Modeling of Common Rail System and Constant Volume Chamber in Biodiesel Combustion: A Review

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Abstracts. Among the challenges faced by diesel engines combustion nowadays are to reduce emission especially Nitrogen Oxide (NO_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 reviewed the development of a single-shot combustion system and constant volume chamber. 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 behavior of injection characteristic that strongly effects the mixture formation especially the spray evaporation and spray interference was discussed.

Introduction

The challenge for the diesel engine today is to reduce raw emission such as Nitrogen Oxide (NO_x) and 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 [1-5]. 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 [6-8]. 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) 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 RCM by method of a very light piston being shot by compressed air and rammed into a tapered stop ring [9]. At the end of the compression, the temperature and pressure can be differentiated by changing the starting position of the piston [10]. 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 [11]. 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 [12]. 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 [13] as shown in Figure 1.
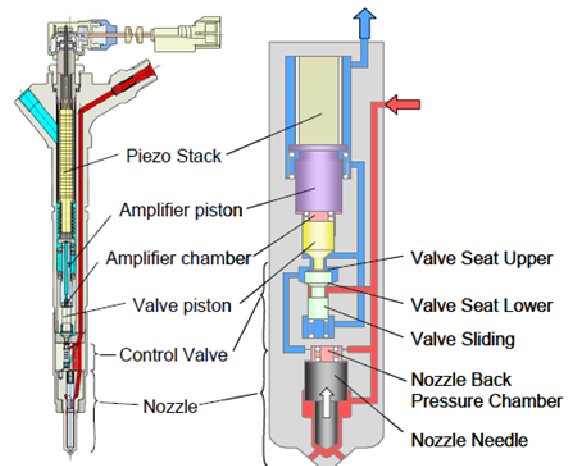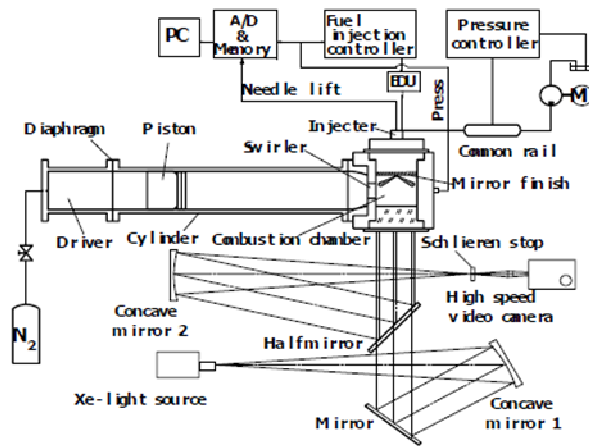
Figure 1: Schematic of RCM and Injection System [11]   Figure 2: Model of Injector [15]

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 NO_x and PM simultaneously generating more engine power [14]. 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 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 [16,17].

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. 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 NO_x [18]. 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 NO_x is not observed due to the decrease of combustion period during the expansion process [19].
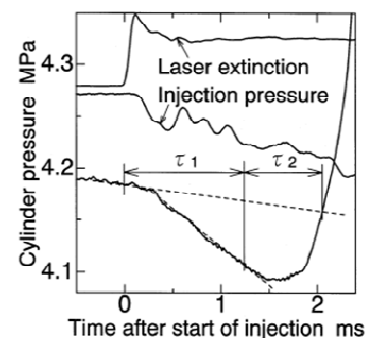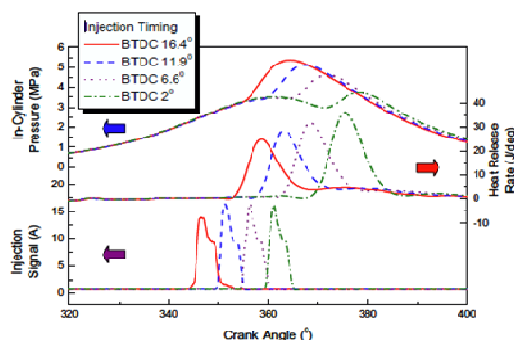

Figure 3: Effect of Injection Timing [17]   Figure 4: Definition of the Ignition Delay [20]

Figure 4 shows the definition of ignition delay during the test in the RCM. Piston pressure and the definition ignition delay times τ_1 and τ_2. For τ_1 is the period of time from the start of injection to when the piston pressure for a acting spray separates from that of an identical spray injected into an inert nitrogen atmosphere [20]. The period time from τ_1 to continuous pressure

curve cross the dated straight line is time τ_2 that represents the heat loss from the combustion chamber. The combination from $\tau_1 + \tau_2$ is defined as the ignition delay time that is used to characterize diesel fuel [21].

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 τ_1 while it has a great influence on τ_2 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. Figure 5 shows measured pressure differences P_f - P_a and P_f - P_n versus time for temperature T_i in which t is the time elapsed from starting injection. The early circular on reach curve of P_f - P_n is net heat release and then the second is the pressure recovering time. The temperature of the non-injection cycle P_a, the nitrogen cycle P_n and the fired cycle pressure P_f were first studied with many initial temperature at an initial pressure of $P_i = 3.8$ MPa.

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 as shown in Figure 6. 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 behavior is still unknown; when rapid pressure increases and becomes slower at temperature higher than 1000 K at higher P_a. The gradient of the Arrehenius curve at around 700 K changes T_a and P_a is increasing when the τ_1 is shorted. From the review, the total time $\tau_1 + \tau_2$ are longer than τ_1 and is more pronounced in $\tau_1 + \tau_2$ is approximately.
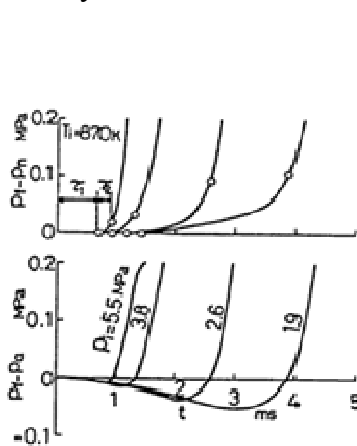

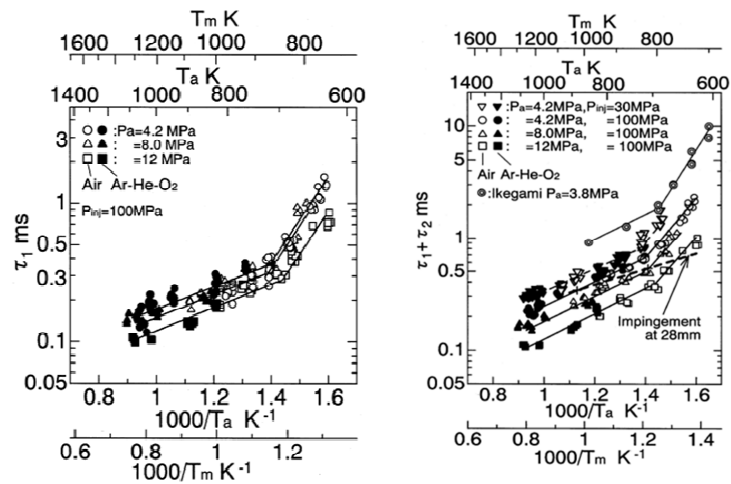Figure 5: p_f - p_a and p_f - p_n versus time [10]

Figure 7: Effect of Ambient Pressure on Ignition Delay τ_1 and $\tau_1 + \tau_2$ [22]

The lower injection of 30 MPa and a P_a of 4.2 MPa data from Arrehenius have been plotted as show in Figure 7. The injection of 14 MPa and a P_a of 3.8 MPa are also plotted by Ikegami and Miwa [23] 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 [24]. The different types of injectors with different geometries, produces different amount of losses in fuel flow rate based on these different injectors [25,26]. 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 [27,28].

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. 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_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

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