Analysis of Diesel Combustion using a Rapid Compression Machine and Optical Visualization Technique

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1. Introduction

In diesel engines, combustion progresses by nature heterogeneous. Diesel spray spontaneous ignites within short period after fuel injection. During this period, mixture formation plays as a key element on burning process that strongly affects the exhaust emissions such as nitrogen oxide(NOx) and Particulate Matter(PM). The reductions of emissions can be achieved with improvement throughout the mixing of fuel and air phenomena\cite{1}. High ambient density resulting from the increasing of boost pressure is anticipated to influence the mixture formation during ignition delay period and burning process. The diesel combustion was simulated with the Rapid Compression Machine(RCM), the mixture formation and combustion images were captured by the high speed camera. Analysis of combustion characteristics and observations of optical visualization of images reveal that the mixture formation exhibit influences to the ignition process and flame development.

2. Experiment set up

Fig.1(a) shows the schematic diagram of a free-piston type rapid compression machine which used to simulate actual phenomenon inside the combustion chamber and the basics specifications are listed in Table 1. The charging pressure $p_c$ were changed to $p_c=100\text{KPa}$, $150\text{KPa}$ and $200\text{KPa}$ with keeping ambient temperature of $T_i=850\text{K}$. At every condition, ambient density $\rho$ was $\rho=16.6\text{kg/m}^3$, $25.0\text{kg/m}^3$, $33.3\text{kg/m}^3$, respectively. Schlieren photograph indicated the detail of mixture formation was resulting from noncombustion diesel sprays which avoided by using nitrogen ambient and the direct photography technique is used to capture the flame development images, as shown in Fig.1(b).

![Fig.1 (a) Schematic diagram of experimental set up, (b) Mixture formation and flame images](image)

![Table 1 Experimental conditions](table)
3. Effects of ambient density

Fig. 2(a) compares tendencies of flame development images well correspond to the distribution of combustible mixture observed in schlieren images. In particular, at $p_c=100$ kPa ($\rho=16.6$ kg/m$^3$) and 150 kPa ($\rho=25.0$ kg/m$^3$), fuel spreads out between each spray and large amount combustible mixture is formed at the time of ignition. At $p_c=100$ kPa and 150 kPa, flame is observed near the spray centerline because of fuel is continuously injected into the spray centerline even after ignition, creates high temperature and rich atmosphere region. However, $p_c=150$ kPa is producing larger area of flame compares to $p_c=100$ kPa due to less formed of combustible mixture. In contrast, at $p_c=200$ kPa ($\rho=33.3$ kg/m$^3$) that is high ambient density, weakens and bended the spray penetration due to the swirl motion, fuel is mainly distributed at the center of the combustion chamber and little fuel is distributed near the chamber wall. Moreover, flame images shows the highest luminosity flame develops within center region of the chamber and possible to create locally rich combustion around chamber center. In this chamber, the condition of $p_c=100$ kPa seems to produce better distribution of the mixture than the cases of $p_c=150$ and 200 kPa.

Fig. 2(b) shows heat release rate $dQ/dt$ together with nozzle needle lift NL against time. According to the figure, increasing ambient density produces high heat capacity at spray boundary reflects shortens ignition delay and earlier rise of heat release rate. However, at high ambient density, increasing rate of initial heat release is gentle and combustion duration becomes long as compared with lower ambient density condition. In addition, heat release pattern related with the changes of flame pattern, are compared within the same of time at all conditions. As result, the mixture formation process may affect heat release history and flame pattern as well.

4. Summary

Increasing ambient density shortens ignition delay. High heat capacity at spray boundary resulting from high density mitigates temperature drop of ambient gas, and promotes formation of combustible mixture. However, this condition tends to produce high intensity bright flame due to locally rich combustion and lengthen combustion duration. It is important to improve mixture formation so as to fully consume oxygen under high ambient density condition.

5. Reference