Experimental Research of HCCI Combustion Based on Compound Injection

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Abstract. Based on the NVO (negative valve overlap) strategy, we have the compound injection experiment of HCCI combustion in a transformed test engine which is equipped with variable valve mechanism. The purpose of this experiment is to investigate the effects of compound injection on the procedure parameters of the combustion and the emissions. The experimental results indicate that the proportion of direct injection has a significant effect on the starting point of combustion. When the proportion increases, the starting point will be postponed, peak pressure and rate of heat release will be decreased gradually and IMEP has a slight decline. The timing of direct injection also affect HCCI combustion, but it is not dominant. Utilizing proportion of direct injection has a relative advantage on controlling spontaneous ignition, combustion rate and emissions of HCCI combustion.

Keywords: HCCI, compound injection, combustion parameters, emissions.

1. Introduction

Homogeneous charge compression ignition (HCCI) is a new type of combustion mode. It utilizes compression ignition to realize the combustion of cylinder. Compared with traditional gasoline engines, HCCI combustion has a great advantage on improving the thermal efficiency of the internal combustion engine and reducing the emission of NOx. Recently HCCI combustion mode has achieved extensive attentions in the internal combustion engine field.

In terms of intake port injection, it is good at obtaining well-distributed fresh medium, but we can’t dominate the degree of hierarchy and the procedure of HCCI combustion. In order to investigate the effects of medium hierarchy to the HCCI mode, we introduce the compound injection, i.e., the most fuel will still be injected in the air inlet (PFI mode) and the rest fuel will be directly injected into the cylinder (DI mode).

We try to adjust the proportion and timing of direct injection to control the level of medium hierarchy in the cylinder and then draw the conclusion about the regulation of compound injection on the procedure parameters of the combustion and the emissions of the HCCI combustion in NVO strategy.

2. Experimental system of compound injection

2.1 Test engine's parameters and test instrument’s model.

Table 1 Engine specifications

Engine type	Four-stroke, single cylinder
Cylinder diameter×Stroke/mm	105×115
Displacement L	0.99
Compression ratio	11.5
Original engine EVO/ EVC	43 °CA BBDC/14 °CA ATDC
Original engine IVO/ IVC	14 °CA BTDC/43 °CA ABDC

The test engine is transformed from a ZS1105 single cylinder diesel engine. To avoid the knocking combustion, we adjust the compression ratio from 17 to 11.5.The main parameters of the engine are shown in table 1. Due to the electronically controlled hydraulic drive valve mechanism, we can use the computer to control the open and close timing of the valve. We use turbulent flow measurement motor to measure the torque, onosokki oil flowmeter to measure oil consumption, AVL GM12D Cylinder Pressure Sensor to measure the pressure and AVL CEB200 exhaust-gas analyzer to analysis the emissions.

2.2 The choice of EGR strategy

The variable valve actuation can achieve a variety of different internal EGR strategies such as NVO strategy, LEVC (late exhaust valve close) strategy, SEVO (secondary exhaust valve open) strategy, etc. Currently NVO strategy is one of the most widely used EGR strategy. It is easy to realize exhaust gas entrapment and it has a better reliability. Combined with recompression and timing of oil injection, NVO strategy can control the evaporation of oil better. Meanwhile, the load limits of NVO is widest among three EGR strategy mentioned. Last but not the least, NVO strategy is sensitive to the medium hierarchy. It is beneficial to the application of medium hierarchy. Based on these reasons, we finally determine to utilize the NVO strategy to conduct the research of compound injection.

3. Experimental results and analysis

Table 1 Experimental cases with different direct injection strategy

	Case1	Case2	Case3	Case4	Case5
Injection strategy	100%PFI	5%DI	10%DI	10%DI	10%DI
Premixed injection time / ℃A BTDC	80	80	80	80	80
Premixed injection quantity /mg	35	33.25	31.5	31.5	31.5
Direct injection time / ℃A BTDC		60	50	120	90
Direct injection quantity /mg		1.75	3.5	3.5	3.5

We use the compound injection and try to control different proportion and timing of direct injection to investigate the effects of HCCI combustion. Different working conditions of injection are in table2

3.1 Proportion of direct injection's effects on parameters and emissions

Firstly, we conduct the experiments of Case1 Case2 and Case3 in the table2 to research the different proportion's effects on procedure parameters and emissions.

Figure 1 shows the experimental results of the different direct injections. (a), (b), (c), (d) in figure1 represent four different procedure parameters of combustion which are remarked in the Y axes. It indicates that proportion has a huge effect on HCCI combustion in NVO strategy. When we increase the proportion, the starting point which is represent by CA10 will be postponed from 356.5℃A to 360.5℃A. Combustion duration has a slight increase from 7.5℃A to 10℃A. According to the compression curve, we find the low temperature reaction of HCCI weakens, at the same time the peak value of cylinder pressure curve and maximum rate of heat release will decrease. Analysis suggests the direct injection model introduced in HCCI combustion affects the temperature field by fuel vaporization leading to the decrease of pocket of oil's temperature.

The temperature stratification interferes the whole temperature field, then, the process of the low temperature reaction decreases and the high temperature reaction will be delayed.

Figure2 indicates the proportion of direct injection's effects on the emissions including NO and CO. (a), (b) in figure2 represent NO and CO respectively. It is easy to draw the conclusion that proportion affects the emissions seriously. Because of the strong dependence on temperature, the formative timing of NO will be postponed and the production of NO will decrease when we add up the proportion of direction injection. Fuel hierarchy decreases the combustion speed, as a result, the production rate of NO also has a reduction.

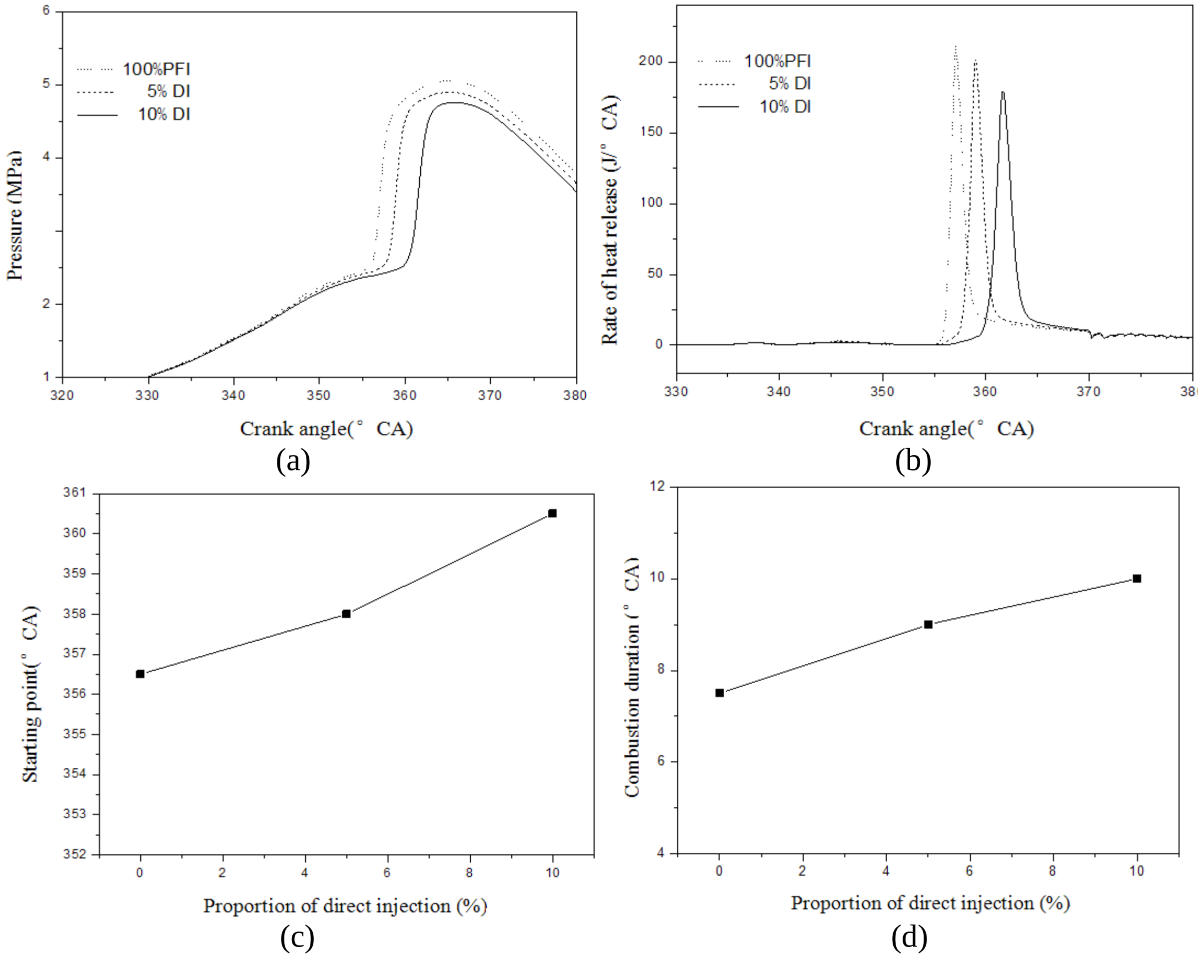


Fig. 1 Experimental results of different direct injection fractions

The formation of CO is also sensitive to the temperature. Because of decrease of temperature by the direct injection, the process of low temperature reaction goes to a lower level, then it leads to the lower production of CO. On the other hand, direct injection decreases the rate of combustion, so the final production of CO has a reduction. The fuel which is not transformed into CO will be released as the form of HC, therefore, the combustion efficiency goes down.

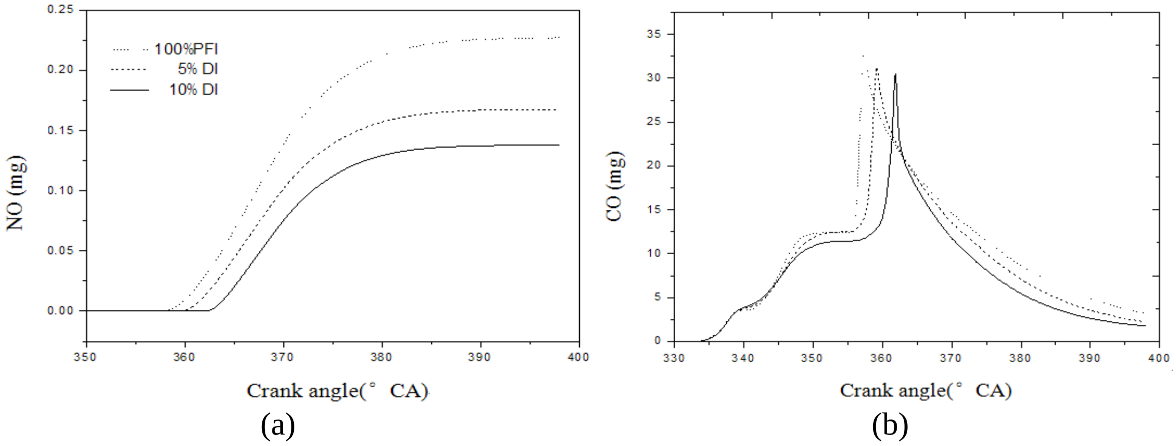


Fig. 2 Profiles of emissions formation for different DI fractions

3.2 Timing of direct injection's effects on procedure parameters and emissions

We conduct the experiments of Case4 and Case5 and compared them with Case1 and Case3 to investigate the different proportion's effects on procedure parameters and emissions.

Figure 3 lists the experimental results of different timings with the 10% direct injection. We find the timing also has an effect on HCCI combustion, but it is unremarkable. When we postpone the timing from 120 °CA BTDC to 60 °CA BTDC, the starting point becomes late, but the range of variation is small. The combustion duration has a little increase. The peak pressure and maximum rate of heat release have almost unchanged. Because it makes the proportion unchanged, the average temperature of cylinder has little variation. When we conduct the direct injection early, the combustion will be in advanced because of the unchanged low temperature reaction. In contrast, if we carry out the direct injection later, due to the effect of fuel evaporation on the low temperature reaction, the starting point has a delay, the combustion speed has a reduction and the combustion duration increases.

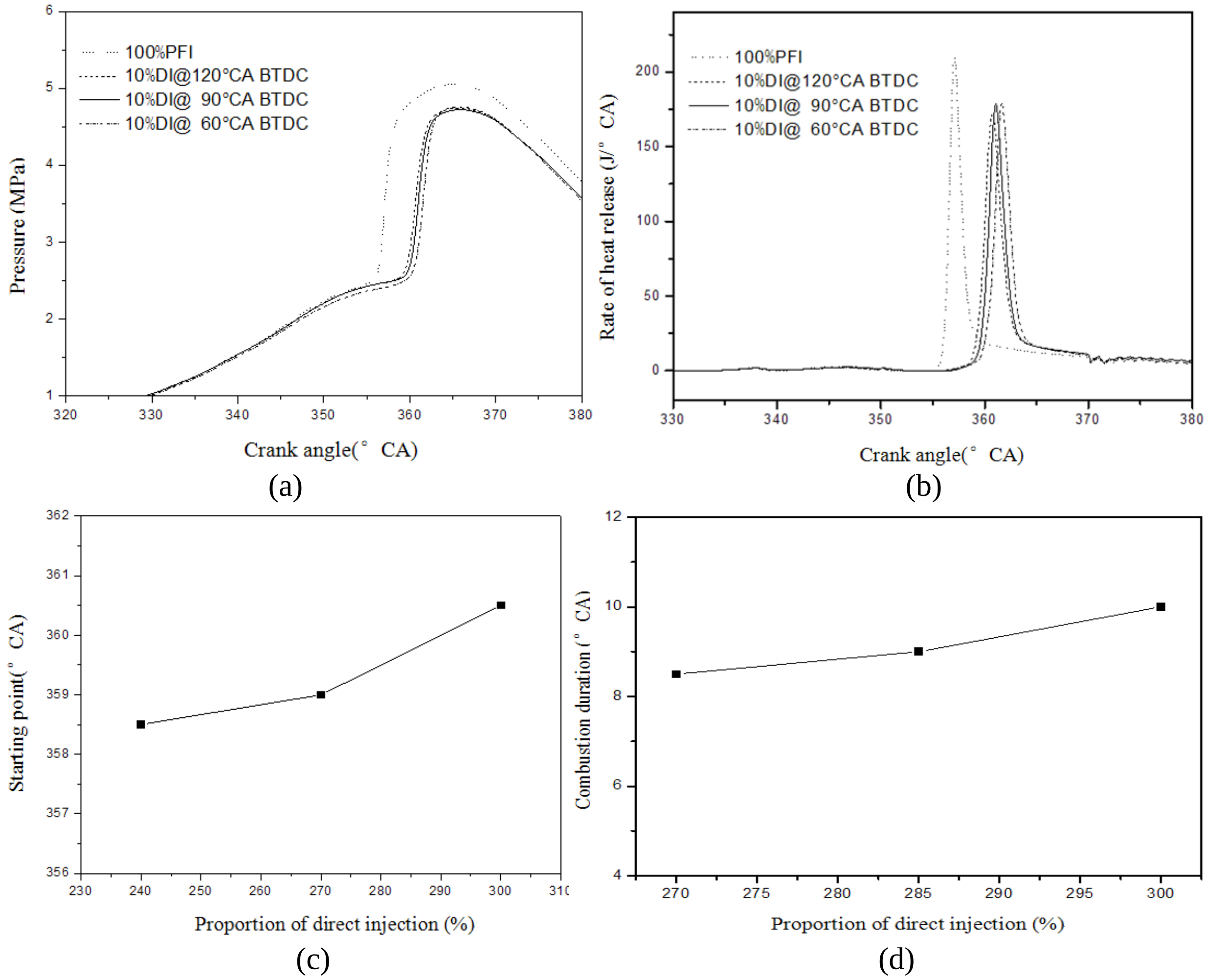
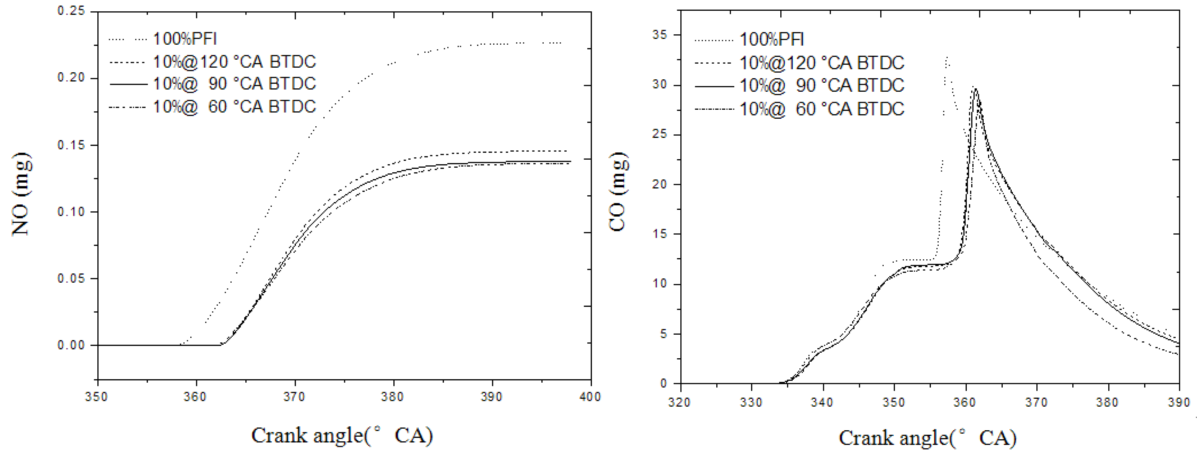


Fig. 3 Experiment results of different direct injection timings

Figure 4 indicates the timing of direct injection's effects on the emissions including NO and CO. It intuitively tells us that the timing of direct injection barely affects the emissions. When we postpone the timing of direct injection, the rate of NO production has a little decrease and the quantity of NO also goes down but not remarkable, because the parameters of NO is dominated by the temperature. Due to the similar low temperature reaction, the variation of CO is small, so the total production of CO has a little decrease and the combustion efficiency is slightly lower.



(a) (b)

Fig. 4 Profiles of emissions formation for different DI timings

4. Conclusion

1. Keeping the timing of direct injection unchanged, the proportion of direct injection has a vital influence on HCCI combustion. When the proportion increases, the starting point has a delay, the peak pressure and rate of heat release decrease and IMEP has a little reduction.

2. Keeping the proportion of direct injection unchanged, the timing of direct injection also has an effect on HCCI combustion, but it is unremarkable.

3. In contrast, we can draw the conclusion that adjusting the proportion of direct injection has an advantage in controlling the parameters and emissions of HCCI combustion.

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