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Research Paper

An Experimental Study on the Ignition Behavior of Blended Fuels Droplets with Crude Coconut Oil and Liquid Metal Catalyst

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Abstract

This study examines the ignition characteristics of blended fuel droplets with crude coconut oil (CCO) and rhodium liquid as a liquid metal catalyst. The ignition behavior was observed by igniting the oil droplet on a junction of a thermocouple and the droplet evolution recorded with the high-speed camera. The results showed that the addition of a liquid metal catalyst successfully reduces the molecular mass of the triglyceride and weakens the bonding force between the carbon chain. Therefore, the viscosity and flash point decreases. Moreover, the addition of liquid metal catalysts increased the reactivity of fuel molecules such as C-H, C-C, C=C, and C-O. Changes in the physical properties of the fuel, the geometry of the carbon chain, and molecular mass ease the absorption of heat by the fuel droplet, thereby increasing fuel ignition performances.

Keywords: Crude coconut oil, Rhodium liquid, Droplet, Fuel ignition performance

Abstrak

Penelitian ini bertujuan untuk menguji karakteristik penyalaan dari campuran tetesan bahan bakar dengan minyak kelapa mentah (CCO) dan cairan rhodium sebagai katalis logam cair. Perilaku pengapian diamati dengan menyalakan droplet minyak pada persimpangan termokopel dan evolusi droplet direkam dengan kamera kecepatan tinggi. Hasil penelitian menunjukkan bahwa penambahan katalis logam cair berhasil mengurangi massa molekul trigliserida dan melemahkan kekuatan ikatan antar rantai karbon. Hal ini menyebabkan viskositas dan titik nyala berkurang. Selain itu, penambahan katalis logam cair mampu meningkatkan reaktivitas molekul bahan bakar seperti C-H, C-C, C=C, dan C-O. Bahkan, terjadi perubahan sifat fisik bahan bakar, geometri rantai karbon, dan massa molekul, sehingga memudahkan penyerapan panas oleh droplet bahan bakar, hal ini membuat kinerja penyalaan bahan bakar menjadi lebih baik.

Kata-kata kunci: *Minyak kelapa mentah, Cairan rhodium, Droplet, Kinerja penyalaan bahan bakar*

1. Introduction

Crude coconut oil (CCO) is an alternative fuel source that can be converted into biodiesel. However, the use of biodiesel in combustion engines is not optimal because it produces emissions and contribute to the greenhouse gas effect [1], [2]. Moreover, the conversion process of crude vegetable oil into biodiesel requires more energy, cost, and materials [3]. Revaluation of the conversion process, such as the trans-esterification and the esterification of crude vegetable oils is essential for energy-efficient conversion processes and cost reduction [4]. On the other hand, when vegetable oil is used as an alternative fuel, the very important thing to note is the combustion characteristics of the fuel [5].

The characteristics of the ignition of vegetable oil fuels can be observed and studied through two things, namely, the presence of random droplets with different diameter sizes and single droplets. From these two things, a single droplet is an alternative method that can be used because it can simplify the problem when it wants to study and uncover fuel ignition characteristics such as evaporation rate, combustion rate, ignition delay, and micro-explosion [6], [7]. To improve fuel performance, liquid metal catalysts such as Rhodium liquid have previously been used [8]–[10]. Unfortunately, the mechanism of liquid metal catalysts in the ignition process of diesel engines based on CCO is very complex. It is difficult to examine the CCO due to its unique characteristics and the complexity of chemical processes through the applied research method [11]. Therefore, to ease observation, combustion droplet experiments were conducted severally using crude vegetable oil at atmospheric pressure [12]–[15].

Scientific information about the effect of liquid metal catalysts on CCO ignition behavior is still unclear. Therefore, this study uses a single drop combustion method with a mixture of CCO fuel and rhodium liquid as a metal-based catalyst. Rhodium is platinum-group metals and is mostly found in southern Africa and Russia, and annually is produced as much as 500 tons [16]. The biggest use is approximately 81% as active catalyst materials and automotive emission control catalysts that are used to accelerate the rate of combustion reactions and reduce emissions of harmful exhaust gases such as carbon monoxide (CO), unburned hydrocarbons and nitrogen oxides (NOx) [16]–[19].

Another advantage of adding rhodium as a solute is that it is not toxic when mixed [20] and the presence of rhodium catalysts in the fuel makes the concentration and density of molecules in the fuel increase so that the distance between the molecules becomes closer. If the distance between the molecules gets closer, the possibility of effective collisions is greater and the reaction rate will increase. Rhodium liquid has a greater amount of proton energy, so the catalyst has the potential to attract hydrogen atoms from carbon triglyceride chain compounds. In view of the fact that the hydrogen atom is very reactive, then when the electrons have enough energy, vibrate and get more active, the electrons have the potential to move to the catalyst surface. By transferring electrons to the catalyst, there is a release of some energy in the form of radiation (photon energy).

Moreover, the addition of catalysts produces dipole-dipole interactions [21] to change the geometrical structure and weaken van der Waals dispersion forces between carbon triglyceride chains [22], [23]. Rhodium liquid catalyst is acceptors 12 hydrogen bond [24] which has the potential to reduce the molecular mass of the CCO carbon chain, making fuel molecules more reactive, reduce the viscosity and the value of flash points thereby increasing fuel performance. Scientific information regarding the effect of liquid metal catalysts on the molecular masses of triglyceride chains and their impact on the physical properties and ignition characteristics of CCO fuels is critical. This necessitates the need for more detailed research and observations.

2. Material and Method

2.1. *Fuel Preparation*

The CCO was mixed with rhodium liquid as a metal-based combustion catalyst at a dosing ratio of catalyst to oil volume of 0.001 ml to 100 ml. The fuel mixture was obtained by mixing the oil and catalyst in the test tube and shuffled manually. The test results on fuel properties are presented in **Table 1**, while **Table 2** shows the effect of rhodium liquid on the molecular mass of carbon chain calculated by chemistry software.

Table 1. Main properties of CCO

Properties	With Catalyst	Without Catalyst
Flash Point (°C)	204	243
Caloric value (cal/gr)	8939	9400
Density at 15 °C (gr/ml)	0.916	0.917
Viscosity at 40 °C (cSt)	32.38	35.52

Table 2. Effect of catalyst on the fatty acid molecules

Fatty acids	Cn:db	Formula	Comp. (%)	Molecular mass, g/mole	
				Without Catalyst	With Catalyst
Lauric	12:0	$C_{12}H_{24}O_2$	7.71	200.3178	188.2225
Myristic	14:0	$C_{14}H_{28}O_2$	3.29	228.3709	216.2756
Palmitic	16:0	$C_{16}H_{32}O_2$	14.62	256.4241	244.3288
Palmitoleic	16:1	$C_{16}H_{30}O_2$	1.47	254.4082	242.3129
Stearic	18:0	$C_{18}H_{36}O_2$	7.36	284.4772	272.3820
Oleic	18:1	$C_{18}H_{34}O_2$	30.38	282.4614	270.3661
Linoleic	18:2	$C_{18}H_{32}O_2$	35.42	280.4455	268.3502

2.2. *Experimental setup and procedures*

The experimental apparatus is shown in **Figure 1**. The oil droplet (7) was suspended at the junction of the thermocouple (6) made of a 13% Pt/Rh with a diameter of 0.1mm. The droplet diameter is about 0.6 - 1.1mm. The droplet is powered by an electric coil heater (5) 0.7mm diameter and made of Ni-Cr wire with a length of 30mm, a resistance of 1.02 Ω, has a voltage of 6 V and a current of 5 A (4). A high-speed CCD camera (3) is used for taking pictures when the droplet is ignited. The shooting process takes place at a frame rate of 120 fps to allow in determining ignition time and burnout time. During the heating and ignition process, the temperature at the center of the droplet oil is recorded by the thermocouple sensor and acquired by a personal computer (1) connected to the data logger (2) with a frequency of 0.01 Hz. The process of taking data is repeated five times.

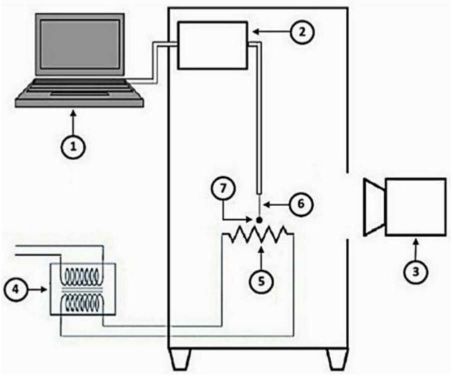

Figure 1. The experimental scheme

3. Resuts and Discussion

The addition of a liquid metal catalyst to CCO accelerates ignition time (see **Figure 2**). Although in general, the ignition rate of droplets without catalysts is 0.03 mm and greater than CCO droplets with catalysts. However, the droplet fuel catalyst ignites around 1.3 s at a diameter of 1.223 mm, while without a catalyst the droplet CCO ignites about 1.4 s at 1.232 mm. This shows that the addition of catalysts makes it easier for fuel droplets to absorb heat. This result is because CCO has a smaller molecular mass, which is directly proportional to the bonding force between carbon chains. Therefore, when the molecular mass of the fuel decreases, the bonding force of the carbon chain also weakens, leading to decreased viscosity and combustible fuel droplets. Moreover, observations show that without a catalyst, the droplet diameter increases with heating time and temperature.

Figure 2 also shows that from the beginning of the heating process 0 s to about 0.15 s, without a catalyst, the CCO droplet reaches 36.03 °C with a droplet diameter of about 1.10 mm. With the catalyst, the fuel droplet reaches a diameter of 1.06 mm at 36.38 °C. Therefore, with a CCO catalyst, it requires less heat to expand and evaporate. When compared to previous studies, fuel ignition time seem to increase along with the double bond C=C in the carbon chain [25]. However, despite having the same fatty acid composition, CCO with catalysts had a shorter ignition time. This shows that the reactivity of the fuel is determined by both the number of C=C double bonds and the molecular mass of the carbon chain. The liquid metal catalyst, as an acceptor 12 hydrogen bonds, pull 12 hydrogen atoms from the triglyceride chain, and therefore, the molecular mass of the CCO decreases and weakens the van der Waals dispersion force. This decreases viscosity makes fuel molecules more reactive, and the fuel is easily ignited since the flashpoints can be accessed freely.

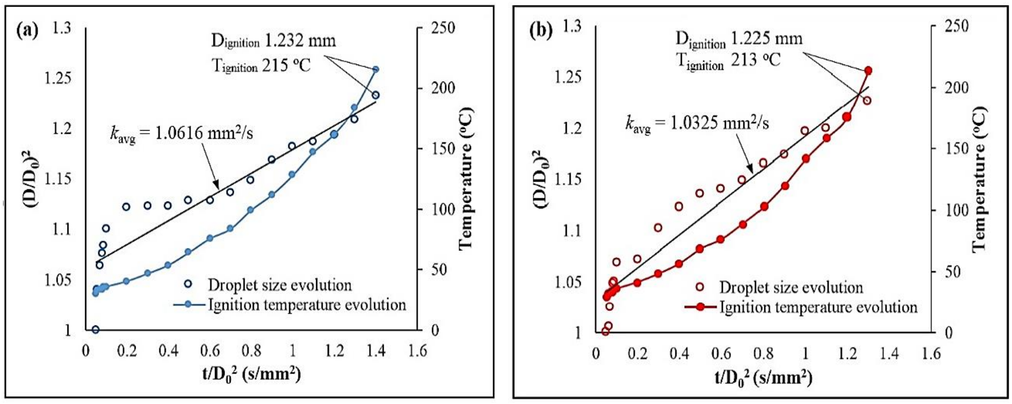

Figure 2. The evolution of droplet: (a) without catalyst and (b) with catalyst

Figure 3 shows that no micro-explosion occurred during the heating process until ignition. These observations are confirmed by the spherical droplet shape with a smooth surface. However, these results are very different when compared with the results of previous studies [26] who used a mixture of soybean oil with butane, in which the results of the study showed that the micro-explosion occurred after the droplet volume had increased due to internal evaporation, showing by bubble trapped in an oil droplet.

Furthermore, **Figure 3** shows that the addition of catalysts makes the ignition time shorter and the diameter of ignitable droplets has a smaller size than the droplet fuel without catalysts, and this also shows the ignition delay of third fuel. This phenomenon shows that the rate of evaporation from fuel with the catalyst is faster when compared to fuel without a catalyst. Moreover, these results prove that the catalyst has succeeded in decreasing the value of fuel viscosity and being able to reduce the mass of carbon chain molecules caused by catalysts attracting 12 hydrogen atoms from the triglyceride chain.

When compared with previous studies, it shows that the fuel ignition time is increasing along with the increase of the double bond C = C in the carbon chain and this reduces the reactivity of the fuel to burn at lower temperatures [25], [27], [28]. However, in this study, we found different results, which although the triglyceride carbon chain of coconut oil with and without catalyst has the same carbon chain structure, but has a different ignition time. This is because the catalyst has succeeded in bending the structure of the saturated CCO carbon chain. This causes the carbon chain to become unstable thereby increasing the reactivity of fuel molecules. The nature of the catalyst as acceptor 12 hydrogen bonds makes the catalyst pull hydrogen atoms from the carbon triglyceride chain so that the molecular mass decreases, the triglyceride carbon chain becomes bent and very unstable, viscosity decreases so that the molecule becomes active, more reactive, the flash-point is easily reached and the fuel is easy to ignite.

Figure 4 shows the results of the FTIR test that explains the response of fuel molecules to infrared (IR) heat. In the C-H, C-C, C=C, and C=O molecules, the peak of the CCO wave with the catalyst is higher than CCO without a catalyst. Also, the amount of transmittance (%T) of infrared heat absorbed by CCO with and without the catalyst is 131% T and 34% T, respectively. The results proved that the addition of liquid metal catalyst weakens the CCO molecular bonds, and therefore, the molecules react faster when absorbing heat energy.

FTIR test results and analysis are confirmed by the time and fuel ignition temperatures. These results indicate that the atoms in a molecular bond are not always in a stationary state, but will always vibrate when absorbing energy. This causes the energy level in the atom to be excited to a higher level so that it has the potential to increase the vibrational energy and rotational energy of the electrons. This potentially increases the ignition process of fuel droplets because the energy needed to break bonds is lower and the absorption of energy becomes faster. Moreover, this phenomenon shows that the molecular bonding energy of C-H, C-C, C=C and C=O is constant, but the diameter of the atom increases with heat. The distance between the nuclei increases while the bonding force between the atoms decreases. Consequently, the energy needed to break the bonds of atoms is smaller and enhances the process of absorption of heat energy.

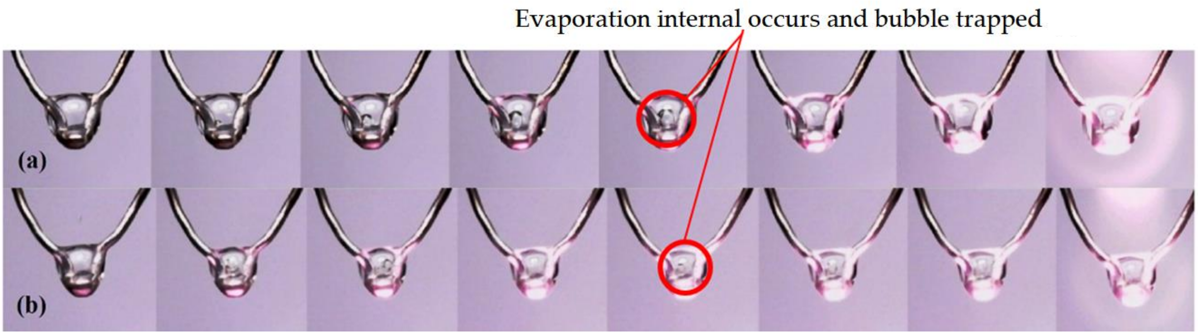

Figure 3. Deformation for a transient droplet on the ignition process at normal pressure: (a) Without catalyst and (b) with catalyst.

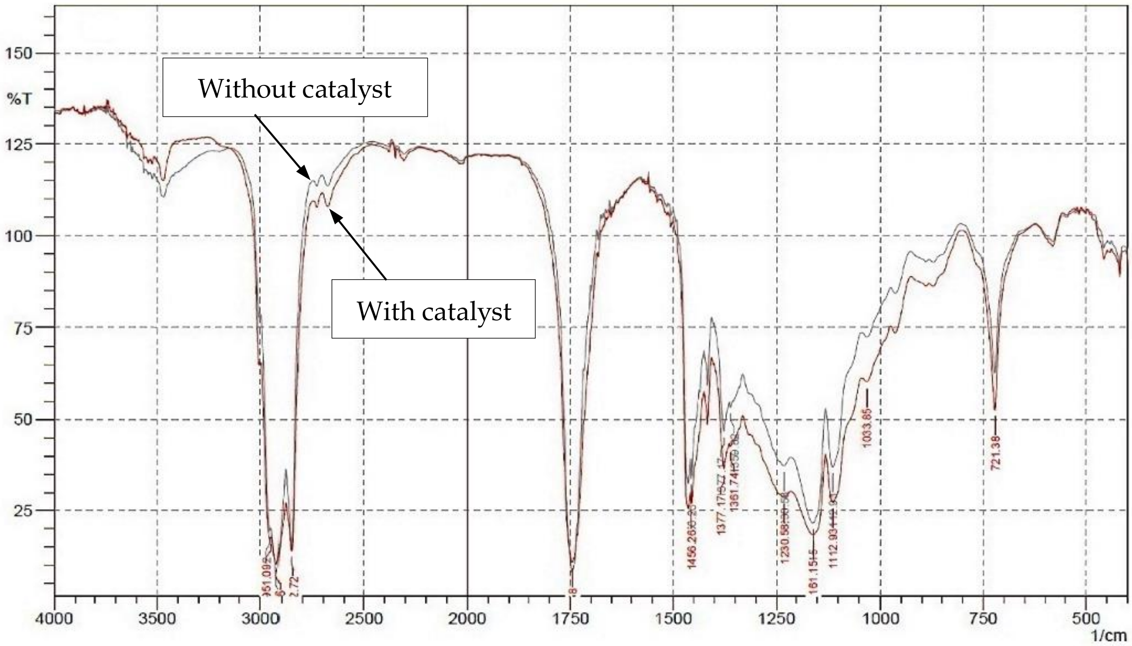

Figure 4. The response of fuel molecular of fuel droplet to IR heat.

4. Conclusion

A comparative study of the effect of liquid metal catalysts has been performed under normal gravity conditions. The results showed that the addition of the liquid metal catalyst was able to improve the ignition performance of fuel droplets. The addition of the catalyst can reduce the molecular mass of the fuel so that the bonding force between the carbon chains is reduced, the viscosity and flash point decrease and the fuel droplet is easily ignited. The results also showed that the fuel ignition time was faster. Moreover, the addition of a liquid metal catalyst can make the fuel molecular bonds of C-H, C-C, and C-O more reactive so that the droplet fuel will heat up and ignite faster.

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Author's Declaration

Authors' contributions and responsibilities

The authors made substantial contributions to the conception and design of the study. The authors took responsibility for data analysis, interpretation and discussion of results. The authors read and approved the final manuscript.

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Availability of data and materials

All data are available from the authors.

Competing interests

The authors declare no competing interest.

Additional information

No additional information from the authors.

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