Analysis of the Effect of Injection Pressure on Ignition Delay and Combustion Process of Biodiesel from Palm Oil, Algae and Waste Cooking Oil

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Abstract. Biodiesel is a domestically produced, renewable fuel that can be manufactured from vegetable oils, animal fats, or recycled restaurant grease for use in diesel engines. The objective of this research is investigation the effects of the variant injection pressure on ignition delay and emission for different biodiesel using rapid compression machine. Rapid Compression Machine (RCM) is used to simulate a single compression stroke of an internal combustion engine as a real engine. Four types of biodiesel which are waste cooking oil, crude palm oil, algae and jatropha were tested at injection pressure of 80 MPa, 90 MPa and 130 MPa under constant ambient temperature at 950 K. Increased in injection pressure resulted shorter ignition delay proven by WCO5 which decreased from 1.3 ms at 80 MPa to 0.7 ms at 130 MPa. Meanwhile, emission for CO2 increased due to better fuel atomization for fuel-air mixture formation lead to completed combustion.

1. Introduction
There are some factors influences the performance and exhaust emission characteristics for diesel engine. The factors involve quantity injected, injection timing and injection pressure. Diesel engine with direct injection system has a high degree of atomization which undergoes evaporation at a very short time and improves combustion efficiency [1-3]. The spray formation analysis and propagation need to be considered during injection process inside the combustion chamber [4]. High pressure gasses and high temperature due to combustion of fuel take place in the constant volume chamber [5]. Ignition delay was analyzed from the pressure in the combustion chamber when air is compressed and combustion occurs. The pressure change is resulting from competition between endothermic process such as fuel evaporation, decomposition and heat loss to the chamber wall, and exothermic process. Ignition delay is the period between start of fuel injection and end of fuel injection which consists of physical delay process and chemical delay process [5-7]. A free-piston type rapid compression machine (RCM) was
used to simulate diesel combustion in a constant volume chamber over a wide range of ambient temperature and pressure conditions similar to actual diesel engines. This system is of a single cylinder, free moving piston and direct injection of fuel and air [8-10].

In this research, the ignition delay and emission are investigated with different injection pressure and constant ambient temperature. The blending machine used for fuel preparation. This experiment was performed in Rapid Compression Machine (RCM). The result from the experiment was compared with results from Palm-Oil biodiesel, Algae biodiesel, Jatropha biodiesel for validation purpose and to find the difference between Waste Cooking Oil biodiesel and different biodiesel.

2. Methodology
Biodiesel is blend with Euro 5 diesel using the blending machine. During blending process, the mixture was stirred at 70°C for 2 hour and the rotating blade speed was maintaining at 270 RPM. Blending ratios of biodiesel produced were varies at 2% until 40% for preparation of tested fuel. The experimental apparatus can be divided into four main systems such as rapid compression machine, data acquisition system, common rail injection system, emission gas analyser for analysis exhaust emission. Figure 1 illustrate the blending machine and Figure 2 illustrate the schematic diagram of blending machine.

Then, the Rapid Compression Machine was used to stimulate the combustion process as real as compression ignition engine. The injection pressure used was 80 MPa, 90 MPa and 130 MPa with constant ambient temperature of 950 K. Figure 3 illustrates the rapid compression machine while Figure 4 shows a schematic diagram of rapid compression machine 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 by the Pico Scope 3000 series.
Furthermore, Table 1 shows the fuel properties for different types of biodiesel and Table 2 shows the experimental condition for the experiment.

### Table 1: Fuel properties

| Fuel Type | Density (g/m³) | Kinematic Viscosity (Cp) |
|-----------|----------------|--------------------------|
| A2        | 0.860          | 4.4                      |
| J2        | 0.831          | 3.6                      |
| J5        | 0.831          | 3.6                      |
| J10       | 0.878          | 4.3                      |
| J15       | 0.838          | 3.6                      |
| B5        | 0.837          | 3.0                      |
| B10       | 0.838          | 2.9                      |
| B15       | 0.840          | 3.0                      |
| WCO5      | 0.889          | 3.0                      |
| WCO10     | 0.890          | 3.18                     |
| WCO15     | 0.892          | 3.2                      |

### Table 2: Experimental condition

| Fuel | Injector type | 6 holes, Ø = 0.16 mm |
|------|---------------|----------------------|
|      | Fuel type     | Wco, Cpo, Algae and Jatropha |
|      | $P_m$ [MPa]   | 80, 90 and 130       |
|      | $q_i$ [ml]    | 0.04                 |
|      | $T_i$ [K]     | 950K                 |
|      | $r_s$ [m/s]   | 19                   |
|      | $\rho$ [kg/m³] | 16.6                |
|      | $O_2$ [vol%]  | 21                   |

### Results and discussion

The effect of variant injection pressure on ignition delay is investigated for Waste Cooking Oil biodiesel. The injection pressures used were 80 MPa, 90 MPa and 130 MPa with constant ambient temperature of 950 K. Figure 5 illustrate the variant injection pressure on ignition delay for waste cooking oil biodiesel (WCO5, WCO10 and WCO15). The ignition delay decreased constantly when increased the injection pressure. For WCO5, the ignition delay at injection pressure of 80 MPa was 1.3 ms and decreased to 1.1 ms at 90 MPa and to 0.7 ms at 130 MPa. Then, the ignition delay were 1.1 ms and 1.5 ms for WCO10 and WCO15 respectively at 80 MPa and this ignition delay continued decreased to 0.8 ms and 0.9 ms at 130 MPa. This situation due to increase in injection pressure effect the increasing of temperature in combustion chamber that helps to improve the air-fuel mixture formation contributes to better premixed combustion which reduced the ignition delay.

Figure 6 illustrate the variation of injection pressure on ignition delay of Waste Cooking Oil biodiesel (WCO5, WCO10 and WCO15) and Palm-Oil Biodiesel (B5, B10 and B15). Injection duration for B5 at 80 MPa was 3.0 ms and decreased to 2.0 ms at 90 MPa and to 1.4 ms at 130 MPa. The similar trend
goes to B10 and B15 fuels. The ignition delay was 2.5 ms and 2.6 ms for B10 and B15 respectively at 80 MPa and continued decreased to 2.0 ms and 2.1 ms at 130 MPa. The higher temperature in combustion chamber assists in improvement for better air-fuel mixture formation effect better premixed combustion.

Furthermore, the heat release combustion for Jatropha with 5% to 15% blending ratio is shown in Figure 7. The ignition delay for J5 was 2.4 ms at 80 MPa of injection pressure and then decreased to 2.3 ms at 130 MPa. The same trend goes to J10 and J15 fuels. The ignition delay was 2.3 ms and 2.9 ms for J10 and J15 respectively at 80 MPa and continued decreased to 2.2 ms and 2.8 ms at 130 MPa. The higher temperature in combustion chamber helps in improvement for better air-fuel mixture formation effect better premixed combustion.

Comparison of ignition delay for different biodiesel is shown in Figure 8. The ignition delay for Algae biodiesel (A2) decreased when the injection pressure increase. Algae biodiesel has the lower viscosity compared to Palm-Oil Biodiesel (B5, B10 and B15) which help to reduce the ignition delay of the fuel. The ignition delay for Algae Biodiesel (A2) was 1.3 ms at 80 MPa of injection pressure and then decreased to 1.2 ms at 90 MPa and further decreased to 1.0 ms at 130 MPa. In addition, The Jatropha Biodiesel (A2) had compared to previous biodiesel. The ignition delay of J2 decreased with increasing the injection pressure. The ignition delay for J2 at 80 MPa was 0.9 ms and decreased to 0.8 ms at 90 MPa and further reduced to 0.7 ms at 130 MPa. Both J2 and A2 had same blending ratio but the ignition delay for J2 was shorter compared to A2. This was due to Jatropha has higher ignitability when compared with Algae. Then, at injection pressure of 80 MPa the ignition delay for J5 is 1.4ms, J10 is 1.3ms and J15 has ignition delay of 0.9 ms. For injection pressure of 90 MPa, it is observed when the pressure is increased, the ignition delay decreases to 0.9 ms for J5, 1.2 ms for J10 and 1.0ms for J15. The pressure are increased to 130 MPa and its can be seen that ignition delay continued decreased to 0.7 ms and 0.9 ms for J20 and J30 respectively while the delay period for J15 remain unchanged. The ignition delay
period of the tested fuel decreases with increasing cylinder pressure and fuel injection pressure. The reduction of ignition delay of Jatropha biodiesel mainly because of cetane number.

Figure 7: Comparison of ignition delay for Jatropha biodiesel

Then, the effects of injection pressure on emission were discussed. The measured emissions were carbon monoxide (CO), nitrogen oxides (NOₓ), carbon dioxide (CO₂) and hydrocarbon (HC). The experiment condition varies at constant ambient temperature of 950 K. Figure 9 illustrates the graph percentage of emission versus injection pressure. Three injection pressures were 80 MPa, 90 MPa and 130 MPa. The emission of carbon monoxide (CO) and hydrocarbon (HC) decreased when increasing the injection pressure for all tested fuels. This was due to better air-fuel mixture formation which leads to complete combustion. In addition, the emission of carbon dioxide (CO₂) and nitrogen oxides (NOₓ) seems to increase when increasing the injection pressure. This was due to high temperature in combustion chamber that helps to improve combustion process which produces higher percentage of carbon dioxide emission.

Figure 8: Comparison of ignition delay for different biodiesel.
4. Conclusion
Increased in injection pressure attribute to shorter ignition delay. This due to high injection pressure varies with high temperature in combustion chamber which influence better air-fuel mixture formation for better premixed combustion. The formation of CO$_2$ increased due to complete combustion in combustion chamber.

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