

Effect of High Swirl Velocity on Mixture Formation and Combustion Process of Diesel Spray

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Abstract. Diesel engines generate undesirable exhaust emissions during combustion process and identified as major source pollution in the worldwide ecosystem. To reduce emissions, the improvements throughout the premixing of fuel and air have been considered especially at early stage of ignition process. Purpose of this study is to clarify the effects of swirl velocity on flow fuel-air premixing mechanism and burning process in diesel combustion that strongly affects the exhaust emissions. The effects of physical factors on mixture formation and combustion process to improve exhaust emissions are discussed in detail. This study investigated diesel combustion fundamentally using a rapid compression machine (RCM) together with the schlieren photography and direct photography methods. RCM was used to simulate actual phenomenon inside the combustion chamber with changing design parameter such as swirl velocity, injection strategies and variable nozzle concept. The detail behavior of mixture formation during ignition delay period was investigated using the schlieren photography system with a high speed digital video camera. This method can capture spray evaporation, spray interference and mixture formation clearly with real images. Ignition process and flame development were investigated by direct photography method using a light sensitive high-speed color digital video camera. Moreover, the mechanism and behavior of mixture formation were analyzed by newly developed image analysis technique. Under high swirl condition, the ignition delay is extended, the higher heat losses and unutilized high-density oxygen associated with slower initial heat recovery begins might be the explanation for the longer combustion duration, reductions of pick heat release and promote combustion and soot oxidation. The real images of mixture formation and flame development reveal that the spray tip penetration is bended by the high swirl motion, fuel is mainly distributed at the center of combustion chamber, resulting that flame is only formed at the center region of the combustion chamber. It is necessary for high swirl condition to improve fuel-air premixing.

Introduction

In diesel engines, combustion process and exhaust emissions are more clearly observed by examining the characteristics of the evaporation of fuel spray and initial heat recovery process during the ignition delay period. The improvement of exhaust emission is dominated by the mixture formation behavior especially fuel-air mixing at early of ignition process. Among the various phenomenon involved in diesel combustion, the fuel-air premixing by the physical factor plays a significant role in the ignition of diesel sprays and linked to the improvement of exhaust emissions [1-5]. In this stage, the physical process prior to ignition is controlled by design parameter and chemical process of fuel decomposition and oxidation. The oxidation reactions at the end of endothermic period depends on the physical process such as breakup of the jet spray and droplets evaporation [6]. The potential of design parameters, injection spray behavior and air movement have proven its ability to achieve the sufficient rapid mixing between the injected fuel and the air [7-8]. Furthermore, Ikegami [9] has proposed that the oxidations reactions during first stage of mixture formation is depends on the physical process such air entrainment rate and responsible to facilitate the breakup of the jet spray and improving evaporation. The interaction between spray and air motion process are analyzed with the variants air motion, ambient condition and injection

pressure. However, it is important to know which regions of the spray contain the fuel injected at the beginning of the injection process and the influences these parameter on flame development and combustion process. The aim of these investigations is to provide a better comprehension of the effect of swirl velocity on air motion mechanism, the interaction between air and fuel, and fuel-air premixing including the fuel atomization and fuel spray propagation prior to ignition. In this research, the characteristics of design parameters and physical factors on mixture formation and diesel combustion are discussed for various parametric studies. Physical phenomena, heat release rate, and the exhaust emission have been examined under various swirl velocity together with the schlieren photograph and direct photograph. Combustion process and exhaust emissions are more clearly observed by examining the characteristics of the evaporation of fuel spray and initial heat recovery process during the ignition delay period. Furthermore, tries to make clear the influence of the operating parameters on the early stage of mixture formation and fuel-air mixing, then it progress on ignition, heat recovery process and combustion characteristic.

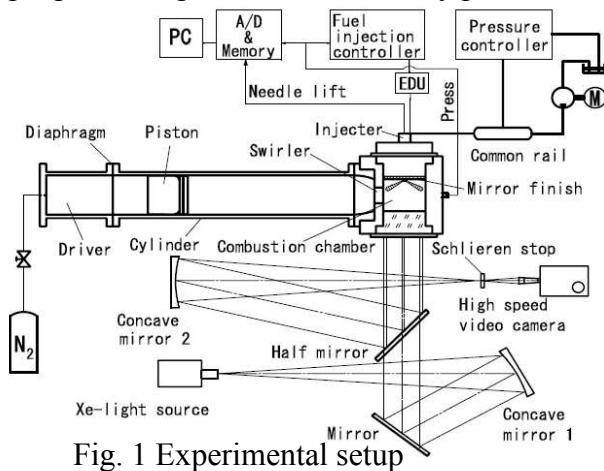


Fig. 1 Experimental setup

Table 1 Experimental conditions as swirl velocity was varied

Fuel	Injector type	6holes, $d = 0.129\text{mm}$		
	q_i	0.05ml		
	P_{inj}	100MPa		
	ϕ	0.37		
Ambient gas	T_i K	850		
	r_s m/s	10	19	30
	ρ kg/m ³	16.6		
	O ₂ vol%	21		

Italic bold : baseline

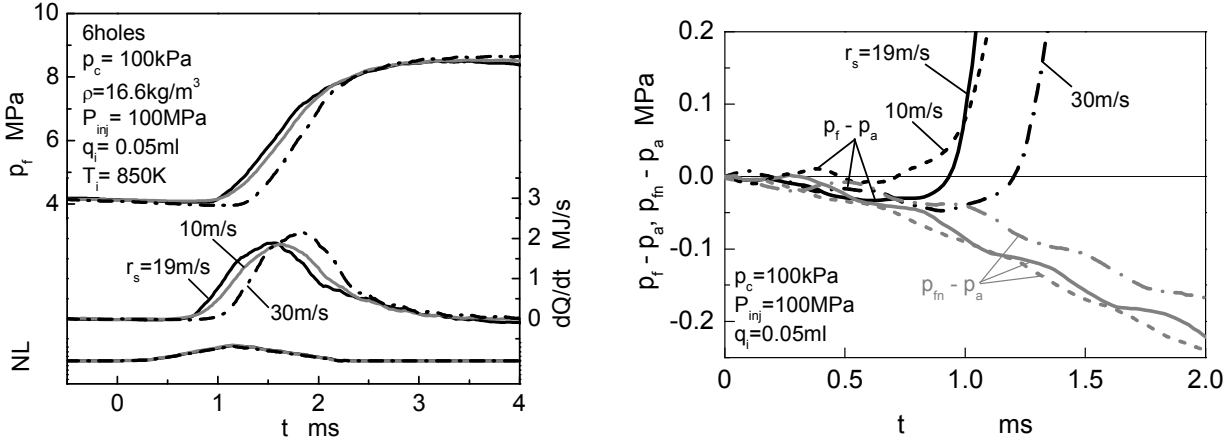
Experimental Setup

Measurements were made in an optically-accessible rapid compression machine (RCM) with intended for diesel engines application, as shown in Figure 1. The RCM is equipped with the Denso single-shot common-rail fuel injection system, capable of a maximum injection pressure up to 160MPa. A constant volume chamber with displacement of 1701.4cm³, RCM was used to simulate the actual diesel combustion related phenomena. The RCM has a portable swirler at intake ports which allow the amount of swirl to be varied at 10-60m/s by changing the port inclination angle controlled swirl velocity. Table 1 summarizes the operating parameters and fuel injection system, including nozzle specification as swirl velocity r_s was varied. The influence of r_s on combustion development was investigated at the base injection pressure $P_{inj}=100\text{MPa}$ for r_s of 10m/s, 19m/s and 30m/s. A common rail fuel injection system and a six-hole injector with hole-diameter of $d_n=0.129\text{mm}$ were used to inject JIS#2 diesel fuel (a density of 836kg/m³ and lower heating value of 42.7MJ/kg) into the spray chamber. At every condition, the investigated initial charging pressure were kept at $p_c=100\text{kPa}$ that corresponds to ambient densities of $\rho=16.6\text{kg/m}^3$ and ambient pressure $p_i=4\text{MPa}$ that corresponds to the equivalence ratio ϕ was $\phi=0.37$. The ambient temperature was held fixed at $T_i=850\text{K}$ and keeping the oxygen concentration of O₂vol%=21.

Experimental Results

Effect of Swirl Velocity on Mixture Formation and Ignition The effects of air motion causes by swirl velocity r_s in the combustion are discussed in this section. Figure 2 clearly shows histories of combustion pressure p_f and heat release rate dQ/dt together with nozzle needle lift NL against time, t from start of injection. As seen in Fig.2(a), increasing swirl velocity, decreased ambient temperature due to higher heat losses in chamber results in long initial heat release, slower heat recovery process and shorten combustion duration. Figure 2(b) shows that the high swirl velocity

extended ignition delay period and results in longer physical process. Particularly, higher swirl velocity associated with the higher heat losses and achieves low in-cylinder temperatures, which slow the chemical reaction rates. Thus, the longer fuel-air premixing time linked with lengthen physical process provide better combustible mixture preparation. This kind of mixture formation during ignition delay under high swirl $r_s=30\text{m/s}$ exhibits the heat release rate progressively increased reaches high peak and lengthen combustion duration. It seems that the rate of heat release is expected to be strongly influenced by fuel-air mixing process.



(a) Combustion process (b) Histories of pressure during ignition delay period
 Fig. 2 Effects of swirl on pressure history in combustion chamber during ignition delay

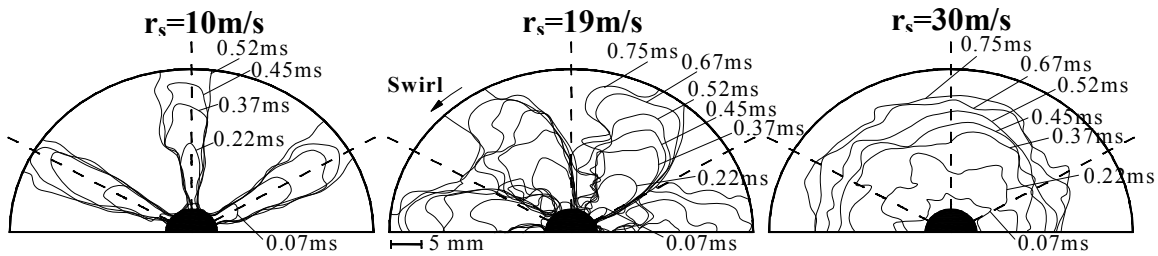


Fig. 3 Spray boundary at different swirl velocity

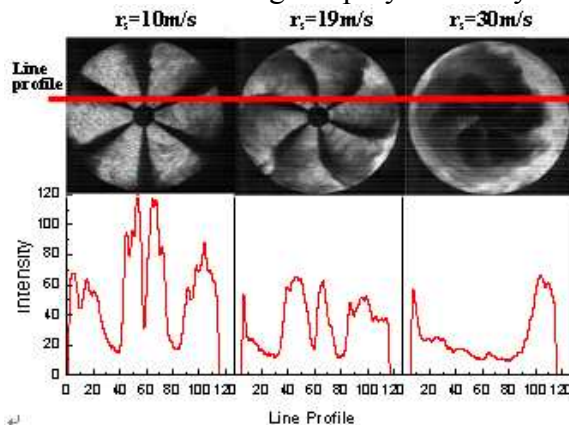


Fig. 4 Distribution of the line profile intensity at different swirl velocity

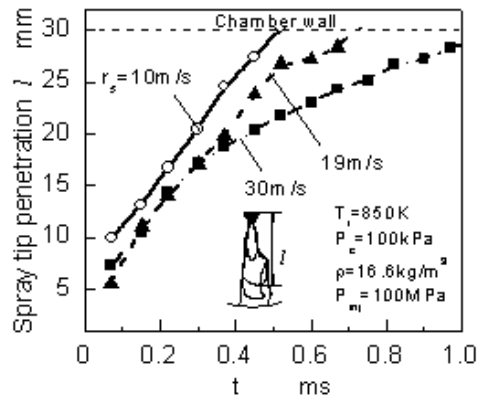


Fig. 5 Comparison of spray tip penetration at different swirl velocity

Next, the influences of swirl velocity are investigated on the point of mixture formation. Figure 3 shows the outer spray boundary of diesel spray against time, t time from start of injection. The outer spray boundaries are identified by image analysis with threshold intensity as shown in Fig. 4. As seen in Fig.3, high swirl velocity $r_s=30\text{m/s}$ case, little fuel is distributed near the chamber wall due to high air motion. Fuel is mainly distributed at the center of combustion chamber and it is possible to create locally rich combustion at this area. On the other hand, at $r_s=19\text{m/s}$ cases, fuel evaporates between the sprays and large amount of combustible mixture is formed at the time of ignition. In this chamber, the condition $r_s=19\text{m/s}$ cases seems to promote the fuel-air mixing and produce better distribution of the mixture than the cases $r_s=10$ and 30m/s .

The effect of swirl velocity on spray tip penetration is shown in Fig.5. It is clearly shown that lowering swirl velocity has an effect of promoting spray tip penetration. However, lower swirl velocity at $r_s=10\text{m/s}$ cases improve the spray tip penetration, but the benefits may not be seen due to air motion inside chamber can hardly bend the spray although the tip penetration is long enough. This mixture formation behavior exits the less amount of well-mixed is formed under $r_s=10\text{m/s}$ as compared with $r_s=19\text{m/s}$ cases as shown in Fig.6.

Next, the effects of swirl velocity are investigated on the point of mixture formation and combustion. Figure 6 compares images of mixture formation (upper row) and flame development. It clearly demonstrates that the flame pattern is dependency to the fuel evaporates during ignition delay period. As seen in schlieren images (upper row), high swirl velocity $r_s=30\text{m/s}$, little fuel is distributed near the chamber due to high air motion. Thus, it is possible to create a slow initial heat recovery and influences the high flame luminance develops at center of chamber. Furthermore, the luminosity occurs because fuel is mainly distributed at the center of combustion chamber and little combustible mixture prepared for ignition. In contrary, at lower swirl velocity $r_s=10\text{m/s}$, swirl flow can hardly bend the spray and less combustible mixture is formed, despite effects the luminance flame develops at spray centerline. This behavior is attributed to the explanation for the difference flame pattern and mixture formation is dominated by the mixture formation behavior and fuel-air mixing process.

Changes in the mixture formation behavior and combustion process with swirl velocity are clearly observed by examining the combustion characteristics presented in Fig.7. The total heat release Q_t , combustion duration Δt_b and maximum heat release rate $(dQ/dt)_{\max}$. Ignition delay τ , which is the amount of heat absorption Q_{ab} during ignition delay period and NOx emission per injected amount of fuel. The variations of flame pattern and mixture formation are attributed to the elucidation for the difference combustion characteristic as shown in Fig.6. Under high swirl condition, the higher heat losses and unutilized high-density oxygen associated with slower initial heat recovery begins might be the explanation for the longer combustion duration Δt_b , reductions of total heat release Q_t and heat release maxima $(dQ/dt)_{\max}$ thus influences to the NOx reductions.

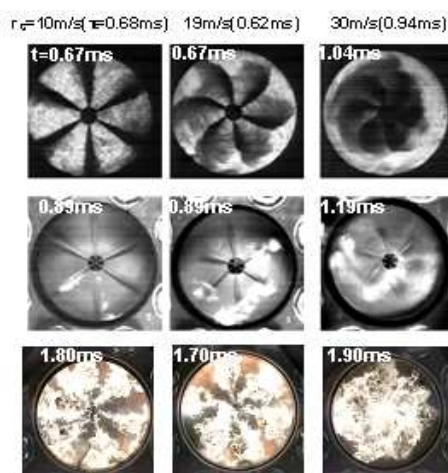


Fig. 6 Images of evaporation, mixture formation and ignition of diesel sprays as a function of swirl velocities

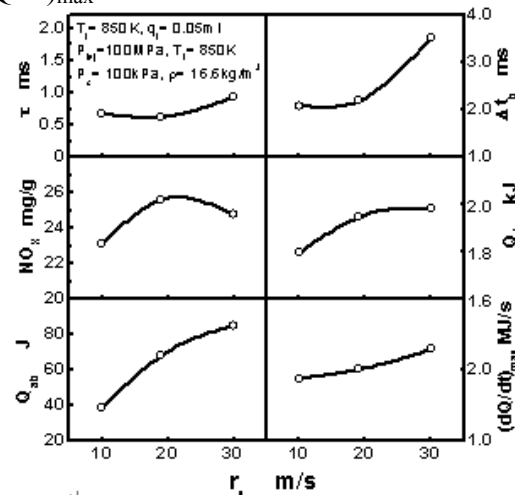


Fig. 7 Effects of swirl on combustion characteristics

Summary

In this research, design parameter of diesel combustion with variants in physical factor and air motion that affects from swirl velocity was investigated, in which r_s was varied from 10-30m/s. Parametric studies of diesel combustion have been fundamentally investigated by using rapid compression machine and image analysis. Discussions were made on relation between design parameter and the mixture formation behavior especially fuel-air mixing during ignition delay period on the ignition, initial heat release and combustion process. Lowering swirl velocity at

$r_s=10\text{m/s}$ cases promoting the spray tip penetration but the benefits may not be seen due to air motion inside chamber can hardly bend the spray although the tip penetration is long enough. Therefore, this mixture formation behavior exhibits the less amount of well-mixed mixture is formed under $r_s=10\text{m/s}$ as compared with $r_s=19\text{m/s}$ cases. On contrary, under high swirl condition $r_s=30\text{m/s}$ the ignition delay is extended and little fuel is distributed near the chamber due to high air motion thus predominantly influences the high flame luminance develops at center of chamber. In addition, the higher heat losses and unutilized high-density oxygen associated with slower initial heat recovery begins might be the explanation for the longer combustion duration and reductions of peak heat release. Furthermore, high swirl cases of $r_s=30\text{m/s}$ obtains high peak heat release in spite of soot formation at initial burning stage. High swirl can effectively promote combustion and soot oxidation.

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