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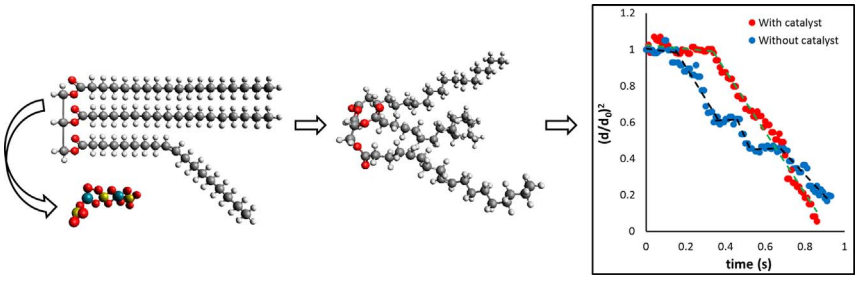
Full Length Article

The effect of Rh^{3+} catalyst on the combustion characteristics of crude vegetable oil droplets

Hendry Y. Nanlohy[a,*], I.N.G. Wardana[a], Nurkholis Hamidi[a], Lilis Yuliati[a], Toshihisa Ueda[b]

[a] Department of Mechanical Engineering, Brawijaya University, Malang 65145, East-Java, Indonesia
[b] Department of Mechanical Engineering, Keio University, Tokyo 108-8345, Japan

GRAPHICAL ABSTRACT



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ABSTRACT

The effect of Rh^{3+} catalyst on the combustion of the Crude Vegetable Oil droplet, namely coconut, jatropha, and sunflower oil has been studied experimentally at atmospheric pressure and room temperature. The oil droplets contain multi-component elements that are saturated fatty acid, monounsaturated fatty acid, polyunsaturated fatty acid, and glycerol. Results demonstrated that the catalyst has a stronger influence on crude coconut oil (CCO) and crude sunflower seed oil (CSFO) polar compounds during combustion, indicated by a greater enlargement of their triglyceride chains relative to those in crude jatropha oil (CJO). The changes in triglyceride geometry were identified as the cause of the distinguishing CVO droplet combustion characteristics. During the heating process preceding ignition, internal evaporation occurs with the appearance of bubbles trapped in oil droplets, and it appears that the diameter of the CJO droplet is greater than that of CCO and CSFO. This result suggests that the non-polar CJO compounds are more saturated, requiring additional heat for evaporation and ignition. The results also show that the catalyst makes multi-step burning droplets becomes shorter in one stage with the highest burning temperature. This proves that the catalyst does not only enlarge the triglyceride geometry but also excites the electrons due to hydrogen atom attraction as well.

1. Introduction

Crude vegetable oil as an alternative fuel (biodiesel) has been widely studied. However, the use of biodiesel is still doubted since it produces gas emission like CO that has an anthropogenic impact on global warming [1]. However, the conversion process of CVO into biodiesel by the *trans*-esterification method [2], degumming/esterification [3] and partial hydrogenation [4] requires additional equipment, energy, and expenses [5,6]; so that the conversion process of vegetable oil as an alternative fuel needs to be re-observed. Several researchers have re-examined the potential of CVO as an alternative fuel. Researchers [7,8] investigated the dynamic viscosity of six types of

* Corresponding author.
E-mail address: hynanlohy@gmail.com (H.Y. Nanlohy).

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vegetable oil and discovered that, at temperatures between 20 and 80 °C, the viscosity decreases as the saturation level of the alkyl chain of fatty acids is reduced. Researchers have also investigated the effect of fatty acid composition on the physical properties of CVO [9,10] and its burning characteristics in a compression ignition (CI) engine [11]. Their results showed that the lower heating value (LHV), cetane number (CNs), and kinematic viscosity of fatty acids increase proportionally to the carbon chain length and decrease when the saturation level of fatty acid alkyl chains is reduced.

Furthermore, the ignition delay time increases when the carbon to hydrogen ratio is increased, indicating the alkyl chain of fatty acids is the main cause of low-temperature reactivity.

The presence of double bonds in the alkyl chain of fatty acids and the addition of polyunsaturated fatty acids (stearic, oleic and linoleic) will reduce CNs by a significant amount [12,13]. Given the negative impact of double bonds on the ignition properties and fuel performance of oils, partial hydrogenation is performed using a liquid metal-based catalyst such as Rhodium [14–18], Platinum-Nickel [19], Palladium, Rhodium, Ruthenium [20], Ruthenium [21,22], Rhodium and Ruthenium [23,24], Rhodium and Iridium [25]. Nevertheless, comprehensive evaluation suggests that the structure of the fatty acid compound and its configuration, the length and position of the double bond have very little impact on the ignition properties of vegetable oil fuel [26]. However, based on our previous study [27], it is shown that, at a temperature of about 80 °C, the viscosity of crude vegetable oil reaches 9–10 cSt, and this value is very close to the needs of diesel engine applications. This phenomenon indicates that, by utilizing the operating temperature of the engine, the viscosity of crude vegetable oil decreases rapidly and has great potential for applications in the internal combustion engine. Moreover, crude vegetable oils have been successfully applied in the sensitive areas such as agricultural areas, forests and water transport areas [28–30], and agricultural machinery in Europe [31–34]. However, the combustion characteristics of crude vegetable oil have not been widely disclosed and still very complex, such as preheating, evaporation, ignition, and chemical reactions from combustion between fuel vapors and air. Crude vegetable oil compounds are composed of multicomponent elements, namely, saturated fatty acids, monounsaturated fatty acids, polyunsaturated fatty acids, and glycerol. The uniqueness of crude vegetable oil characteristics make it difficult to single out and to understand at the mechanistic level.

Therefore, some researchers examined the combustion characteristics of vegetable oils through the single droplet combustion [27,35–51] method. Unfortunately, these studies have not revealed the effect of fatty acid composition on crude vegetable oils combustion characteristics. The effect of fatty acid composition on the ignition behavior of nine crude vegetable oils was studied [52]. The results indicated that the ignition behavior is influenced by the fatty acid structure and the ignition delay increases with the increasing number of double bonds. However, these results did not reveal much about molecular dynamics and the influence of fatty acid composition, mass changes and the structure of the triglyceride chain geometry to the fuel properties and combustion characteristics of crude vegetable oils. Moreover, other research on the effect of the molecular structure of fuel on ignition delay and ignition behavior of crude vegetable oils is necessary so that it can be optimized for real engine applications [52]. Scientific information about the dynamics of the multicomponent molecular structure of the fuel and its effects on combustion characteristics is needed because this is an unsolved problem to date [53].

These results suggest that the combustion characteristics of crude vegetable oils still require intensive investigation, especially about molecular mass, molecular structure and molecular dynamics of the triglyceride chain. Edible and non-edible oils are composed of multicomponent compounds. The properties and effects of these compounds need to be studied, so that vegetable oils which contain these components may be understood. The focus of this study was to examine the effect of changes in the molecular composition of molecular fatty acids and the structure of triglyceride chain geometry, and their effects on the combustion characteristics of crude vegetable oils by the addition of liquid Rh^{3+} catalysts as homogeneous combustion catalysts. The selection of vegetable oils like CCO, CJO and CSFO as an alternative fuel to represent the saturated, monounsaturated, and polyunsaturated oils. The sustainability of edible oil like CCO and CSFO and its availability can be well maintained because the waste can be used as an alternative fuel. Furthermore, the liquid Rh^{3+} catalyst is characterized by its acceptance of 12 hydrogens, allowing it to generate an electronegative potential between itself and the carbon chains in triglycerides. This enables the polarization interaction that weakens the van der Waals dispersion forces in the triglyceride chains. These factors have the potential to alter the properties and combustion characteristics of crude vegetable oils.

2. Experiments

2.1. Material

The Rh^{3+} catalyst used in this research was from Umicore-Germany. The selected catalyst concentration in CVO was 10 ppm. The CVOs observed in this study were CCO, CJO, and CSFO. These three oils represented both saturated and unsaturated vegetable oils. CCO is a saturated oil, whereas CJO is a monounsaturated oil, and CSFO is a polyunsaturated oil.

2.2. Experimental procedures and conditions

The experimental apparatus is shown in Fig. 1. The measurement technique used in this study followed the procedure of our previous study given in [27]. One droplet of vegetable oil was suspended at the junction of a thermocouple made of Pt/Rh13% (diameter 0.1 mm). The droplet had a diameter of approximately 0.6–1.1 mm. The droplet was ignited using a Ni–Cr electric coil heater (diameter 0.7 mm, length 30 mm). The wire resistance was 1.02 Ω. The electric heater was powered by a 6-V DC power supply with an electric current of 5 A. The droplet was created using a micro syringe, and combustion was conducted at standard atmospheric pressure and room temperature. A high-speed charge-coupled device (CCD) camera (Sony Cyber-shot DSC-RX100 IV) was used to capture images of the droplet flame from the beginning of ignition until extinction at a recording speed of 120 fps, enabling the determination of ignition delay time and total burning time. Deformations in the CVO droplets were observed using a micro camera with a 100X magnification. The temperature of the CVO droplets during combustion was recorded by the thermocouple sensor, which was connected to a data logger with a sampling frequency of 1 kHz. Temperature data were recorded five times.

2.3. Fuels investigated

An observation was conducted on the three types of vegetable oil that represent saturated, monounsaturated, and polyunsaturated to observe the response of the molecular structure to Rh^{3+} catalyst. The response was observed through changes in fuel properties and fuel combustion characteristics. The effect of the catalyst on the fuel properties is presented in Table 1. The characteristic of Rh^{3+} catalyst as an acceptor of 12 hydrogen bonds (see Fig. 2) enables the hydrogen to be pulled out from the chain of triglycerides compound to catalyst so that the change of molecular mass of fatty acid takes place. The composition of fatty acid is determined using gas chromatography (GC) and the change of molecular mass of fatty acid is estimated using free chemistry software, which is molar mass, molecular weight, and elemental composition calculator. The result is provided in Table 2. Meanwhile, the effect of Rh^{3+} catalyst on the change of structural molecular geometry of triglycerides is simulated using another free chemistry software, Avogadro 1.1.1, and the result can be seen in Fig. 3.