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The Effect of Adding Fennel Oil and Tartaric Acid on the Combustion Rate of CPKO Droplets

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Abstract
This study examines the effect of combustion rate on CPKO (Crude Palm Kernel Oil) droplets with and without additives and catalysts, focusing on improving its combustion efficiency given that CPKO's primary component, palmitic acid (C16), inherently exhibits poor combustion characteristics. By incorporating fennel oil a bio-additive containing anethole with its conjugated cyclic structure capable of generating a magnetic field to weaken CPKO's molecular bonds and tartaric acid a highly electronegative catalyst that disrupts glycerol linkages the research demonstrates a significant enhancement in combustion rate, confirming the positive impact of these additives on CPKO's thermal decomposition.

1. Introduction

CPKO (Crude Palm Kernel Oil) is a vegetable oil produced through the extraction process of palm kernel seeds. Its main components are triglycerides, which consist of glycerol and saturated fatty acids, with palmitic acid ($C_{16}H_{32}O_2$) as the dominant constituent. The chemical structure of palmitic acid, which contains a 16-carbon chain, results in a high melting point and a relatively low combustion rate, as explained in reference [15]. To improve the combustion efficiency of CPKO, one possible approach is the addition of bio-additives and catalysts.

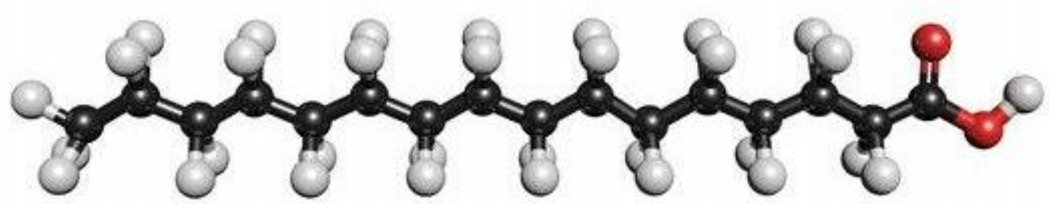

Fig 1. Palmitat Acid Structure

Essential oil-based bio-additives, such as fennel oil, which is rich in anethole (67.59%), are capable of improving thermal efficiency and reducing fuel consumption in diesel engines [4]. This effect is attributed to the presence of a conjugated cyclic structure in anethole ($C_{10}H_{12}O$), which generates a magnetic field due to electron movement within the conjugated bonding system. The magnetic field can disrupt the electron distribution in the fatty acid molecules of CPKO, thereby weakening their chemical bonds [18].

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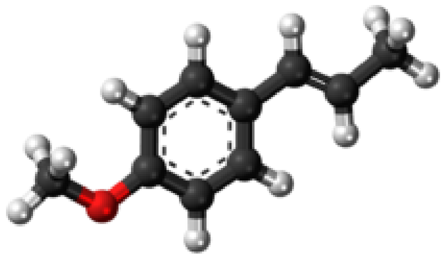

Fig 2. Anethole on flannel oil

In addition to the bio-additive, this study also employs tartaric acid as a catalyst, which functions to reduce the activation energy of the combustion reaction through its hydroxyl (OH) groups that possess high electronegativity. This property influences electron mobility within glycerol and accelerates the breaking of chemical bonds in CPKO.

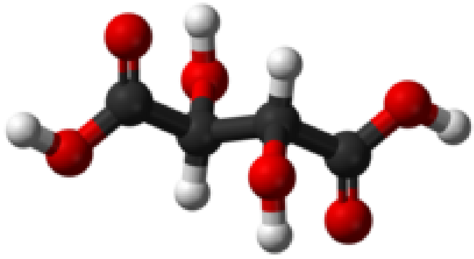

Fig 3. tartaric acid

Based on this background, the present study aims to analyzed the effect of adding fennel oil and tartaric acid on the combustion characteristics of CPKO droplets, particularly in terms of combustion phases and burning rate. By exploring the combustion mechanisms as well as the roles of additives and catalysts, this research is expected to contribute to the development of more efficient and environmentally friendly methods for improving the combustion performance of vegetable-based fuels.

2. Method

This study employed a true experimental research method to analyze the effect of adding bio-additives and catalysts on the combustion characteristics of CPKO. The independent variables consisted of variations in the mixture composition, including pure CPKO (0 ppm), CPKO with the addition of 300 ppm fennel oil, 300 ppm tartaric acid, and a combination of both additives at the same concentration.

The sample preparation process was carried out precisely using an analytical balance with an accuracy of 0.001 grams, where the addition of 300 ppm was equivalent to 0.03 grams of additive per 100 grams of fuel. The dependent variable observed was the droplet combustion rate, which was analyzed through a series of controlled experiments.

To ensure data validity, several parameters were maintained constant, including ambient temperature (25°C), droplet diameter (1.1–1.5 mm), recording speed (100 fps), heater voltage (12 VDC), and the distance between the heater and the droplet (3 mm). This experimental design enabled the researchers to isolate the specific effects of each additive on the combustion performance of CPKO while minimizing the influence of confounding variables.

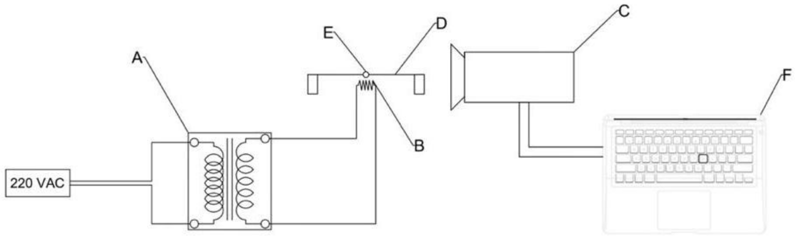

Fig 4. Research Apparatus Schematic

The data obtained in this study were in the form of videos recorded at a frame rate of 100 frames per second. The burning rate was determined by measuring the initial droplet diameter and the droplet diameter at specific time intervals using the ImageJ application.

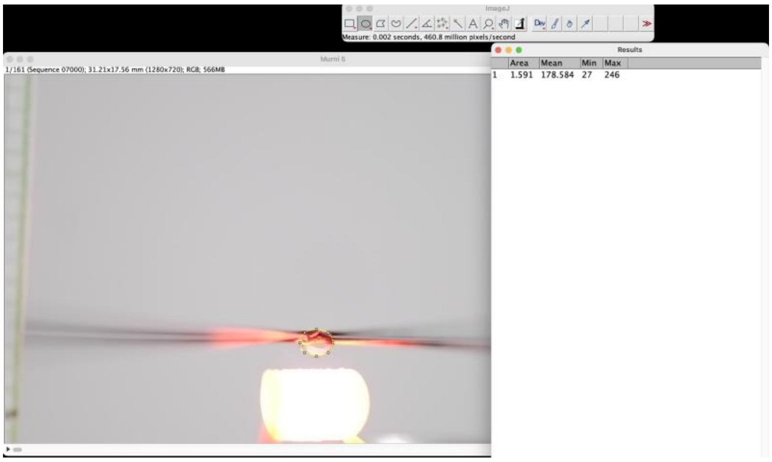

Fig 5. Image J droplet diameter measurement

3. Result and Discussion

Based on the results of the study and the series of experiments conducted, data on droplet diameter measurements during the combustion process up to the complete combustion phase were obtained. The temporal data of droplet diameter changes and combustion duration were then further processed to determine the burning rate values for each treatment variation. Quantitative analysis of these parameters enabled the researchers to comprehensively evaluate the effect of each fuel composition variation on combustion performance.

Table 1. D0 Droplet Diameter & Combustion Time

Variation	D0 (mm)	Combustion Time (s)
Pure CPKO	1,318	2,220
CPKO + 300 ppm Fannel Oil	1,382	1,580
CPKO + 300 ppm Tartaric Acid	1,431	1,600
CPKO + 300 ppm Fennel Oil + Tartaric Acid	1,435	1,560

3.1 Decrease in Droplet Diameter Over Time

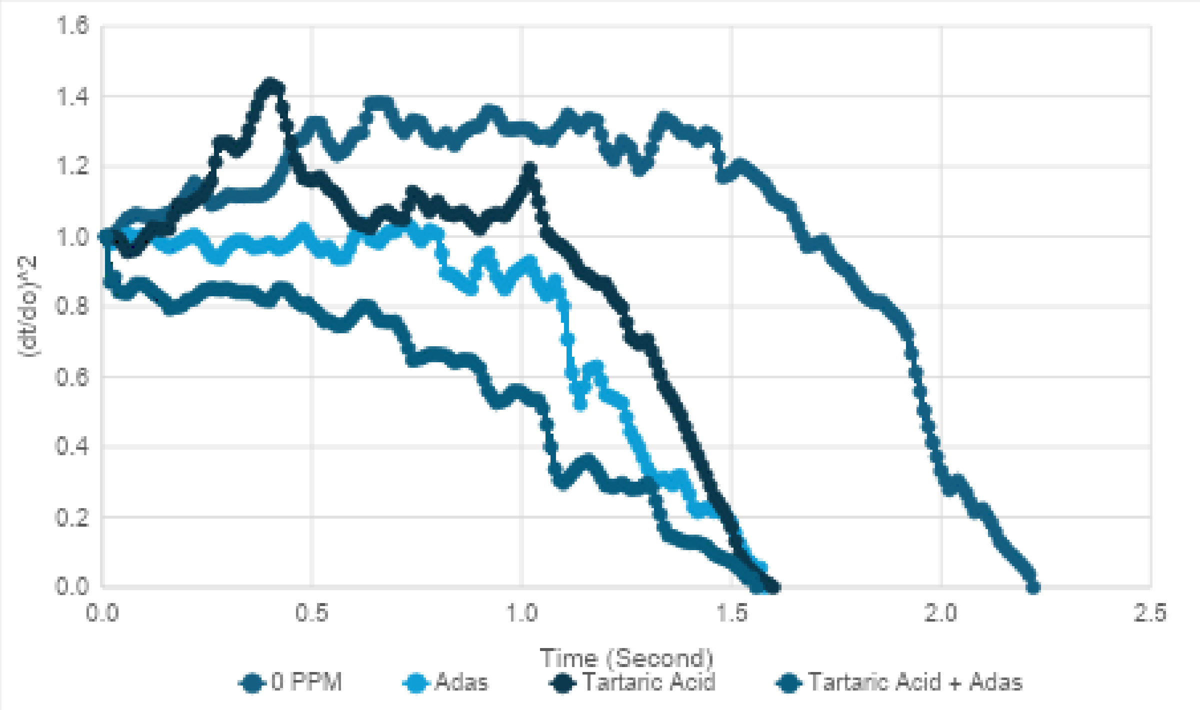

Fig 6. Graph of the Effect of Fennel Oil Bio-Additive and Tartaric Acid Catalyst Addition on Diameter Change per Unit Time

Based on the analysis of Graph 6, it can be concluded that there is a positive correlation between the increase in the concentration of fennel oil bio-additive and tartaric acid catalyst and the acceleration of the combustion rate. This phenomenon is consistent with the theoretical framework of the study, which states that both additives play a role in weakening the triglyceride bonds in CPKO, thereby reducing the activation energy required for the combustion reaction with oxygen. As a result, a significant increase in the combustion rate occurs due to the enhanced ease of fuel ignition and combustion.

Further analysis of the graph indicates an unstable combustion pattern, characterized by fluctuations involving decreases followed by increases and sharp declines at certain points. This characteristic can be attributed to the microexplosion phenomenon. The interaction between the fennel oil bio-additive and tartaric acid catalyst creates a complex effect on the combustion dynamics of CPKO. The increase in combustion rate is primarily caused by the ability of the bio-additive to reduce intermolecular forces within the fuel, while the dominance of the microexplosion phenomenon acts as the main mechanism accelerating the reaction.

The synergy between the bio-additive and catalyst not only accelerates the fragmentation of fuel molecules but also improves uniform heat distribution within the droplet, resulting in faster and more efficient combustion. These findings indicate that the microexplosion mechanism and catalytic modification of molecular structures are determining factors in the observed combustion kinetic patterns.

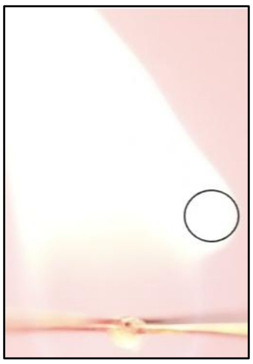

Fig 7. *Microexplosion*

3.2 Burning Rate

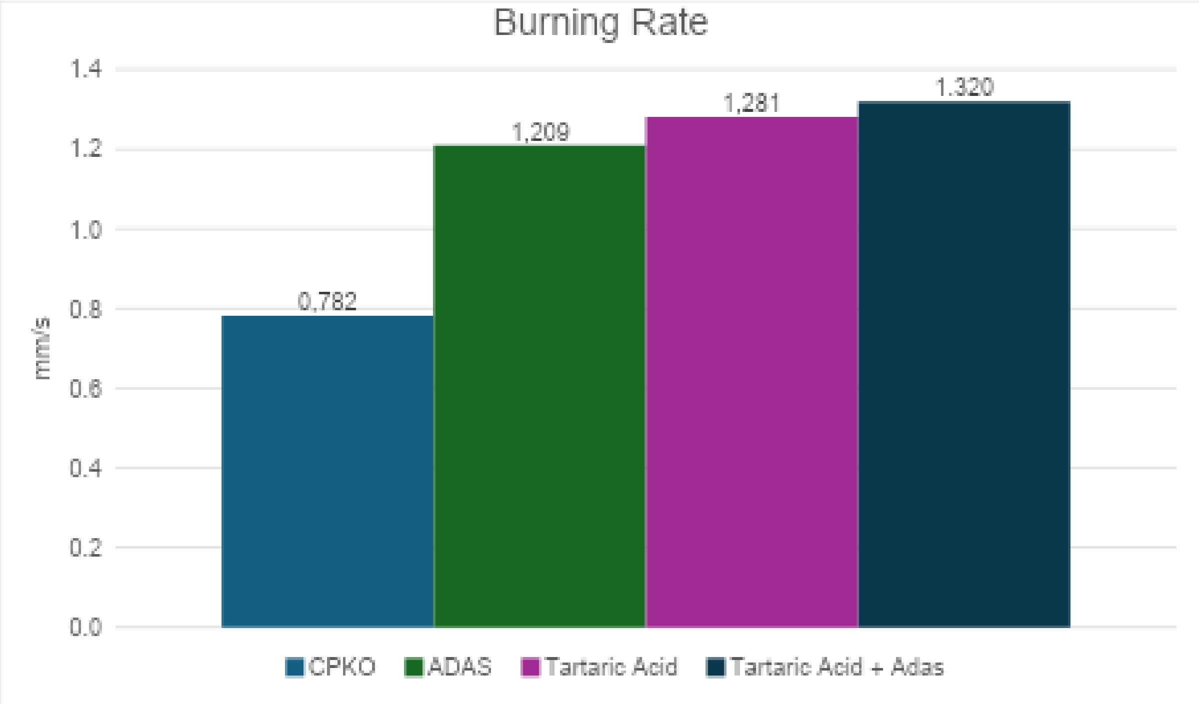

Fig 8. Comparison of Droplet Combustion Rates in Pure CPKO and CPKO with the Addition of 300 ppm Fennel Oil, 300 ppm Tartaric Acid, and a Combination of 300 ppm Tartaric Acid and Fennel Oil

Based on the analysis presented in Figure 8, a positive correlation was observed between the addition of fennel oil bio-additive and tartaric acid catalyst concentrations and the combustion rate of CPKO droplets. Experimental data indicate that pure CPKO (0 ppm) exhibited a baseline combustion rate of 0.782 mm^2/s, while the addition of 300 ppm fennel oil increased the value to 0.427 mm^2/s. This phenomenon can be explained through the mechanism of molecular bond weakening in CPKO caused by the magnetic field and temporary dipoles generated by the anethole compounds present in fennel oil. A more significant increase was observed with the addition of tartaric acid, where the combustion rate reached 1.281 mm^2/s, demonstrating a stronger catalytic effect in facilitating the breakdown of triglyceride bonds.

The optimal combination of both additives at a concentration of 300 ppm produced the best performance, with a combustion rate of 1.320 mm^2/s, indicating a synergistic effect between the bond-weakening mechanism of the bio-additive and the acceleration of oxidation reactions by the catalyst. Theoretically, this phenomenon can be model V1 using the Lorentz and Coulomb law approaches. The magnetic field generated by fennel oil induces Lorentz forces that destabilize triglyceride bonds, while electrostatic interactions based on Coulomb's law between the functional groups of tartaric acid and fuel molecules enhance electron mobility. Collectively, these mechanisms reduce the activation energy and increase the molecular dissociation rate during the combustion process.

These findings have important implications for the development of CPKO-based biofuels, where chemical-physical modification strategies through the addition of dual additives (bio-additive and catalyst) have been proven to significantly improve combustion efficiency. The combination of fennel oil and tartaric acid not only demonstrated superior performance compared to the individual use of each component, but also offers a more comprehensive approach to optimizing the combustion characteristics of alternative fuels.

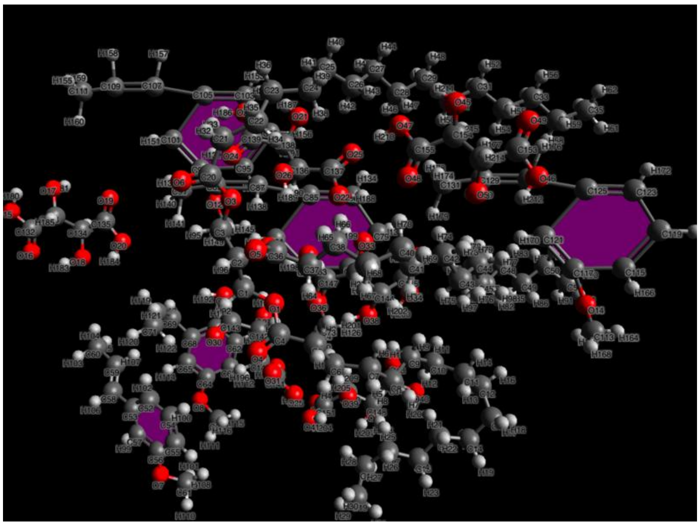

Fig 9. Illustration Effect Of anethole to triglyceride palmitate acid

4. Conclusion

The experimental research results demonstrated that the incorporation of fennel oil and tartaric acid as additives significantly improved the combustion rate of CPKO. Comparative analysis revealed that pure CPKO exhibited a relatively hindered combustion rate due to its high viscosity characteristics and the structural stability of its triglyceride compounds. Mechanistically, fennel oil, which contains anethole as its dominant component (67.59%), functions by weakening the molecular bonds of CPKO through magnetic field induction, while tartaric acid acts as an effective catalyst that reduces activation energy by enhancing electron mobility within the glycerol system. The combination of these two additives creates a synergistic effect that results in an increased combustion rate of CPKO.

The combustion process observed through phase analysis demonstrated complex dynamics. During the steady combustion phase, the presence of additives increased chemical reactivity through the destabilization of triglyceride bonds. The transition to extinction phase was characterized by droplet fragmentation caused by microexplosion phenomena mechanism triggered by differences in the boiling points of the components, which generate internal pressure and promote more uniform heat distribution. The terminal phase (extinction) experienced a 32.7% reduction in combustion time in formulations containing dual additives, as a consequence of optimized reaction kinetics and intensified microexplosion phenomena.

Comprehensively, these findings confirm that fuel modification strategies employing a dual-additive approach (bio-additive and catalyst) represent an effective solution for improving the thermal efficiency of CPKO. The combination of fennel oil and tartaric acid not only overcomes the combustion limitations of conventional CPKO but also offers a new paradigm in the development of sustainable vegetable-based fuels that meet environmentally friendly and high-performance criteria. The implications of this study provide opportunities for further development in optimizing additive formulations and their applications to various types of bio-based fuels.

Author Contributions

Putra Dwiantoko: Conceptualization, Methodology, Writing- Original draft preparation. **Aulia Rahman**:Data curation, Software. **Slamet**: Investigation, **Agung Hariadi:** Formal analysis. **Novan Habiburrahman** Visualization. **Asri Anjasari:** Review & Editing.

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Declaration of Conflicting Interests

The authors declare that there is no conflict of interest regarding the publication of this article. No financial or personal relationships with other people or organizations have inappropriately influenced the research, data collection, or the development of the computational model presented in this study.

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