Chapter 15
Test Study on Characteristics of Multi-Hole Injector for Gasoline Direct Injection Engine

Jujiang Liu, Hong Chen, Sicong Lin, Yuhuai Li, Lin Ye and Shuang Zhang

Abstract By means of High speed camera and CCD camera, combining with high energy laser device, spray characteristics test of multi-hole injector for gasoline direct injection engine have been done on the constant volume chamber bench. The variation laws of spray penetration, spray angle and spray target were studied under different injection pressures, different injection pulses and different injection background pressures. Also the variation tendency for spray penetration of different injector flow ranges have been tested and analyzed. The results indicate that injecting pressure boosting can strengthen the initial penetration developing of spray plume, fuel atomizing becoming better, resulting in increasing of spray angle. The effects of changing background pressure on spray angle and target are not obvious. And spray target coordinate is mainly determined by the injector hole layout. Under the same injection pressure and flow quantity, injector having the larger flow range has shorter penetration than that of smaller flow range.

Keywords Gasoline direct injection engine · Multi-hole injector · Spray characteristics · Test study

15.1 Introduction

With passenger vehicle fuel consumption regulations being more and more stringent and serious environmental protection pressure, it is of great importance to develop energy saving and emission reduction gasoline engine. Gasoline direct injection engine has good power, economic performance and better transient characteristics, which has been becoming the mainstream of modern gasoline engine [1, 2]. The function of engine is to convert the fuel combustion energy into the output of mechanical energy. And this process is carried out by engine combustion system, which is a core system of the engine. Spray characteristics and

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spray target design in GDI cylinder have significant effects on combustion chamber structure layout and piston crown shape design [3, 4]. Reports can be seen at present that research has been done on spray matching and its characteristics [5–7]. Spray penetration has close relationship with interaction between spray plume and cylinder liner, playing important roles on HC emission and oil dilution phenomenon. Spray target design is one of the main factors which should be taken into consideration when designing piston crown shape. Meanwhile, injector structural parameters, injection pressure and the interaction of spray plume and air flow will determine the Sauter mean diameter. And all factors above will have effects on engine combustion performance.

On the basis of the discussion and analysis above, spray characteristics testing of GDI multi-hole injector has been done on a constant volume chamber bench in this chapter. Variation laws of spray penetration and angle are investigated under different injector pressures, different background pressures. And spray targets under different flow quantities and injection pressures are tested and analyzed. Also research has been done on spray penetration changing trends of injectors whose flow ranges are different.

15.2 Testing Systems and Methodologies

15.2.1 Testing System

Systematical parameters of the adopted constant volume chamber in this chapter are shown in Table 15.1, which is composed of constant volume chamber block, water cooling system, high pressure fuel supplying pipes system, intake pipes, exhaust pipes and injector controlling and monitoring systems. Optical devices include Nd: YAG pulsed UV laser (60 mJ@266 nm), CMOS high speed camera (20 kHz@ 1024 × 1024 pixel), CCD camera (2048 × 1024 pixel), diffuser and program timing unit. Spray tests results can be post processed by DaVis post processing software.

15.2.2 Testing Methodologies

Decompressing lower nitrogen source, whose pressure is 15 MPa, is applied as the background gas of spray injection, and higher 20 MPa nitrogen source is used for the supplying source of injector pressure accumulator. Water cooling circulation system can control the temperature of injecting fuel. In the controlling and testing system of constant volume chamber bench, injection pulse will be controlled by means of inputting the driven current curves of injector. When injection happens, the TRIG signal of injecting starting is produced at the same time, which will be synchronized with camera and laser signal through PTU timing unit, guaranteeing the right spray picture can be captured.

Table 15.1 Constant volume chamber structure and its main parameters

Constant volume chamber structure	Window diameter: Φ100; angle: 90°, 120°/150°, 180°	Window	UV transmittance
Temperature limit	0–800 K	Pressure limit	6000 kPa
Temperature fluctuating range	Chamber variation: <+5 °C, test zone: <+3 °C	Test range	Temperature: 0–1000 K; Pressure: 0–8 MPa; Humidity: 2–98% RH
Seal performance	Pressure drop ≤ 1%/10 min	Fuel temperature controlling	−20 to 90 °C
Vacuum degree controlling accuracy	+1 kPa	Test accuracy	Temperature: ±1 °C; Pressure: 0.1% FS; Humidity: ±2% RH
Vacuum degree pressure range	10 kPa–1 bar	Pressure fluctuating range	±1%
Fuel pressure controlling	0.4–20 MPa	Pressure controlling accuracy	0.1% of maximum pressure
Injector voltage and current	0–120 V; 0–25 A (0–200 μs)	Injection pulse	0–10 ms

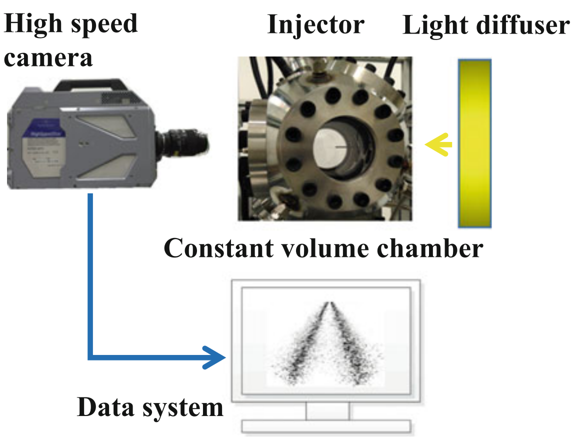


Fig. 15.1 Optical layout of shadow method

Shadow method is adopted to test the macro spray shape, spray angle and penetration of the injector. The beam of high energy laser is distributed uniformly through a diffuser, which is taken as background light. Developing process of macro spray shape will be photoed through high speed camera. Spray picture data will be post processed by DaVis software, from which spray angle and penetration are achieved. Optical layout of shadow method is shown in Fig. 15.1.

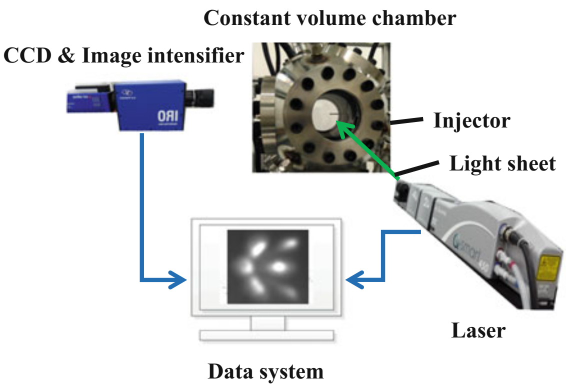


Fig. 15.2 Optical layout of laser induced fluorescence

Injection spray target can be tested by laser induced fluorescence method. Sheet optic element can convert the laser beam into light sheet, which is used to illuminate Z30 plane, perpendicular with the injector axis, and the laser energy is 60 mJ@266 nm. The 300–400 nm fluorescence, which is induced form gasoline can be captured by CCD camera mounting image intensifier. Spray target can be achieved by means of DaVis post process software. Optical layout of laser induced fluorescence is shown in Fig. 15.2.

15.3 Research on Macro Spray Characteristics

15.3.1 Effects of Different Injection Pressures

On the constant volume chamber, setting the injection pressure as 5, 10 and 18 MPa, the injection back pressure is 0.1 and 0.2 MPa, while the injection pulse is 1.5, 3 and 6 ms, and the macro spray characteristics are tested respectively. The fuel temperature and environmental temperature are both 25 °C. The post processing sketch of spray picture is indicated in Fig. 15.3. And the macro developing process of spray is shown in Fig. 15.4.

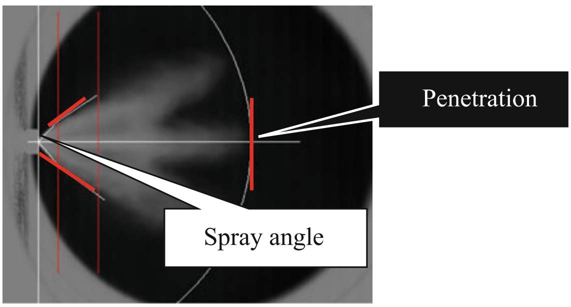


Fig. 15.3 Sketch of spray post processing

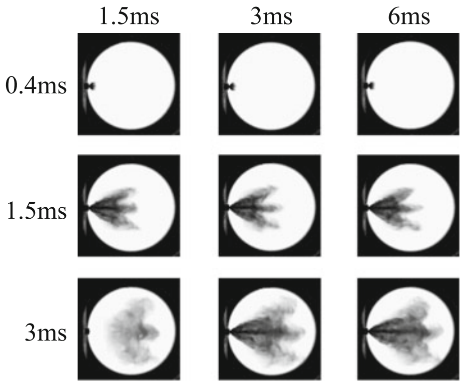


Fig. 15.4 Macro developing of spray with 10 MPa injection pressure and 0.1 MPa injection pulse

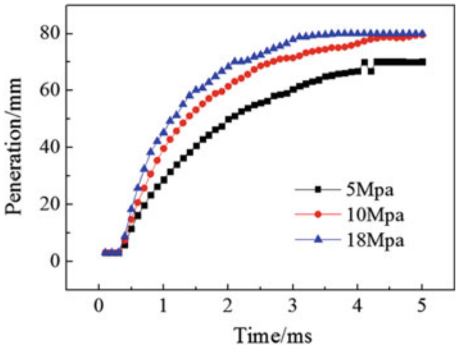
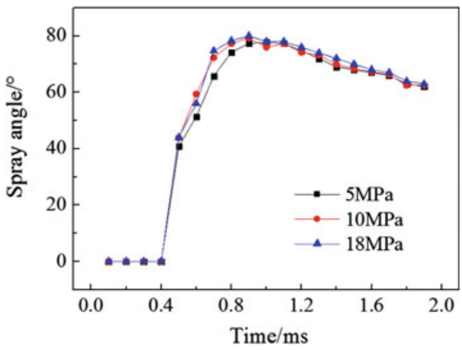


Fig. 15.5 Penetration developing under different injection pressures

It can be seen from Fig. 15.4 that after fuel ejected from nozzle, spray plume is formed, developing along with the flow passage direction of injector hole. Spray plume interacts with air continuously, with emerging of entrainment, diffusion, atomization. The periphery of front tip plume is relatively smooth, while the end of the plume takes on strong fluctuating because of long time interaction with air in the chamber, and this phenomenon will promote atomization and mixing of plume and air.

Figure 15.5 indicates effects of different injection pressures on penetration of spray plume, and the spray background pressure is 0.1 MPa. From Fig. 15.5, it can be known that at the beginning of spray plume forming, bigger injection pressure will produce quick development of penetration, while with the continuous development of spray plume, the increasing trend of penetration is suppressed. Analysis shows that initial injection speed of spray is determined by the fuel injection pressure. At the beginning of spray plume developing, larger injection pressure will produce bigger initial injection velocity, resulting in initial penetration increasing, while with deep development of the plume, the edge fuel of the plume will gradually atomize, make the relative density of the air around increase, leading to the resistance on the plume boosting, so the penetration of the plume is hindered.

Fig. 15.6 Spray angle developing under different injection pressures



Spray angle developing process with time under different injection pressures is figured in Fig. 15.6. The results indicate that injection pressure has minor effects on spray angle, and the spray angle is mainly determined by internal flow passage and injector hole layout. Increasing injection pressure can strengthen the atomization of spray plume, so spray angle takes on boosting trend with the increasing of injection pressure.

15.3.2 Effects of Injection Background Pressures

Developing trends of spray angle and penetration of injection pulse 1.5 ms, injection pressure 10 MPa under different injection background pressures are shown in Figs. 15.7 and 15.8.

The reason of changing tendency for the spray angle in Fig. 15.7 can be explained furtherly that spray angle is up to the injector hole layout position, and hardly influenced by the injection pressure and background pressure. From Fig. 15.8, penetration is becoming shorter with the increasing of background pressure, which results from the resistance of spray plume developing is strengthened with injection background pressure increasing.

Fig. 15.7 Spray angle developing under different background pressures

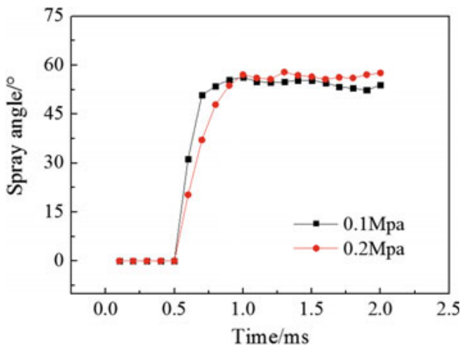
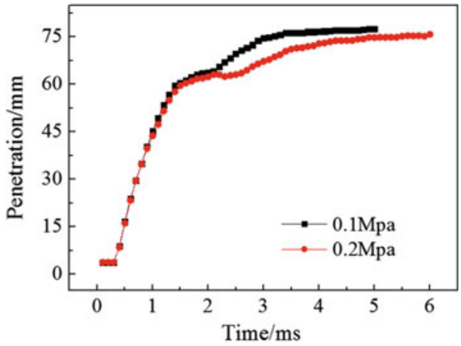


Fig. 15.8 Spray penetration developing under different background pressures

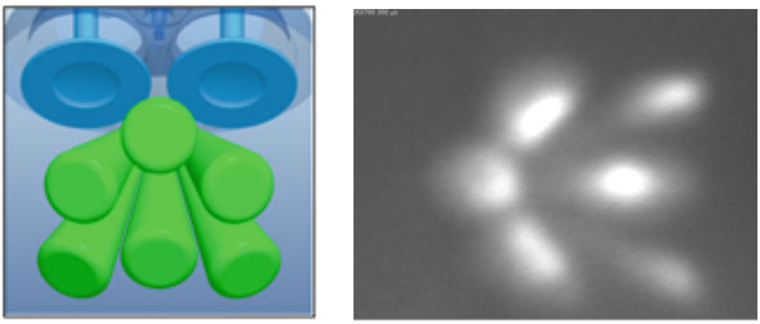


15.4 Research on Injector Spray Target

Setting the injection pressure as 10, 15 and 18 MPa, and the injection pulse is 1.5 ms, the spray targets are tested respectively. Also spray targets are tested in turn when injection pulse is 1.5, 3 and 6 ms, under 10 MPa injection pressure. Fuel temperature and environmental temperature are both 25 °C, and background pressure is 0.1 MPa. Laser induced fluorescence picture, when injection pressure is 10 MPa, and injection pulse is 1.5 ms, is displayed in Fig. 15.9, while spray target post processing picture is depicted in Fig. 15.10.

Figures 15.10 and 15.11 have shown the effects of different injection pressures and injection pulses on spray target coordinate. It can be deduced that spray target position has very minor changes with the boosting of injection pressure. When injection pressure boosts from 10 to 18 MPa, spray target has little variation, which is mainly because spray angle increases, resulting from atomization strengthening.

The spray target position in Fig. 15.11 illustrates that different injection pulses almost have no effects on spray target coordinate. Once again, confirmation can be made that spray target position is up to the injector hole layout.



(a) CAD design of spray target (b) Laser induced fluorescence picture

Fig. 15.9 Laser induced fluorescence picture of injection pulse 1.5 ms under 10 MPa injection pressure

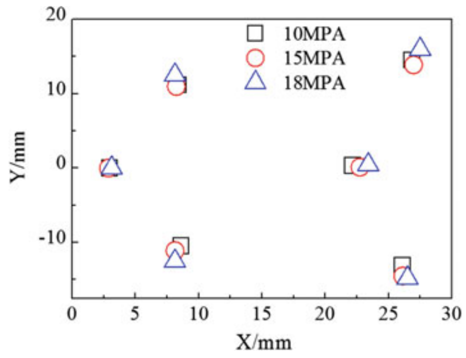


Fig. 15.10 Spray coordinate layout under different injection pressures

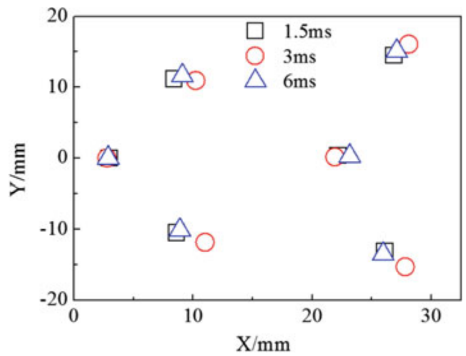


Fig. 15.11 Spray coordinate layout under different injection pulses

15.5 Research on Effects of Injector Flow Range on Penetration

Penetrations of different injector flow ranges are tested respectively when the same quantities are ejected. The results are described through curves in Figs. 15.12 and 15.13.

Testing results of Figs. 15.12 and 15.13 illustrates that under the same injection pressure and same fuel ejecting quantity, larger flow range injector produces smaller penetration, which is beneficial to alleviate oil dilution in the cylinder of GDI engine. It is believed that larger flow range injector uses bigger injecting hole, forming bigger spray angle plume, which is apt to penetration reducing, but designing larger flow range injector should take the possibility of ballistic flow area into consideration.

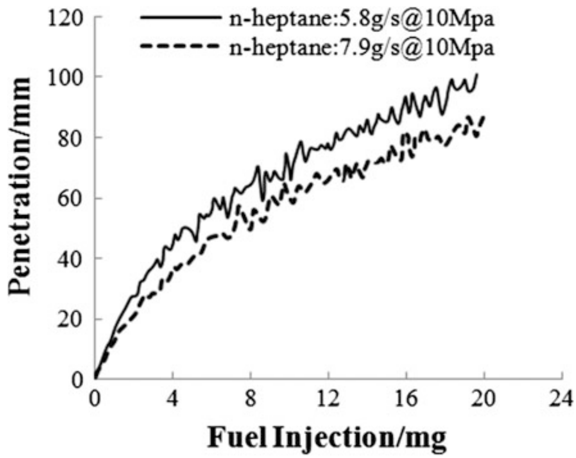


Fig. 15.12 Penetrations of different flow range injector with the same injection quantities under 10 MPa injection pressure

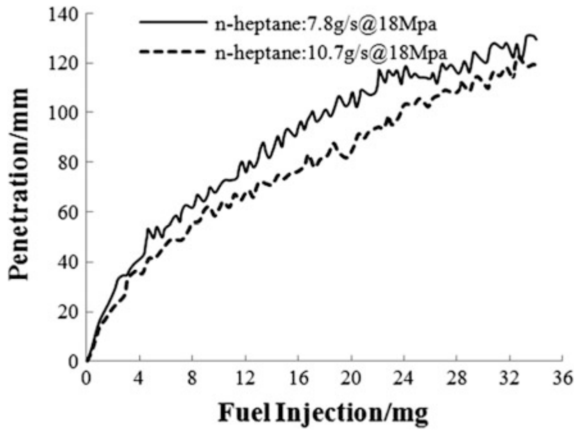


Fig. 15.13 Penetrations of different flow range injector with the same injection quantities under 18 MPa injection pressure

15.6 Comprehensive Analyzation of Constant Volume Bench Testing Results

From spray characteristics testing results and comprehensive analysis process above, conclusions can be drawn that four main factors, including initial injection velocity, spray background media, mixing speed between atomized fuel and air, injector flow range, can account for the spray penetration development. Spray angle and target is mainly up to the internal flow and hole layout of the injector. Increasing injection pressure can accelerate atomization speed, spray angle boosting slightly. Under the condition of injection pressure and ejected fuel quantity, injector having bigger flow range is apt to achieve smaller spray penetration.

Therefore, reasonable design of spray target of multi-hole injector is the key point to the matching between spray plume and combustion chamber. Using high injection pressure system is beneficial to control the spray penetration, while the spray itemization quality is also improved. In order to reduce the risk of oil dilution, and taking flow quantity ballistic area of injector into consideration, large flow range injector can be used to obtain shorter spray penetration, which can also shorten the injection pulse, resulting in much longer time for the mixture forming in cylinder.

15.7 Conclusion

Firstly, development speed of initial spray penetration will accelerate with increasing of injection pressure, while the case of that will be suppressed later because of resistance strengthening.

Secondly, spray angle is mainly determined by internal flow passage direction and hole layout of injector, and is not remarkably influenced by spray background pressure and injection pressure variation. With increasing of injection pressure, single plume atomizing strengthened, resulting in spray angle boosting slightly.

Thirdly, injection pressure and pulse do not have obvious effects on spray target coordinate. Spray target position is also determined by internal flow and hole layout of the injector.

Fourthly, under the same injection pressure and flow quantity, larger flow range injector will produce shorter spray penetration.

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