

Effect of Algae-Derived Biodiesel on Ignition Delay, Combustion Process and Emission

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Abstract. Algae oil methyl esters produced from algae oil were blended with diesel at various volumetric percentages to evaluate the variations in the fuel properties. Microalgae biodiesel production has received much interest in an effort for sustainable development as the microalgae seem to be an attractive way to produce the biodiesel due to their ability to accumulate lipids and their very high actual photosynthetic yields. Correlations between fuel properties, including the calorific heat, density, kinematic viscosity, and oxidation stability of the Algae oil–diesel blends, and the blending ratio of the algae biodiesel have been established. As a result, low blending ratio of the Algae oil with diesel was recommended up to 2vol % in comparison with other type of biodiesel–diesel blends. The objective of this research is to investigate effect of biodiesel blending ratio on ignition delay, combustion process and emission for different type of biodiesel. The combustion tests of the Algae-Derived biodiesel blends were performed in a Rapid Compression Machine (RCM). The combustion tests were carried out at injection pressure of 130 MPa and ambient temperature were varied between 750 K and 1100 K. The result from the experiment is compared with Palm-Oil biodiesel which are varied in biodiesel percentage from 5vol% to 15vol% and jatropha biodiesel. Higher ignition delay period were clearly observed with higher blending ratio. It seems that increasing blending ratio exhibits relatively weakens in fuel ignitability and therefore prolongs the ignition delay of algae biodiesel. A2 had the lowest ignition delay period when compared with J2, B5, B10 and B15 due to lower density that present in A2 molecules. The concentration of carbon dioxide and nitrogen monoxide in the exhaust gas increased with higher blending ratio while the concentration of carbon monoxide and hydrocarbon decreased.

1. Introduction

Fossil fuel depletion and global warming issues have strongly motivated research in fuel production. Increasing industrialization and motorization has leads to greater use of fossil fuel products and the disadvantages of diesel engine are in the form of emission. They produce higher level of nitrogen oxides (NO_x), which is classified as a toxic emission by most environmental regulatory bodies throughout the world. The exhaust emissions largely depend on the combustion characteristics in the engine combustion chamber. Biodiesel is a form of diesel fuel manufactured from animal fats or vegetable oils by



employing process of transesterification and it containing mono-alkyl ester [1]. Microalgae biodiesel production has received much interest in an effort for sustainable development as the microalgae seem to be an attractive way to produce the biodiesel due to their ability to accumulate lipids and their very high actual photosynthetic yields [2-3]. Biodiesel produced from microalgae is both economically viable and environmentally sustainable compared to the other oil-producing terrestrial crops. The use of algae as energy crops has potential due to their easy adaptability to growth conditions and the high possibility of growing either in fresh or marine waters and avoiding the use of land [3]. Recently, the major issues the automotive industry facing are to control fuel consumption, increasing price of standard diesel fuel and pollutant emissions [4]. Ignition delay is defined as the period between the injection of fuel and the first sign of ignition [5-6]. The fuel that is injected into the cylinder in the compression stroke undergoes a series of process start from atomization, vaporization, mixing and self-ignition to ensure proper combustion process. The process in ignition delay divided into the following physical and chemical processes. Physical delay processes corresponds to the mixture formation that involved atomization, penetration, entrainment and vaporization. Meanwhile, the chemical delay to the time necessary to get an exponential increase in the chemical reaction rate that consist processes such as fuel decomposition and oxidation. Ignition delay in engine is influenced by several of factor such as combustion temperature, pressure, engine speed, and compression ratio [7-8]. A clear understanding of the processes involved in ignition delay is important to achieve improved engine performance with lower emissions.

An important technique for characterizing the combustion process is a combustion model which can be used to calculate different types of thermodynamic characteristics of the engine and heat release model is the single most important tool used to analyse the combustion characteristics of an engine since it will reflect the performance and emission characteristics such as exhaust oxygen concentration, engine load level or ignition delay [9-10]. Blending ratio of biodiesel denoted to the percentage of crude oil biodiesel that present in the fuel. Different type of blending ratio can be produced depend on the amount of crude oil that been added [11]. The percentage of crude biodiesel oil that present influenced the properties of the fuel such as viscosity, density, flash point, water content, and surface tension. These fuels properties have greater contribute on the combustion characteristics and performance of the engine.

The purpose of this paper is to study the effects the biodiesel blending ratio on combustion characteristics and emissions. In this research, the characteristics of combustion properties are investigated focusing on ignition delay and emission with varied biodiesel blending ratio. This experiment was performed in Rapid Compression Machine (RCM). The result from the experiment was compared with result from Palm-Oil biodiesel for validation purpose and to find the difference in behaviour between Algae biodiesel with Jatropha biodiesel and Palm-Oil biodiesel.

2. Experimental Setup and Procedure

Algae biodiesel (A2) and Jatropha biodiesel (J2) are blend with original diesel for 2vol% of biodiesel content using the blending machine. The Algae species that used in this experiment is *Botryococcus braunii* type of algae species. The blending process was done by stirring the mixture at 70°C for 2 hour while maintaining rotating blade speed at 270 RPM as shown in Figure 1. The experimental apparatus can be divided into several systems such as rapid compression machine, common rail system, gas analyse for analysis exhaust emission. Table 1 display the fuel properties for the fuel that used in this experiment. A0 and J0 represent the crude Algae and Jatropha oil while B5, B10 and B15 represent Palm-Oil biodiesel with blending ratio of 5vol% to 15vol%.

Table 2 summarized the experimental condition in this research. The combustion tests were performed using Rapid Compression Machine (RCM). In **Figure 2**, a schematic diagram of Rapid Compression machine is shown, together with fuel injection system. A free piston is placed inside the cylinder and partitioned by a diaphragm as a start of the experiment. Then, the driver chamber and the pressure reservoir are filled with nitrogen gas which pressures are held below and above the pressure of the diaphragm respectively. Once the valve is opened, the diaphragm bursts and the piston is rammed into a tapered stop ring installed in front of the combustion chamber. Fuel was injected after a fixed

interval from the time the piston stopped. The measured air temperature and pressure at the start of injection were used to identify the combustion behaviour at end of injection by the Pico Scope 3000 series. The gas analyzer was used to measure the concentrations of carbon dioxide (CO_2), carbon monoxide (CO), hydrocarbon (HC), nitrogen oxide (NO_x) in the exhaust stream.



Figure-1. Blending Machine

Table 1. Fuel Properties

Fuel Type	Properties	
	Density (g/m^3)	Kinematic Viscosity (Cp)
A0	0.860	4.4
A2	0.831	3.6
J0	0.878	4.3
J2	0.830	3.6
B5	0.837	3.0
B10	0.838	2.9
B15	0.840	3.0

Table 2. Experimental Conditions

Fuel	Injector type	6 holes, $\phi = 0.16 \text{ mm}$
	Fuel type	A2 and J2
	$P_{inj} [\text{MPa}]$	130
	$q_i [\text{ml}]$	0.04
Ambient	$T_i [^\circ\text{C}]$	80
	$r_s [\text{m/s}]$	19
	$\rho [\text{kg/m}^3]$	16.6
	$\text{O}_2 [\text{vol}\%]$	21

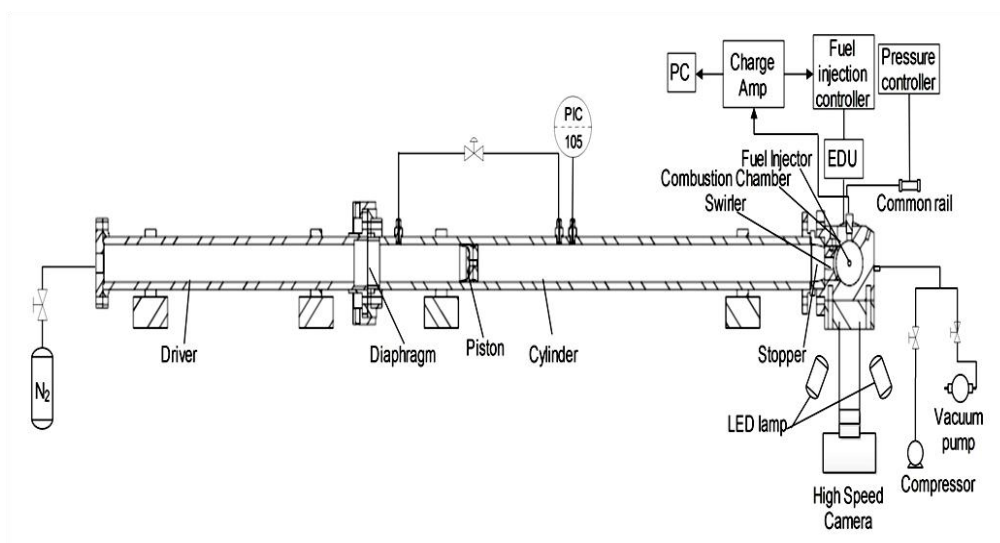


Figure 2. Schematic Diagram of RCM

3. Result and Discussion

The aim of this research is to investigate the effect of biodiesel blending ratio on ignition delay and emission for different type of biodiesel using Rapid Compression Machine (RCM). For validation purpose, a comparison between five types of blend biodiesel which are Palm-Oil Biodiesel (B5, B10 and B15), A2 and J2 was investigated in this experiment. Influence of blending ratio on ignition delay for Algae biodiesel (A2) was firstly investigated. The investigated initial charging pressure were $P_c = 0.1$ MPa, that corresponds to ambient densities of $\rho = 16.6$ kg/m³. The other parameters were kept constant as swirl velocity $r_s = 19$ m/s. Fuel was injected by a 6-hole injector with hole-diameter of 0.16 mm and injection pressure of $P_{inj} = 130$ MPa with initial ambient temperature $T_i = 80^\circ\text{C}$.

Figure 3 shows histories of combustion pressure against time and injection duration under injection pressure 130 MPa for B5, B10 and B15. From the figure, the ignition delay for B5 is the shortest when compared to the B10 and B15 which is 1.4 ms. The ignition delay increased markedly with a higher blending ratio of the Palm-Oil biodiesel to approach the ignition delay of 2.1 ms. From Figure 4.1, it noticed that the ignition delay decreased remarkably at higher volumetric percentage of the Palm-Oil biodiesel particularly in the range of B5-B15. The increase in ignition delay was attributed to the increase in fuel viscosity that results in poor atomization, slower mixing, and resulted in longer ignition delay. As theoretically, fuel viscosity are significantly influences the ignition delay of the corresponding fuel. B5 fuel have the lower viscosity when compared to B10 and B15, thus it has the lower ignition delay.

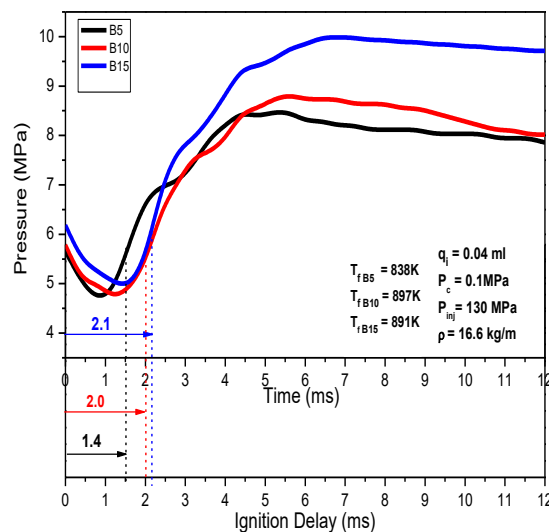


Figure 3. Variation of ignition delay of B5, B10 and B15 blends diesel

Figure 4 shows the variation of algae biodiesel (A2) on the ignition delay and this experiment is also investigated at 130 MPa with initial ambient temperature, $T_i = 80^\circ\text{C}$. From the figure, it shows that the ignition delay for A2 biodiesel is 1.0 ms and it is lower when compared to B5, B10 and B15. This was attributed to the blending ratio for A2 is lower compared to other fuel since it only consist of 2vol% of algae fuel and remaining 98vol% diesel. Low fuel viscosity and high ignitibility of A2 has also contributed to shorter ignition delay time.

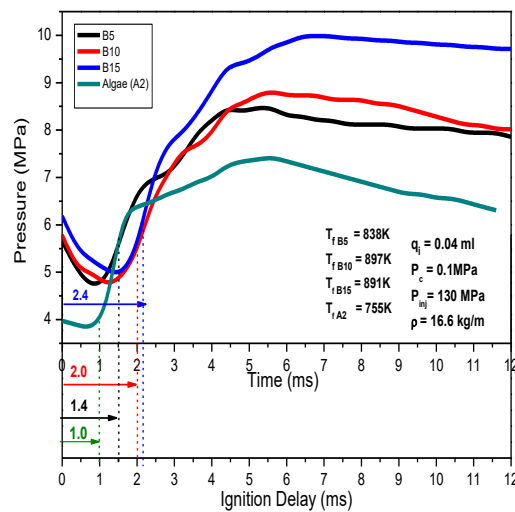


Figure 4. Comparison of A2 and Palm-Oil biodiesel (B5, B10 and B15) on ignition delay

The experiment is continued by the same injection parameter used on B5, B10, B15 and A2 biodiesel fuel but in different types of biodiesel blend, 2vol% of Jatropha biodiesel (J2). **Figure 5** illustrates the variation of Jatropha biodiesel (J2) that consists of 2vol% of Jatropha fuel. From the figure, it can be known that the ignition delay for J2 is 0.7 ms. The lower density of Jatropha oil is the factor that contributed to shorter ignition delay. The lowest density which caused J2 to be less compressible and came out of the injector nozzle earlier than other fuels, resulting in the earlier start of combustion of J2 versus A2, B5, B10 and B15.

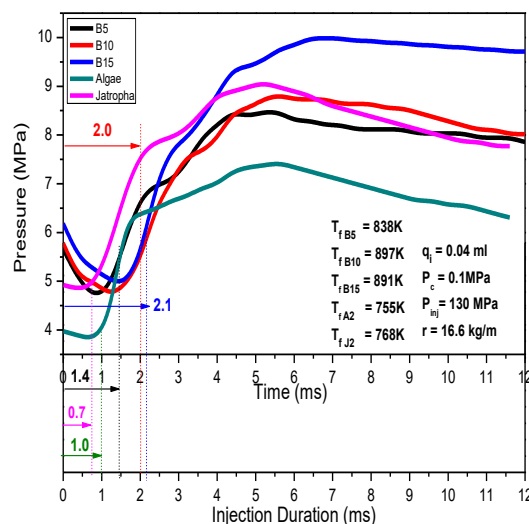


Figure-5: Comparison of J2 with A2 and Palm-Oil biodiesel (B5, B10 and B15) on ignition delay.

Next the effects of biodiesel blending ratio on the exhaust emission are discussed in the section. The effects of biodiesel blending ratio on exhaust emission is investigated for biodiesel fuel of B5, B10, B15, A2 and J2 for injection pressure of 130 MPa with initial ambient temperature, $T_i = 80^\circ\text{C}$. **Figure 6** shows the variations of HC, NO_x , CO_2 , and CO concentrations in the exhaust gas of different biodiesel blends. The CO concentration, which came from the incomplete combustion of the fuel, was generally reduced with higher blending ratio contributing to the increase in oxygen content. The high

oxygen content in biodiesel blends attributed to combustion become more complete as most of the carbon present is converted to carbon dioxide. For blending ratio of 2vol%, the emission of carbon monoxide higher for J2 compared with A2 is due to the oxygen content of algae molecules contain more oxygen. The emission of hydrocarbon and soot formation found to be decreased also as the blending ratio increases due to the presence of higher amount of organic condensates and volatile particles such as oxygen. The blending ratio of biodiesel exhibited linear contribution to the CO₂ and NO_x concentrations. The presences of high oxygen content significantly improve the combustion to be more complete and the emission of CO₂ is increases since most carbon turn to carbon dioxide rather than carbon monoxide. The biodiesel molecules contain higher oxygen content that diesel molecule hence complete combustion present in higher blending ratio biodiesel. The NO_x concentration significantly increased with higher blending ratio because NO_x was produced mainly from thermal formation and enhanced by the higher combustion temperature in the engine.

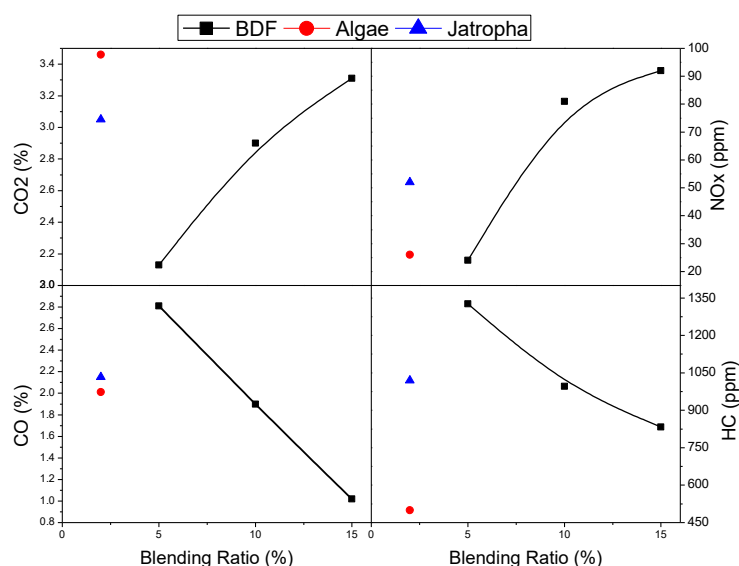


Figure 6. Effect of biodiesel blending ratio on the emissions

4. Conclusion

The distinct variations of the ignition delay, combustion process and emission with the volumetric percentage of the biodiesel blends were determined. The correlations between ignition delay and the concentrations of CO₂, NO_x, CO and HC in the exhaust gas associated blending ratio of the biodiesel have been successfully established. A satisfactory performance has been obtained from a study of effect of biodiesel blending ratio on ignition delay and emission for different type of biodiesel. From a series of tests carried out on rapid compression machine, the following conclusions are obtained:

- 1) Ignition delay of biodiesel increased with increasing blending ratio of biodiesel. The increasing blending ratio attributed in poor atomization and slower mixing which reduce fuel ignitibility that will result in longer ignition delay. A2 have the lowest ignition delay period when compared with J2, B5, B10 and B15 due to lower density that present in A2 molecules.
- 2) Lowest density of Jatropha oil is the factor that lead to shortest ignition delay which caused J2 to be less compressible and came out of the injector nozzle earlier than other fuels, resulting in the earlier start of combustion of J2 versus A2, B5, B10 and B15.
- 3) The present of high oxygen content in biodiesel blends as the biodiesel blending ratio increases has contribute to the more complete combustion as most of the carbon present is converted to carbon dioxide that reduce the emission of CO and HC.

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6. References

- [1] Meher LC, Sagar DV, Naik SN. 2006 Technical aspects of biodiesel production by transesterification – a review. *Renew Sustain Energy Rev*;10:248–pg 68.
- [2] G.Khola and B.Ghazala 2012 Biodiesel Production from Algae. Department of Botany, *Govt. College University*,. pg1-2.
- [3] Khalid, A., “Effect of Ambient Temperature and Oxygen Concentration on Ignition and Combustion Process of Diesel Spray”, *Asian Journal of Scientific Research*, Volume 6, Issue 3, 2013, Pages 434-444, Asian Network for Scientific Information, DOI: 10.3923/ajsr.2013.434-444
- [4] Liandong Zhu 2014. Sustainable Biodiesel Production from Microalgae Cultivated with Piggery Wastewater, *Acta Wasaensia* 292 *University of Vaasa*. pg 1-122
- [5] A. Khalid, N. Jaat, A. Sapit, A. Razali, B. Manshoor, I. Zaman and A.A. Abdullah, “Performance And Emissions Characteristics Of Crude Jatropha Oil Biodiesel Blends In A Diesel Engine”, *International Journal of Automotive and Mechanical Engineering (IJAME)* ISSN: 2229-8649 (Print); ISSN: 2180-1606 (Online); Volume 11, pp. 2447-2457, January-June 2015, DOI: <http://dx.doi.org/10.15282/ijame.11.2015.25.0206>.
- [6] Wilbur, A. A. 1974 Ignition Studies- The Determination of Auto Ignition Temperatures of Hydrocarbon Fuels. *Washington DC: Naval Research Laboratory*.
- [7] Lyn,W and Valdmanis 1968 The Effect of Physical Factors on Ignition Delay.
- [8] M. P. B. Musculus, T. Lachaux, L. M. Pickett, and C. a Idicheria, “Hydrocarbon Emissions in Low-Temperature- Combustion Diesel Engines,” vol. 2007, no. 724, pp. 776–790, 2007.
- [9] Khalid, A., Hayashi, K., Kidoguchi, Y., Yatsufusa, T., “Effect of air entrainment and oxygen concentration on endothermic and heat recovery process of diesel ignition”, *SAE Technical Papers*, 2011, Society of Automotive Engineers of Japan, Inc. and SAE International, DOI: 10.4271/2011-01-1834
- [10] Khalid, A., Yatsufusa, T., Miyamoto, T., Kawakami, J., Kidoguchi, Y., “Analysis of relation between mixture formation during ignition delay period and burning process in diesel combustion”, *SAE Technical Papers*, 2009, SAE International.
- [11] M. Mofijura, H.H. Masjuki, M.A Kalam, M.G Rasul, A.E Atabani, M.A Hazrat and H.M Mahmudul 2015 Effect of Biodiesel-Diesel Blending on Physico- Chemical Properties of Biodiesel produced from *Moringa Oleifera*. *Procedia Engineering* 105 page 665 – 669.