Modeling of Common Rail System and Constant Volume Chamber in Biodiesel Combustion: A Review
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ABSTRACT. Among the challenges faced by diesel engines combustion nowadays are to reduce emission especially Nitrogen Oxide (NO\textsubscript{x}) and Particular Matter (PM) while enhancing fuel efficiency and power. The purpose of this review is to explore the mixture formation of biodiesel combustion using constant volume chamber and optical visualization. This paper will review the development of a single-shot combustion system and constant volume chamber. An overview of the relation of mixture formation and combustion process in diesel combustion is provided first. This review has shown that the application of Rapid compression Machine (RCM) is used to simulate actual condition especially the injection pressure and air motion. The review also found that the mixing between fuel and air is unavoidable and very important during ignition delay period thus predominantly influences the exhaust emission. The detailed behaviour of injection characteristic that strongly effects the mixture formation especially the spray evaporation and spray interference are discussed.

INTRODUCTION
Direct injection diesel engine is not attractive and economical fuel only but low CO2 emissions also. Nevertheless, the light duty passenger cars and heavy duty vehicles are still needed and applicable of diesel engines. In addition, the agricultural and industrial sectors are also used diesel engines widely [1-7]. Therefore, the challenge for the diesel engine today is to reduce raw emission such as Nitrogen Oxide (NO\textsubscript{x}), Particular Matter (PM). To meet this challenge, the mixture formation is indispensable to improve exhaust emission from diesel engine must be control especially fuel-air mixing at early of ignition process. Various phenomena that involved in the diesel combustion, the physical factor plays a significant role in the ignition of diesel sprays and linked to the improvement of exhaust emission by fuel-air premixing. Furthermore some technique to reduce particulate emission was carried out, one of most promising is high pressure injection that able to the production engine gives remarkable improvement of particulate emission [8-10]. To do interesting in diesel engine application, common studied about injection, mixing and combustion diesel engine [11]. In this review, authors have started review to investigate the relation between injection pressure, injection timing and mixture formation. For this review, the focusing improvement mixture formation in delay ignition such as, ambient gas pressure, fuel system, pressure and temperature of air. The methodology of this review is using Rapid Compression Machine (RCM) with single-shot of common rail system.

Rapid Compression Machine (RCM) Rapid Compression Machine (RCM) is used to simulate the diesel combustion in a combustion chamber over a wide range of ambient pressure and ambient temperature by varying the compression ratio. The high pressure and temperature can be yield through the Rapid Compression Machine by method of a very light piston being shot by compressed air and rammed into a tapered stop ring[12]. At the end of the compression, the temperature and pressure can be differentiated by changing the starting position of the piston[13]. The decision made is to use a very light piston to obtain sufficient
compression speed and strong impulse acting on the stopping device. On one side contains the base surface of the chamber, this chamber is composed of pyrex glass to enable observation of the spray and flame development[14]. When the piston motion induces air inside the chamber, a swirl connecting port was used to produce a swirl flow inside the chamber. The port inclination angle can control the swirl velocity where velocity at 2/3-location from chamber centre is defined as swirl velocity[15, 16]. However, to obtain a quiescence gas flow of the duration fuel, the injection must be straight port. For the fuel injection system, an electronically controlled single-shot common rail injection system is employed to inject the fuel (biodiesel) into a combustion chamber. The time and amount of injected fuel is controlled by a fuel injection controller[17] as shown in Figure 1.

![Figure 1: Schematic of RCM and Injection System][14] ![Figure 2: Model of Injector][18]

A single-shot common rail fuel injection system is used to inject the fuel into a combustion chamber. The common rail system can reduce exhaust emission such as Nitrogen Oxide (NOx) and Particular Matter (PM) simultaneously generating more engine power[17, 19]. Figure 2 show the model of piezo injector, a comparison between second generation Common Rail System (CRS)-Piezo and solenoid fuel injectors that run reliably up to 180 MPa while injecting precisely-measured fuel delivers up to 5 times per combustion cycle. The injection pressure of 180 MPa introduces injection duration and a more fine spray atomization. The atomization can be improved through a combustion chamber which contributes to emission reduction by shortening the nozzle orifice diameter. Various particulate filters have been developed to reduce PM emission. The high injection pressure, clean burning, less soot loading occurs and thus smaller and less expensive particulate filters are the benefits of the reduction in PM emission[20, 21].

![Figure 3: Effect of injection timing][21]  
![Figure 4: Definition of the Ignition Delay][24]
Generally, high pressure injection results in smaller spray droplets and shorter injection periods. The well atomized spray shortens the ignition delay, activates combustion and reduces fuel consumption, smoke, Hydrocarbon (HC) and PM. However, activated combustion increases NOx and combustion noise. It was commonly believed that the purpose of high injection pressure was the reduction of PM and the injection timing was retarded so as to reduce NOx[22]. Figure 3 shows the combustion period decreased with retarded injection timing. The decreasing temperature due to the decrease of combustion period freezes the NO chemistry. As injection timing was retarded, the heat release rate curve showed that most of energy was released by pre-mixed combustion and only a small portion of the energy was released by diffusion controlled combustion. It is believed that the in-cylinder temperature is increased at retarded injection timing, but the increase in NOx is not observed due to the decrease of combustion period during the expansion process[23].

The first test carried out using the RCM is to elucidate the ignition process of a fuel spray. However, a rapid pressure through the compression ignition process increases due to an explosive burning of a combustible mixture which was accumulated during the ignition delay period. From figure 4, piston pressure and the definition ignition delay times t1 and t2. For t1 is the period of time from the start of injection to when the piston pressure for aacting spray separates from that of an identical spray injected into an inert nitrogen atmosphere[25]. The period time from t1 to continuous pressure curve cross the dated straight line is time t2 that represents the heat loss from the combustion chamber. The combination from t1 + t2 is defined as the ignition delay time that is used to characterize diesel fuel [24]. Fuel is injected into a high temperature and high pressure air condition, when the pressure rises the ignition starts to reduce and cracking and gasification is observed through heat loss from surrounding air[13].From figure 5 shows the pressure recorded during ignition delay reproduced at a temperature of 780 K and air pressure at 4 MPa. From Figure 5 shows the lower trace the pressure change of the fired cycle, Pf the pressure change of the non-injection, Pa and the pressure change because a fuel is injected into nitrogen gas, Pn. the endothermic process like composition, evaporation and heat loss varying rapid rise cause the curve Pf drop. While middle trace shown at different magnification have a difference pressure of Pf - Pn. The time is detected ignition delay when the period from the beginning injection is measured. Top trace show Pf - Pa that means difference pressure does not affect wall cooling.

![Figure 5: Pressure for initial stage][13]

**Factor Effecting Ignition Delay in Diesel Combustion**

The factor effecting ignition delay is air pressure, the physical process such as fuel atomization and spray penetration. It directly influences ignition delay. When the temperature is higher, pressure almost gives no effect on t1 while it has a great influence on t2 because of larger droplets and lower fuel-air mixing rate as the pressure decreases by fact of fuel atomization is poor. Air temperature also governs ignition delay. The temperature of the non-injection cycle
The cylinder pressure is traced during the ignition delay, at ambient temperature and ambient pressure reacting of 4.2, 8.0 and 12.0 MPa. When the ambient temperature, $T_a$ and ambient pressure, $P_a$ increase the injection is started and the timing is rise with cylinder pressure increase steeply a short. The reason for such behaviour is still unknown; when rapid pressure increases and becomes slower at temperature higher than 1000 K at higher $P_a$. The Figure 7 shows that the relation between ignition delay, $t_1$ and ambient temperature, $T_a$ and ambient pressure, $P_a$ of 4.2, 8.0 and 12.0 MPa[13]. The gradient of the Arrhenius curve at around 700 K changes $T_a$ and $P_a$ is increasing when the $t_1$ is shorted. From the review, the total time $t_1 + t_2$ are longer than $t_1$ and is more pronounced in $t_1 + t_2$ is approximately.

**Fuel Injection Pressure and Nozzle Characteristics Power**

The lower injection of 30 MPa and a $P_a$ of 4.2 MPa data from Arrehenius have been plotted as show in Figure 8. The injection of 14 MPa and a $P_a$ of 3.8 MPa are also plotted by Ikegami and Miwa [28]from their experiment data. The different injection pressure of 14, 30 and 100 MPa was obtained from the data. It is very clear that varying increased injection pressure can shorten the ignition delay. The high injection pressure is because of the better mixing achievable[27]. The different types of injectors with different geometries, produces different amount of losses in fuel flow rate based on these different injectors[29, 30]. Different types of injectors have different pattern nozzle, the nozzle concept is that after the closing of the nozzle in high pressure part of the combustion process, the fuel is stored in the injector holes. The temperature starts to increase the injector body because of the fuel expansion during the expansion stroke. Hence a liquid film is formed outside the holes at the nozzle tip. Furthermore, the fuel expanding out of the nozzle holes is adsorbed in the sooty deposit and reacts to increase deposit formation rate[31, 32].

**CONCLUSION**

The review of this paper is to study and investigate the basic characteristics of combustion that strongly give effect on mixing composition and affect the ignition delay. The common rail system combines between single-shot common rail injection system and RCM. Based on the review that was studied, the following conclusion can be made:
1. The pressure is dependent on the delay is lost at high pressure. High temperature is influenced the temperature that depend on ignition delay.

2. To reduce the Nitrogen Oxide (NO\textsubscript{x}) and Particulate Matter the injection timing should be retarded. The mixture formation during delay period large amount of combustible mixture is formed because of high injection pressure.

REFERENCES


