Chapter 1
Effect of Compression Ratio on the Combustion Characteristics of Premixed Charge Induced Ignition for Diesel Engine

Yujie Guo, Jianjun Zhu, Zhiwei Su, Wei Han and Zilong Wu

Abstract In order to explore the combustion performance of premixed charge induced ignition for dual fuel engine, an experiment was undertaken on CY25TQ diesel engine to investigate the combustion and emission characteristics by changing the compression ratio. Experimental results show that under the condition of 1200 r/min, when the compression ratio is reduced from 16.9 to 15.4, and the premixed charge induced ignition leading to the start of combustion reaches the maximum delay to 1.5°CA ATDC, the biggest drops of maximum pressure, maximum pressure rise rate and peak of instantaneous heat release rate reach 52, 47 and 29% respectively. But the effective thermal efficiency declines 24%.

Keywords Premixed charge induced ignition · Methanol · F-T diesel · Compression ratio · Combustion

1.1 Introduction

China a country which is rich in coal resources, Coal-based methanol and F-T diesel as the high-level products of coal conversion, which are considered as the alternative fuel of engine that has value of application because the good combustion and emissions properties. When using the premixed charge induced ignition mode, coal-based methanol can be successfully applied to the compression ignition engine. It not only solves the problem that the low efficiency of the traditional gasoline engine, bur also solves the problem that the conventional diesel engine soot and NO_x cannot be reduced at the same time [1].

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The basic idea of premixed charge induced ignition mode is using high octane value and light volatile fuel as premixed mixture, and adding the high-cetane fuel in order to ignite the premixed mixture multi-point. Compared with the traditional spark ignition combustion mode, compression ignition combustion with direct injection mode can make the widespread ignition at the multi-point that will accelerate burn rate, get a higher isopycnal and improve the thermal efficiency of engine, thus can realize the domain objection of internal combustion engine energy conservation and environmental protection radically.

The research of Wang [2] about homogeneous charge induced ignition (HCII) combustion mode showed that: HCCI combustion mode, even better than diesel engine at some operating conditions, can get a higher thermal efficiency. The experimental results of Yao [3] showed that: under the compound combustion mode, using methanol can significantly improve the combustion and engine thermal efficiency because of contain oxygen. Although both at home and abroad a lot of researches about premixed charge induced ignition mode have be conducted, but the problem that maximum pressure rise rate and combustion heat release rate are too high under such mode in heavy load cannot be solved. It restricts the application of premixed charge induced ignition mode in heavy load conditions. In order to improve the engine roughness which under premixed charge induced ignition mode, we use F-T diesel that high-cetane value and light volatile as well the high-cetane fuel coal-based methanol [4, 5] try to extend the range of upper and lower load of premixed charge induced ignition mode, combining with the change of the compression ratio to explore engine combustion characteristic.

1.2 Experimental Fuels, Apparatus and Procedures

Table 1.1 show the comparison of 0# diesel and F-T diesel, ignition delay of F-T diesel is shorter than 0# diesel, so well as the combustion noise. This is mainly related to the physical and chemical properties of itself. F-T diesel has high cetane number which contributed to decrease the ignition delay. Heat release of premixed combustion declined, but diffusion combustion improved [6]. The operating condition used in experiment is $n = 2000$ r/min, BMEP = 0.6 MPa (Table 1.2).

Table 1.1 The combustion parameters of the original diesel engine

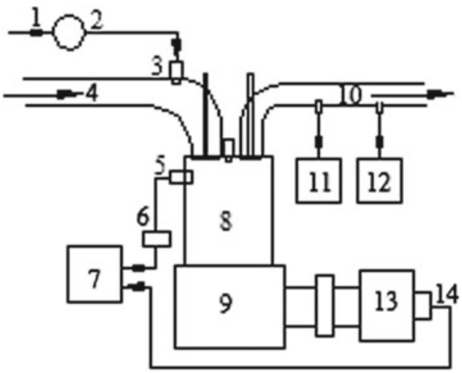
Fuel	0#	F-T
Maximum pressure (MPa)	8.2	5.7
Maximum pressure rise rate (MPa/°CA)	0.8	0.6
Peak of heat release (J/°CA)	163.4	103.8
Start of combustion (°CA)	−10.6	−13.2
Combustion duration (°CA)	51.2	56.6
Maximum combustion temperatures (°C)	1497	1407

Table 1.2 Major parameters of the test engine

Item	Parameter
Combustor type	ω
Bore × stroke	115 × 115 mm
Displacement	1.25 L
Compression ratio	17:1
Rated power	12.5 kW/(2200 r/min)
Maximum torque	63.8 N m/(1600 r/min)
Fuel supply advance angle	20°CA BTDC

We applied premixed charge induced ignition mode on a single cylinder direct injection diesel engine, it controlled by measurement and control system. The combustion pressure in cylinder was obtained by cylinder pressure sensor and charge amplifier, and then we used the combustion analyzer to collect and analyze data (Fig. 1.1).

In this experiment, fuel supply advance angle was set in 20°CA BTDC constantly, set the timing of methanol inject is 10°CA BTDC, brake mean effective pressure is 0.6 MPa and the injection starting pressure of F-T diesel is 20 MPa. We tried to find the biggest methanol energy proportion that engine get the limit of misfire by adjusting the proportion of F-T diesel and methanol, then turning down the proportion of methanol and recording the methanol energy proportion multiple times in same operating condition. Finally, changing the compression ratio and repeat the steps above. The methanol energy proportion of different compression ratio is uncertain. We define the methanol energy proportion as the ratio of



1.Methanol 2. Controller 3.Injector 4.Intake5. Cylinder Pressure Sensor
6. Charge amplifier 7. Combustion analyzer 8. Cylinder 9. Engine 10. Exhaust
11. Gas analyzer 12.FTIR 13. Dynamometer 14. Angle instrument

Fig. 1.1 Schematic diagram of experimental setup methanol energy to total energy cost by operating cycle of engine. By changing the thickness of the cylinder gasket, thus the compression clearance would be changed in order to change the compression ratio in our experiment.

1.3 Results and Discussion

Figure 1.2 shows the effect of compression ratio on the maximum cylinder pressure and the peak value of initial heat release. With the decreasing of compression ratio, the maximum cylinder pressure drops dramatically, and the largest decline is more than 50% in low speed operating conditions. Decreasing when the peak value of initial heat release at low speed, it is greatly increasing at the high speed, and the biggest increase is more than 55%. The maximum cylinder pressure and maximum cylinder pressure with the increase of methanol energy proportion will go to a downward trend.

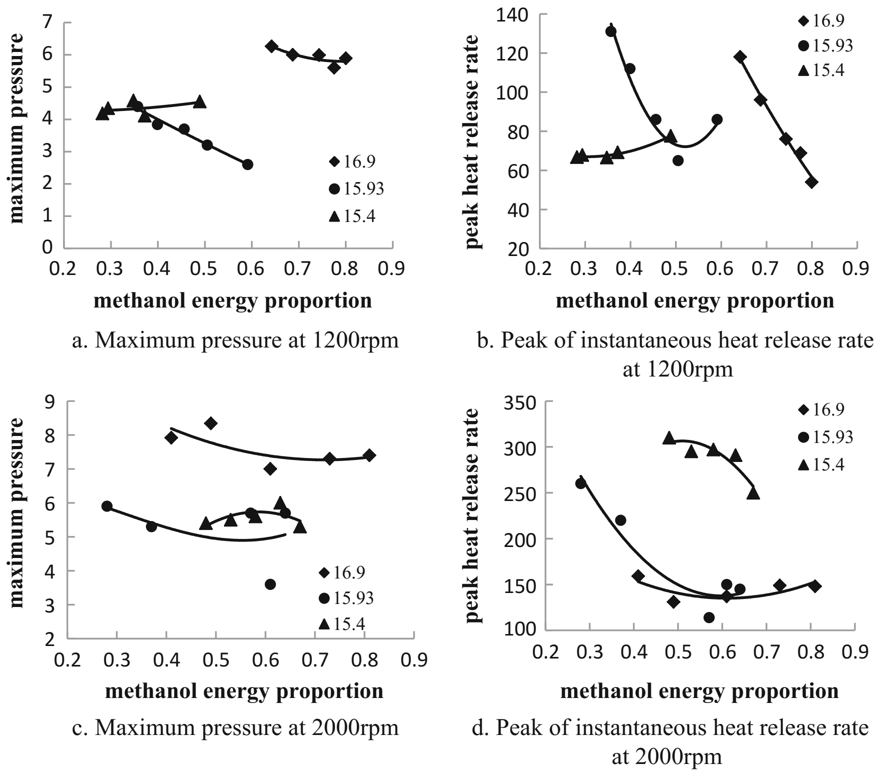


Fig. 1.2 Effects of compression ratio on maximum pressure and peak rate of instantaneous heat release

In the premixed charge induced ignition combustion mode, the maximum cylinder pressure is decided by two factors: the temperature in cylinder and the concentration of premixed mixture [7]. With the decrease of compress ratio and the increase of methanol energy proportion, which will cause the loss of the temperature in cylinder, delay the start timing of combustion. But with the increase of methanol energy proportion, and raising the ratio of premixed charge induced ignition in cylinder, it is helpful to accelerate combustion rate. The change of the maximum cylinder pressure is due to the two factors which affect the speed and timing of combustion. The main factors affecting the peak heat release rate are burning rate, combustion phase and the temperature in cylinder. At the faster of the burning rate, the start timing of combustion is more near the top dead center which leads to the increase of peak heat release rate. As the temperature of engine is low in low speed, the concentration of methanol premixed mixture is lower. And with the decrease of compression ratio aggravates the decline of temperature. They both result in the peak heat release rate decline. But in high speed operating mode, the temperature of engine is high, the time of combustion reaction in cylinder is shorter, and the center of heat release rate curve more closes to the top dead center. So the impact that reduces of compression ratio is less than the positive impact that combustion phase at peak heat release rate.

Figure 1.3 shows the effect of compression ratio on maximum pressure rise rate and the start timing of combustion. With the decrease of compression ratio and the increase of methanol energy proportion, the start timing of combustion is delayed, and the largest delay is 7°CA; In low speed operating conditions, the maximum pressure rise rate is at the downtrend in the process of the compression ratio of 16.9–15.4, and the combustion noise is decreasing. But the performance of high speed operating conditions is entirely different, the increase of methanol energy proportion is negative to improve of maximum pressure rise rate.

That is due to the start timing of combustion which depends on the fuel quality and the thermal condition state of compression process in cylinder. With the decreasing compression ratio, the lower pressure in cylinder leads to the temperature of ignition limit raise. Although the F-T diesel has high cetane number, fuel evaporation is better than diesel. But with the methanol injected into the cylinder, it absorbs a lot of heat in the process of evaporation, resulting in the lower temperature of cylinder which decreases the peak heat release rate and prolongs the ignition delay [4, 8, 9], and finally delays the start timing of combustion. Due to reduce the compression ratio by increasing the clearance volume in our experiment, with the compression ratio reduced, and the start timing of combustion near the top dead center, cycle thermal efficiency of engine is higher. But the physical reaction time in cylinder is long at low speed, the rate of heat removal determines the change of the maximum pressure rise rate. In high speed operating condition, the positive impact of start timing of combustion delay is bigger than the negative impact of temperature decreased on maximum pressure rise rate. When the methanol energy proportion is low, the latent heat of vaporization of methanol has little influence on temperature in cylinder. Therefore when the temperature of cylinder at a high level, it is helpful to accelerate combustion heat release.

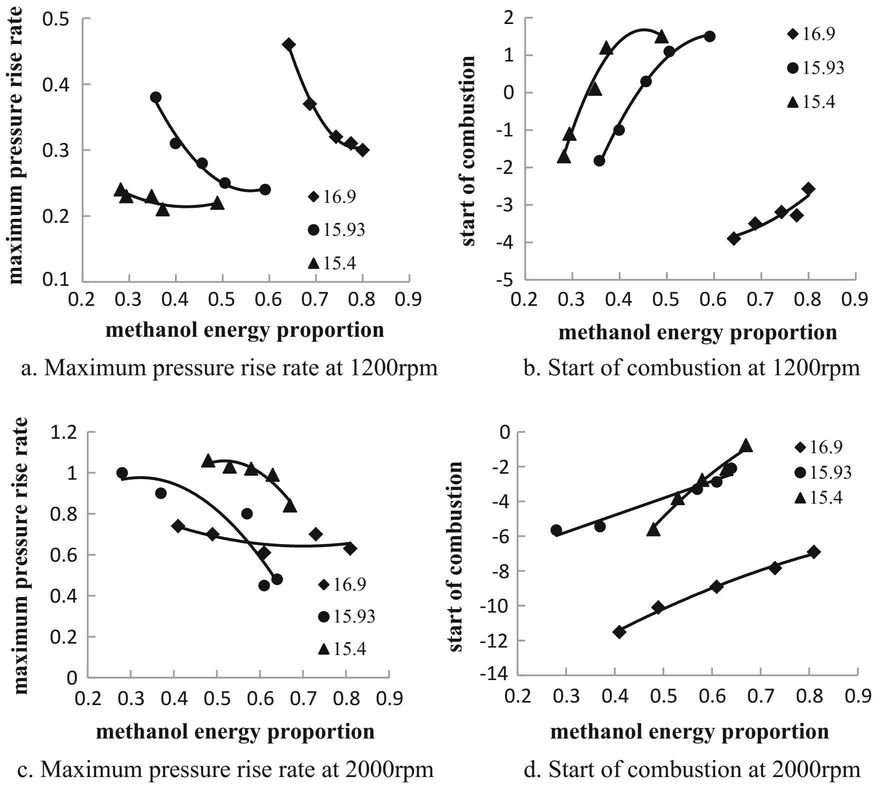
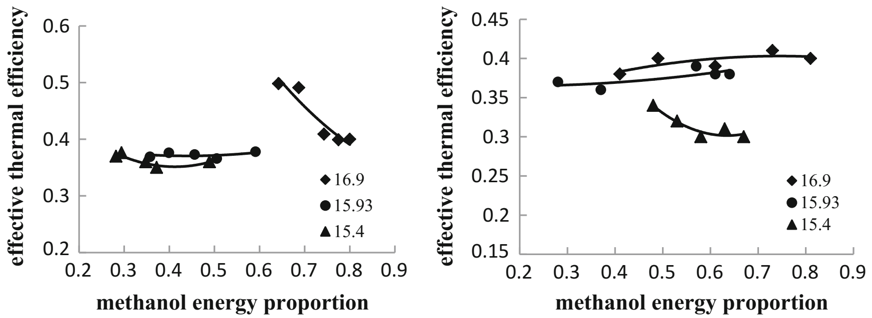


Fig. 1.3 Effects of compression ratio on maximum pressure rise rate and start of combustion

Figure 1.4 reflects the effective thermal efficiency varies with the change of the compression ratio. At low speed, the effective thermal efficiency decreases with the reduction of the compression ratio; At high speed, compression ratio decreases from 16.9 to 15.9, while the effective thermal efficiency is decreased slightly about 5%; But when the compression ratio continues to reduce to 15.4, the effective thermal efficiency will greatly decreased, and the largest drop of 42%, thus the engine fuel economy will be decreased. What is more, compared with the ratio of 15.4, with the increase of methanol energy proportion, the change of effective thermal efficiency is quite different from that of the middle and high compression ratio, and it is in a downward trend.

Because the effective thermal efficiency is not only affected by the compression ratio, but also the isopycnal of the combustion in cylinder. With the decrease of compression ratio, both the temperature in cylinder and brake thermal efficiency are reduced. Figure 1.3d shows that: when compression ratio reduces to 15.4 again in high speed, and the latest start timing of combustion reaches to 1°CA BTDC, it is



a. Effective thermal efficiency at 1200rpm b. Effective thermal efficiency at 2000rpm

Fig. 1.4 Effects of compression ratio on effective thermal efficiency

very close to the top dead center. Besides, with the increase of methanol energy proportion, the center of combustion heat release is moved back, the combustion efficiency declined and the brake thermal efficiency decreased significantly.

1.4 Summary

(1) The engine uses premixed charge induced ignition combustion mode, when in the process of compression ratio reduced from 16.9 to 15.4, brake thermal efficiency has a downward trend, and the biggest drop reached 24%, leading to the decrease of the engine economical efficiency.

(2) With the decrease of compression ratio, the start timing of combustion is delayed, and the largest delay is 7°CA, which almost near the top dead center; The peak heat release rate is increased in high speed, and the largest increase is 55%; It also leads to the temperature in cylinder and the maximum pressure rise rate raise, which are easy to cause running harshly of engine; Combustion duration shows a rises first and fall later trend.

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