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Combustion characteristics of crude jatropha oil droplets using rhodium liquid as a homogeneous combustion catalyst

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Abstract. Combustion characteristics of crude jatropha oil droplet at room temperature with and without catalyst have been studied experimentally. Its combustion characteristics have been observed by igniting the oil droplet on a junction of a thermocouple, and the combustion characteristics of oil droplets are observed using a high-speed camera. The results show that the uniqueness of crude jatropha oil as alternative fuel is evidenced by the different stages of combustion caused by thermal cracking in burning droplets. The results also show that the role of the catalyst is not only an accelerator agent, but there are other unique functions and roles as a stabilizer. Moreover, the results also found that the catalyst was able to shorten the ignition timing and burnout time. This phenomenon proves that the presence of catalysts alters and weakens the structure of the triglyceride geometry so that the viscosity and flash point is reduced, the fuel absorbs heat well and flammable.

1. Introduction
Crude vegetable oil such as jatropha is one of the alternative fuel sources that can be converted into biodiesel. Unfortunately, the use of biodiesel in the combustion process has not been maximized because it produces carbon dioxide causes global warming [1]. Moreover, the conversion process of crude vegetable oil into biodiesel requires additional energy, cost, and materials [2, 3]. Therefore, a reassessment of the conversion process such as the trans-esterification process and the esterification of crude vegetable oils become essential to finding energy-efficient conversion processes and costs resulting in energy-efficient fuels. In addition to the process of trans-esterification and esterification, there is also a hydrogenation process used to remove the double bond on the triglyceride chain because it can reduce the ignition properties such as oxidation stability [4]. Therefore, some researchers perform a partial process of hydrogenation using metal-based catalysts such as Rhodium [5-9], Rhodium and Ruthenium [10, 11], Rhodium and Iridium [12]. Unfortunately, the hydrogenation process has a very small influenced to fuel properties and improved fuel performance [13]. Moreover, the mechanism of homogeneous catalysts in the combustion process of diesel engine based crude jatropha oils has not been much revealed and very complex, including, the ignition process and the complex combustion chemical reaction between the fuel and air vapor. The unique characteristics of crude jatropha oil and the complexity of chemical processes make the effect of metal-based catalysts in combustion difficult to know through the performance of diesel engines. Therefore, more detailed research and observation of the catalyst mechanism and its effect on combustion characteristics using single droplet combustion method of crude jatropha oil using rhodium sulfate as homogenous combustion catalyst was performed.
2. Fuel preparations

The vegetable oil used is crude jatropha oil which is mixed with rhodium sulfate as a metal based combustion catalyst with dosing ratio of catalyst to oil volume of 0.001 ml: 100 ml. The fuel mixture was obtained by mixing the oil and catalyst in the test tube and shuffled manually. Meanwhile, the effect of the catalyst on the geometry of triglycerides chain is simulated using free chemistry software, which is Avogadro 1.1.1, and the result is displayed in figure 3. Fuel properties test results are presented in Table 1 and changes in the molecular mass of fatty acids are shown in Table 2.

<table>
<thead>
<tr>
<th>Properties</th>
<th>With Catalyst</th>
<th>Without Catalyst</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flash Point(°C)</td>
<td>204</td>
<td>243</td>
</tr>
<tr>
<td>Caloric value (cal/gr)</td>
<td>8939</td>
<td>9400</td>
</tr>
<tr>
<td>Density at 15 °C (gr/ml)</td>
<td>0.916</td>
<td>0.917</td>
</tr>
<tr>
<td>Viscosity at 40 °C (cSt)</td>
<td>32.38</td>
<td>35.52</td>
</tr>
</tbody>
</table>

3. 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). 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.

<table>
<thead>
<tr>
<th>Chemical Composition</th>
<th>Cn:db</th>
<th>Formula</th>
<th>Composition %</th>
<th>Molecular mass, g/mole</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Without Catalyst</td>
</tr>
<tr>
<td>Caprylic</td>
<td>8:0</td>
<td>C₈H₁₆O₂</td>
<td>1.70</td>
<td>144.2114</td>
</tr>
<tr>
<td>Capric</td>
<td>10:0</td>
<td>C₁₀H₂₀O₂</td>
<td>1.66</td>
<td>172.2646</td>
</tr>
<tr>
<td>Lauric</td>
<td>12:0</td>
<td>C₁₂H₂₄O₂</td>
<td>7.71</td>
<td>200.3178</td>
</tr>
<tr>
<td>Myristic</td>
<td>14:0</td>
<td>C₁₄H₂₈O₂</td>
<td>3.29</td>
<td>228.3709</td>
</tr>
<tr>
<td>Palmitic</td>
<td>16:0</td>
<td>C₁₆H₃₂O₂</td>
<td>14.62</td>
<td>256.4241</td>
</tr>
<tr>
<td>Palmitoleic</td>
<td>16:1</td>
<td>C₁₆H₃₀O₂</td>
<td>1.47</td>
<td>254.4082</td>
</tr>
<tr>
<td>Stearic</td>
<td>18:0</td>
<td>C₁₈H₃₆O₂</td>
<td>7.36</td>
<td>284.4772</td>
</tr>
<tr>
<td>Oleic</td>
<td>18:1</td>
<td>C₁₈H₃₄O₂</td>
<td>30.38</td>
<td>282.4614</td>
</tr>
<tr>
<td>Linoleic</td>
<td>18:2</td>
<td>C₁₈H₃₂O₂</td>
<td>35.42</td>
<td>280.4455</td>
</tr>
</tbody>
</table>
4. Result and discussion

Figures 2 and 3 show the triglyceride chains pulled by the catalyst and the adsorption models. The Rh^{3+} catalyst is an acceptor of 12 hydrogen bonds or a deficiency of 12 hydrogen atoms. With a larger amount of proton energy, the Rh^{3+} catalyst will attract 12 hydrogen atoms from the triglycerides hydrocarbon compound. The potential difference between the catalyst and the hydrocarbon chain allows for the transfer of electrons so that the mass of the carbon chain molecules decreases (see Table 2) causing weak van der Waals bonds marked by changing geometric structures and the distance between the triglyceride chains away from each other. This phenomenon is line with [14, 15] and proved by decreased viscosity and flash point (see table 1) and highly possible because it corresponds to Newton's law that force is directly proportional to mass and inversely proportional to distance.

Figure 2. Interaction of the triglyceride chain with the catalyst.
Figure 3. Hydrocarbon chain models when pulled by the catalyst. Adapted from [16]

Figure 4 shows the response of triglyceride chain jatropha crude oil to the catalyst work. It seems that when the triglyceride chain geometry catalyst is widened and the distance between the carbon chains away from each other. Changes in the geometry of triglycerides chain reduce and weaken the interaction of dipole and van der Waals bond between carbon chains and this phenomenon has an impact on combustion characteristics of crude Jatropha oil such as temperature evolution, micro-explosion, and burnout time.

Figure 5 shows the evolution of temperature in the center of oil droplets with and without the catalyst. The evolution of temperature consists of three main processes, namely the process of heating, evaporation, and combustion. The heating process begins with the heat transient that occurs in the droplet oil with and without catalyst which is about 0s to 1s and followed by steady heat transfer from the coil heater to the droplet that occurs at about the same time that is about seconds to 0.4 s. For oil without the catalyst, droplets ignite at temperatures of about 160 °C and accompanied by evaporation processes occurring at a constant temperature of about 1.22 s. As for the fuel with the catalyst, the droplet is ignited and accompanied by evaporation process occurs at around 148 °C temperature at 1.15 s second. For droplet oil without the catalyst, droplet ignite along with an increase in temperature at the beginning of the burning droplets reach around 355 °C, and at the same time, there is a second evaporation process around 2.1 s. As for the fuel with the catalyst, droplet burns along with an increase in temperature of about 320 °C and the second evaporation takes place around 1.96 s. The peak of the chart shows the highest temperature reached and simultaneously indicates the end of the combustion process, without the catalyst around 556 °C and with a catalyst 564 °C. From figure 5, it is also shown that the fuel with the catalyst has a shorter evolution time of 2.61 s, while the fuel with catalyst is about 2.81 s. These results are also confirmed and evident through figure 6 and figure 7, it shows that the amount of flame produced by oil with the catalyst is less than oil without catalyst and this phenomenon indicates that the fuel with the catalyst has greater power than fuel without the catalyst.

Figure 4. Effect of catalyst on geometry of triglyceride chains
Figure 5. Temperature evolution in the center of the droplet with and without catalyst

Figures 6 and 7 show the evolution of flame oil droplets with and without the catalyst, such as the sequence of occurrence of micro-explosion of different intensities characterized by a spike-like flame form, this phenomenon consistent with the results of the study [17]. Figure 6 also shows that, the flame with catalyst looks calm and produces no smoke without catalysts. Whereas, the flame without catalyst look more volatile and produce more smoke (see figure 7). This phenomenon proves that the catalyst reduces the turmoil that occurs in the combustion process and produce emissions of clean and environmentally friendly.

Figure 6. Flame evolution of oil droplet with catalyst

Figure 7. Flame evolution of oil droplet without catalyst
Figure 8. The evolution of burning droplet

Figure 8 shows the evolution of decreasing the volume of droplets during the burning points. Without a catalyst, it is shown that the droplet oil combustion process is unstable, this is indicated by the presence of several stages of combustion caused by thermal cracking. Crude jatropha oil is composed of multicomponent carbon chains such as saturated fatty acids, monounsaturated fatty acids, polyunsaturated fatty acids and glycerol, and each carbon chain burns at different times. This phenomenon is in line with [17]. Moreover, the result showed that fuel droplets without catalysts more volatile and oil droplets require more heat to evaporate and ignite that it impacts longer burnout time. In contrast, the fuel combustion process with the catalyst looks more stable and occurs only in one stage. This phenomenon shows that the catalyst is not only a reaction accelerator agent, but there is a new and unique role in the combustion process of crude jatropha oil that is as stabilizer and reducer. These results prove that the catalyst alters the molecular structure of the triglyceride chain (see figure 3) and weakening the van der Waals bonds. This phenomenon is in line with [14, 15] which is discussed with different points of view. Therefore, oil droplets can absorb heat rapidly and accelerate the occurrence of molecular diffusion, and this makes the combustion process of crude jatropha oil more stable.

5. Conclusion and positive impacts for implementation
A comparative study of the effect of rhodium sulfate as a homogeneous combustion catalyst on jatropha crude oil combustion characteristics has been performed. The results showed that the addition of the catalyst was able to improve the combustion performance. Moreover, the result also found that jatropha crude oil has unique combustion characteristics and is shown by distinct stages of combustion. It was also found that the catalyst not only acted as an accelerator agent of the combustion reaction but found another unique role, namely as a stabilizer to the combustion process of crude jatropha oil. The results also show that the catalyst is capable of shortening ignition timing and burnout time, as well as being environmentally friendly. The results prove that the catalyst alters the molecular structure of the triglyceride chain and weakening the van der Waals bonds. Hence, the fuel rapid absorbs heat, molecule balance occurs and the combustion process of crude jatropha oil becomes stable.

These results prove that to produce an alternative fuel that is efficient and environmentally friendly, the process of trans-esterification, esterification, and hydrogenation can be ignored. Moreover, these
results have a very positive impact to be applied as it saves production time, saves the use of oil and additives, and saves on production costs.

References


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