustion science. Liquid fuels are usually introduced into combustion chambers as sprays of droplets, making it reasonable to assume that the collective gasification of individual droplets significantly affects the evaporation and oxidation characteristics of the entire spray, which in turn influences the performance of the combustion chamber (Ando, Wu, Nakaya, Tsue, & Flame, 2020). The single droplet method serves as a model to study fuel combustion characteristics by observing individual fuel droplets directly within a combustion chamber. Several studies have used this method to explore the combustion behavior of biodiesel.

Botero, Huang, Zhu, Molina, and Law (2012) conducted droplet combustion tests on ethanol, diesel, castor oil biodiesel, and their blends. The results showed that adding biodiesel to diesel significantly reduced soot formation and slightly decreased the combustion rate. Rentería, Gallego, Gamboa, Cacua, and Herrera (2023) analyzed the effect of adding carbon nanotubes (CNTs) functionalized with amide groups on the ignition delay of diesel and biodiesel fuels using the droplet combustion method. Their findings indicated that functionalized CNTs were more effective in reducing ignition delay in biodiesel than in diesel. Other studies have also examined biodiesel combustion characteristics such as evaporation rate (Li et al., 2025) and droplet lifetime (Han et al., 2022) using the single droplet test.

Previous studies have assessed the performance of soybean oil-based biodiesel in diesel engines; however, the combustion characteristics of biodiesel produced with heterogeneous catalysts have not been thoroughly examined. Various factors, including combustion rate, ignition delay, evaporation rate, droplet lifetime, and droplet temperature, influence biodiesel combustion. Most previous research has focused on engine performance and the impact of catalysts on biodiesel yield, without exploring how these catalysts affect combustion behavior. Only a few studies have used the single droplet method to evaluate biodiesel made with heterogeneous catalysts.

This study aims to fill that gap by analyzing the combustion characteristics of soybean oil-based biodiesel using the single droplet method. Specifically, it uses biodiesel produced by (Arifin et al., 2023) with a heterogeneous catalyst derived from organic waste specifically, a mixture of papaya leaves and animal bones to further explore how such catalysts affect biodiesel combustion properties.

This study evaluates the evaporation stage, combustion rate, ignition delay, droplet lifetime, flame temperature, and droplet temperature to gain insights into the potential of heterogeneous catalyst-based biodiesel as an alternative fuel. The results aim to support the idea that biodiesel made with heterogeneous catalysts can deliver competitive combustion performance, making it a more sustainable option in the shift toward renewable energy. Additionally, the findings may help develop more efficient and eco-friendly biodiesel production methods and contribute to academic discussions on the performance of heterogeneous catalyst-based biodiesel.

## 1.2. Problem Statement

How is the combustion characteristic of soybean oil as biodiesel produced with papaya leaf and animal bone as catalysts using single droplet method?

## 1.3. Scope of The Problem

The scope of the problem in this research are:

1. Supporting data for this research using GC-MS, Specific Gravity, Densitas, and Lower Heating Value (LHV)
2. Not discussing the biodiesel production
3. Not discussing any other aspect, like emission or fuel efficiency, of the diesel engine directly.

## 1.4. Research Objective

According to the problem statement of this research, the objective of this research is to know the combustion characteristics of soybean oil as biodiesel produced with papaya leaf and animal bone as catalysts using single droplet method.

### 1.5. Research Benefits

Using the single droplet method, this research helps understand the combustion characteristics of biodiesel on a microscopic scale. This research also supports the Sustainable Development Goals (SDGs), especially:

1. SDG 7 (*Affordable and Clean Energy*): by exploring heterogeneous catalyst-based biodiesel as a cleaner and more sustainable form of renewable energy.
2. SDG 12 (*Responsible Consumption and Production*): through the utilization of organic waste such as animal bones and papaya leaves as catalysts, thereby reducing waste and enhancing resource efficiency.
3. SDG 13 (*Climate Action*): by promoting the use of more environmentally friendly alternative fuels, which can help reduce carbon emissions and mitigate the negative impacts of climate change.

# BAB V
# CONCLUSIONS AND SUGGESTIONS

## 5.1. Conclusions

Transesterified biodiesel with 6wt% has a FAME content of 98%, much higher than 2wt% which is only 45.66%. The low FAME content in 2wt% biodiesel indicates that the triglyceride conversion process is not optimal, so there are still a number of non-FAME identified in GC MS such as fatty acids, alcohols, and others. The specific gravity and density of 2wt% biodiesel (0.9265 and 0.9275 g/mL) are higher than 6wt% (0.9013 and 0.9241 g/mL), indicating that 2wt% biodiesel is heavier. The LHV value of 2wt% biodiesel (39.26 kJ/g) is higher than 6wt% (37.92 kJ/g), indicating that increasing the degree of FAME conversion tends to decrease the LHV.

The single droplet test results of 6wt% Biodiesel showed more stable droplet evolution during combustion, with fewer microexplosions. 2wt% Biodiesel experienced many weak microexplosions that caused fluctuations in droplet diameter, and reduced combustion stability. The transient heating phase at 2wt% ended faster due to faster bubble nucleation, while at 6wt% the heating ended after the thermal expansion reached its maximum. The evaporation rate in 6wt% biodiesel was higher, due to its high FAME content and lower density. In the burning phase, 2wt% biodiesel displayed two microexplosions that affected the shape and dimensions of the flame at high temperatures, while 6wt% showed a stable flame without microexplosions. The flame lifetime of 6wt% burning phase was shorter than 2wt% due to its low LHV and compositional stability.

## 5.2. Suggestions

Based on the conclusions above, there are several suggestions for further research. To improve the validity and completeness of the results, it is recommended to conduct direct performance tests in diesel engines to observe the effects of microexplosion phenomena on combustion efficiency and exhaust emissions. Comparing the performance of biodiesel with high and low FAME content to determine the effect of FAME content percentage on exhaust emissions and power output.

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