Gasoline Fuel Injector Selection and Its Effects on Engine Performance

Shuxia Miao, Daijun Deng and Hui Zheng

Abstract Fuel injector is very important for engine performance. Normally it is supplied by system suppliers as a package and OEMs do not have much choice in China. This study offered an experimental method of fuel injector selection. Based on CAE simulation, two types of fuel injectors were selected and their key parameters and the engine dynamometer performances are tested in lab. An optimized fuel injector is selected based on the comprehensive test results.

Keywords Engine · Fuel injector · Calibration · CAE

1 Introduction

Gasoline fuel injector selection is very important for engine performance including fuel economic and emission performance [1, 2], properly selected fuel injector could improve engine dynamical performance; reduce the fuel consumption and emission as well. Very often the fuel injector is supplied by Engine Management System (EMS) suppliers as a package with fuel rail, engine control unit and even oxygen sensors together, China Original Equipment Manufacturers (OEMs) do not have much choice.

This study offered a way of fuel injector selection by analyzing the key injector characteristics together with the dynamical performance on engine dynamometer.

F2012-D01-009

S. Miao (✉) · D. Deng · H. Zheng
Changan Auto Global R&D Center, Changan Automobile Co LTD,
Chongqing, People's Republic of China
e-mail: miaosx@changan.com.cn

SAE-China and FISITA (eds.), *Proceedings of the FISITA 2012 World Automotive Congress*, Lecture Notes in Electrical Engineering 194,
DOI: 10.1007/978-3-642-33829-8_5,

Two different types of fuel injectors for a manifold-injected spark ignition engine were selected based on supplier's recommendation and Computer Aided Engineering (CAE) simulation, then the fuel injectors are tested in laboratory on the critical characteristics; such characteristic parameters measured in lab include injection cone angle, stroke penetration distance, fuel mist particulate distribution, etc. under different combined conditions of fuel pressure, back pressure and inject fuel mass. Fuel injector model is also set-up and verified with the testing results.

The injectors are further dynamically calibrated within the system on engine dynamometer. Engine performance map of power, torque and emission are measured with each injector. Based on the comprehensive performance of component test and engine/vehicle results, an optimized fuel injector is selected finally.

2 Test Method of Fuel Injector Selection

The test method of fuel injector selection includes CAE analysis of oil beam, component test and engine dynamometer test as discussed later on. Considering the available resources and future commercial application, injector selection is limited in a reservoir of regular 4-hole injectors with a hole diameter of 0.2 mm.

2.1 CAE Analysis of Oil Beam

The injector spray model is built up based on the injector 3D data. The characteristic effects of wet wall, spray distribution, atomizing and mixing are simulated. Based on the simulation results, the basic parameters of stroke penetration distance, installation angle, injection cone angle are determined.

Errors may result from equipment precision, experiences of operator, etc. therefore, CAE method is also necessary to validate the correctness of experiment results.

2.2 Component Test

In China, injectors are always selected by supplier according to their experiences and CAE. Since the supplier does not have the detail information about engine, this method results in numerous wastes of time and resources, yet without optimized performance. In this paper, a series of test conditions are designed and customized according to Society of Automotive Engineering (SAE) standard [3, 4], and experiences. The detailed test conditions are listed in Table 1.

Table 1 Component test conditions (room temperature: 25 °C)

Index	Injection pressure (bar)	Injection amount (mg/stroke)	Ambient pressure (bar)
1	3.5	5	0.3
2	3.5	15	0.7
3	3.5	35	1.0
4	3.8	5	0.3
5	3.8	15	0.7
6	3.8	25	0.7
7	3.8	35	1.0
8	4.0	5	0.3
9	4.0	15	0.7
10	4.0	35	1.0

2.2.1 Injector Flow Rate Test

Averaging method is used in flow rate test. The injection pulse width is selected between 1.5 and 20 ms based on normal engine performance. Under each condition, the total amount of fuel in 100 strokes is summarized and the tests were repeated 3 times. Average value is the final flow rate.

2.2.2 Stroke Penetration Distance and Injection Cone Angle Test

A synchronized high speed camera was used to test and then the data was analyzed automatically in order to obtain data of stroke penetration, injection corn angles, etc. The experimental setting is similar to that in Ref. [5] which was used to study gasoline direct injectors (GDI). 95 % statistical probability is setup as measuring limitation, the stroke penetration distance is the projection of the line, which connects the farthest point and the injector orifice centre, along the injector axis. The max angle relative to the injector axis at the section, which is 30 mm below the injector orifice, is injection cone angle.

2.2.3 Fuel Mass Distribution and Fuel Mist Particulate Distribution Test

The fuel mist particulate distribution is derived according to the spray distribution at the cross section, which is 30 mm below the injector orifice. The fuel mist particle distribution tests are done based on standard SAE J2715 [6].

2.3 Engine Dynamometer Test

Engine dynamometer tests with the 2 different injectors were run to further confirm the component differences and applicable performance. The test was run on AVL

Table 2 Test engine parameters

Parameter	Unit	Value
Displacement	L	1.5
Rated power	kW	80
Speed at rated power	r/m	5,500 ~ 6,500
Max torque	Nm	140
Speed at max torque	r/m	3,300 ~ 4,300
Lowest fuel consumption rate	g/KWh	250
Idle speed	r/m	720 ± 50

DynoRoad 202/12SL 220KW dynamometer with AVL 735S fuel meter and Horiba 7,200 emission analyzer. The main parameters of the test engine are shown in Table 2. To make better comparison between the 2 injectors, engine was equipped with same hardware except injectors, and is controlled by the same EMS system with specific calibration catering to different injectors.

The universal characteristic is tested using different injectors. The injector is selected considering both the component and dynamometer test results.

3 Test Results and Analysis

Two injectors are selected. One is labelled injector #1 and the other is injector #2.

3.1 CAE Analysis of Oil Beam

The objective is to determine the primary parameters. Based on the manifold model analysis, the best injector installation angle is 135°, with the spray cone angle is 30 ~ 45° and the stroke penetration distance is 110 mm which can avoid severe wet-wall phenomena.

3.2 Component Characteristics Test

The injector flow rate test results are shown in the Fig. 1. Averagely, injector #1 has an 11 % higher flow rate than that of injector #2. There is no significant difference of the stroke penetration distances between the two injectors in most cases as shown in Fig. 2a. However, it is noted that such penetration distance is affected by many factors including spray pressure; stroke fuel amount (i.e. injection pulse width) and back pressure, when the spray pressure or stoke fuel

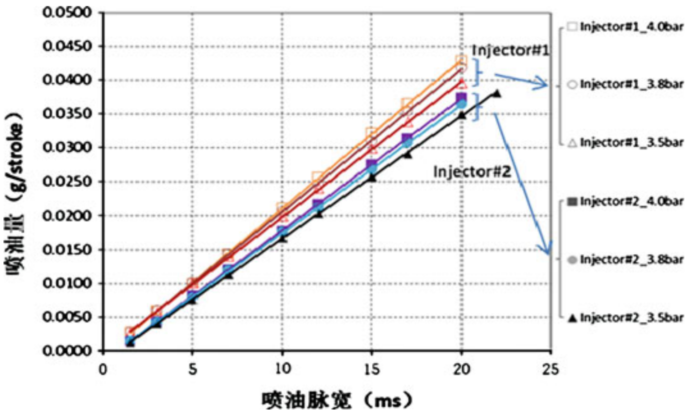

Fig. 1 Injector flow rate test results

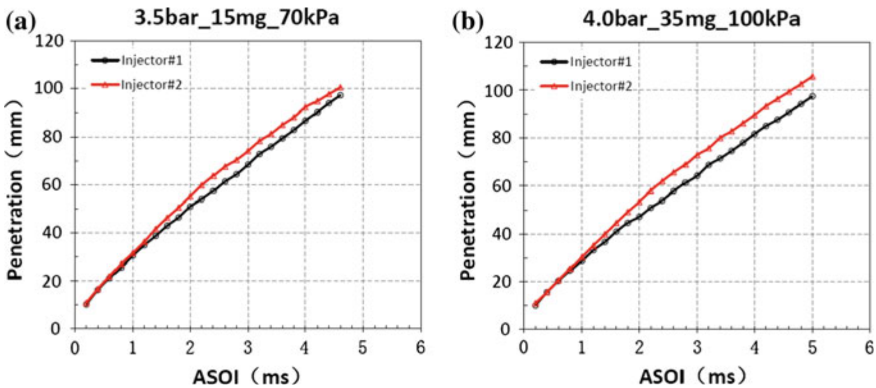

Fig. 2 The injector penetration distance under condition of injection pressure/fuel mass/back pressure as: **a** 3.5 bar/15 mg/70 kPa, and **b** 4.0 bar/35 mg/100 kPa

mass increase, the differences of the 2 injectors become visible as injector #2 leads as much as 9 mm longer penetration distance as shown in Fig. 2b.

Under different testing conditions, the injection cone angle of injector #1 is always larger than that of injector #2. The test results are shown in the Fig. 3. As it can be seen, the higher spray pressure, the larger the differences are. When spray pressure reaches 4.0 bar, the differences of cone angle of these two injectors can reach as much as 30 %. Larger injection cone angle may results better mixture, but it could also lead to worse wet-wall in SPI engine as well.

One of the typical result photos of fuel mass distribution tests are shown in the following Fig. 4. Injector #1 shows better distribution pattern than injector #2 in same testing conditions.

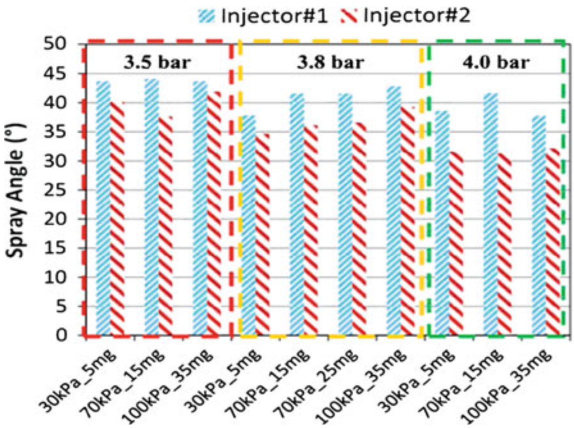

Fig. 3 Comparison of injection cone angles

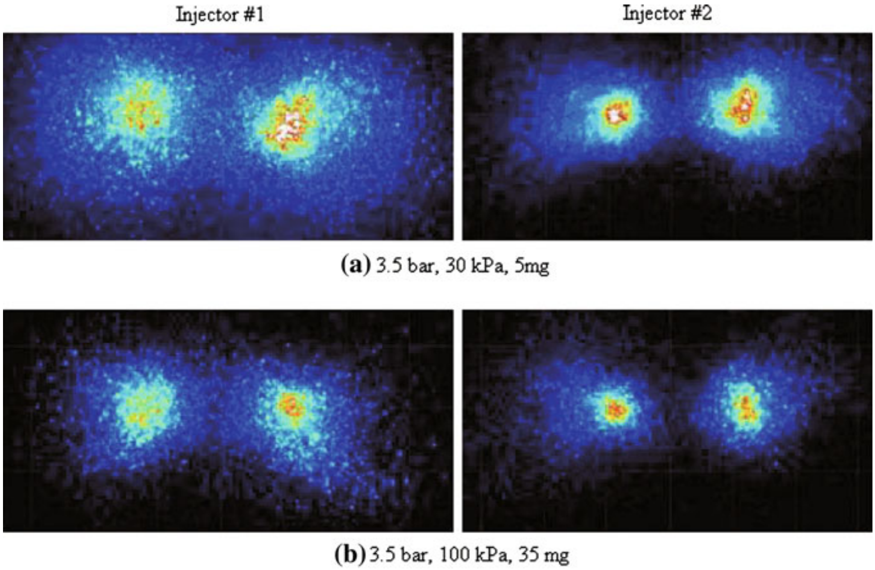

Fig. 4 Typical injection fuel mass distribution **a** 3.5 bar, 30 kPa, 5 mg, and **b** 3.5 bar, 100 kPa, 35 mg

3.2.1 Fuel Mist Particulate Distribution Test

The test results of statistics are shown in the Fig. 5. Injector #1 is much better than injector #2. The fuel particulates Sauter Mean Diameter (SMD) of injector #1 with a peak distribution concentrated around 20 um is about 20–30 % smaller that that of injector #2, theoretically, it should help better fuel–air mixture and better complete combustion in the chamber.

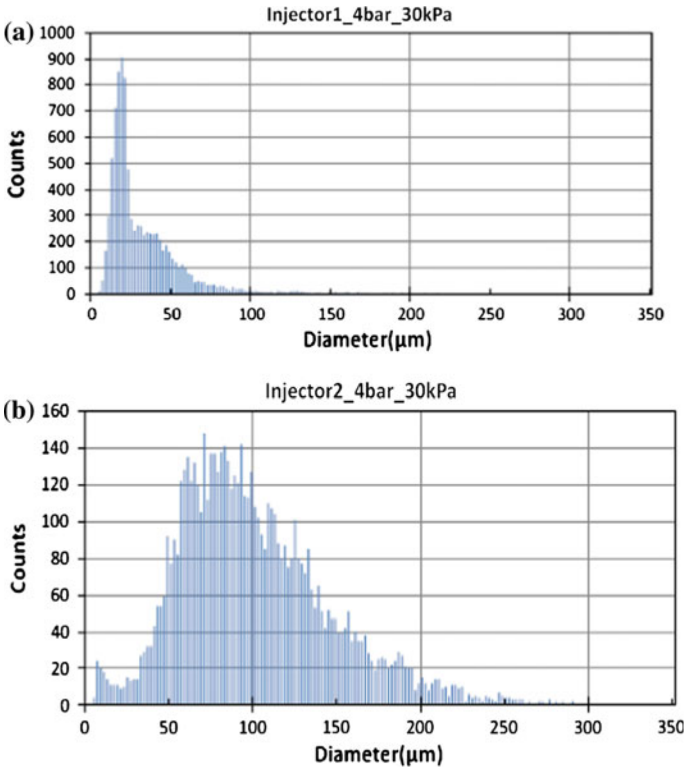

Fig. 5 SMD distribution of fuel particulates of 2 injectors. **a** Injector #1. **b** Injector #2

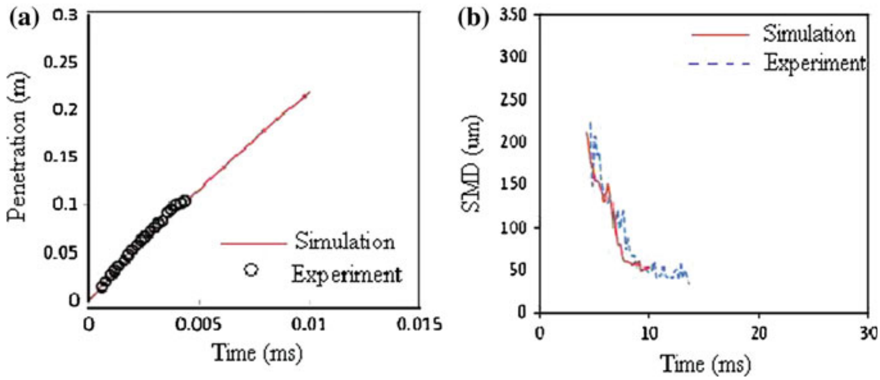

Fig. 6 CAE simulation and verification of component testing results. **a** Penetration distance. **b** SMD distribution

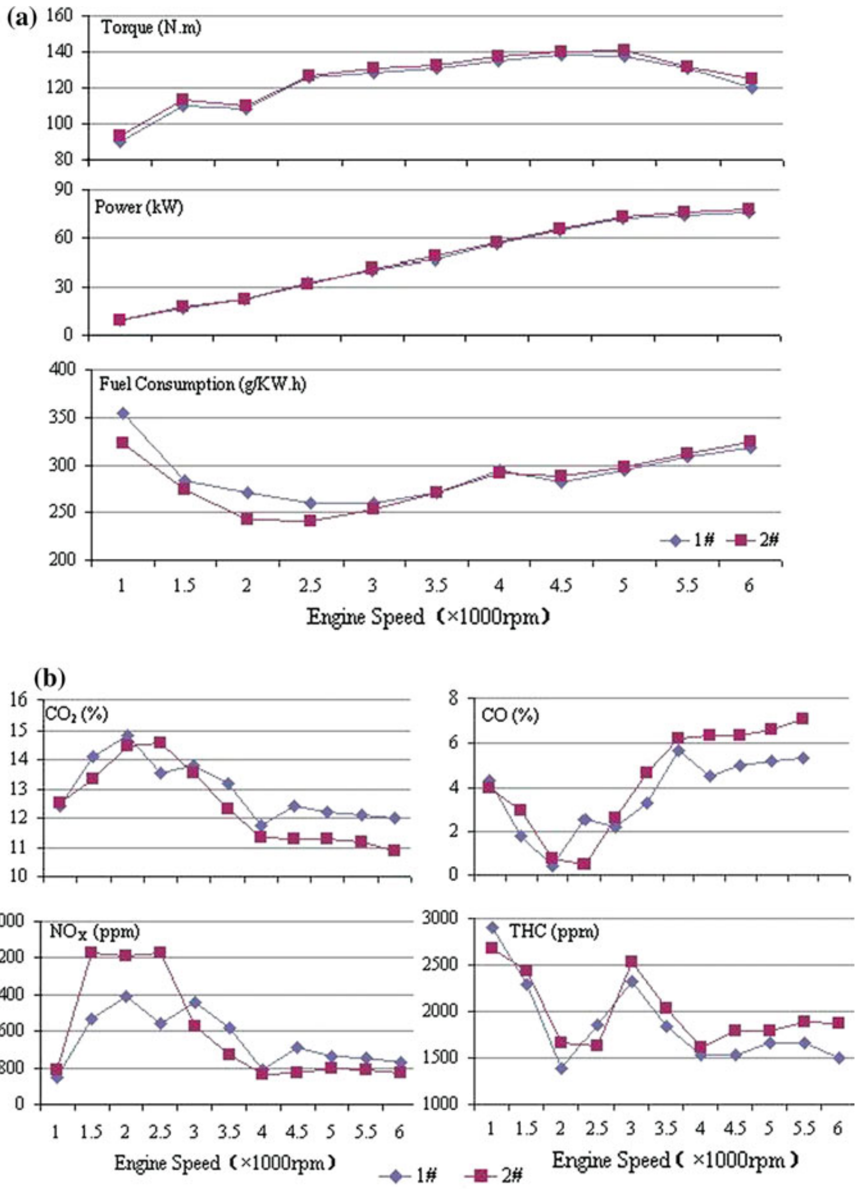

Fig. 7 Engine dynamometer test results with 2 different injectors. **a** Engine dynamic performance. **b** Emission results

3.2.2 CAE Analysis

Simulations have been done under different conditions by using AVL-FIRE software. The deviation is smaller than 3 %. Some typical comparison results are shown in the Fig. 6. It validates that the experimental results are generally accurate in spite of complicated testing conditions, and the CAE results are also verified through experiments in contrast.

In sum, the component test results show that there are some differences between the 2 selected injectors. Injector #1 has larger fuel rate and larger cone angles, but relatively minor penetration distance, much smaller fuel particulate SMD and better mass distribution. The test results and CAE analysis verified the correctness of each other.

3.3 Engine Dynamometer Test

The engine dynamometer test results are shown in the Fig. 7.

When the engine is running in wide open throttle (WOT) condition, the fuel economy performance of injector #1 is worse than injector #2 under 3,000 rpm, and then the differences become meaningless. The dynamic performances of the two injectors are almost the same means both injectors have sufficient flow rate without surprise. It also reminds that injectors can not be selected simply based on engine characteristic power and torque performances.

Yet, the emission results show complicated patterns. It seems that the combustion with injector #2 is less completed with less CO2 but more CO/THC in tailpipe especially when engine rpm goes beyond 3,000 rpm. It is still under investigation whether such phenomenal is related to the worse fuel distribution and relatively longer stroke pulse width of inject #2 to supply same amount fuel under WOT condition. Each engine cycle time will be less than 40 ms, e.g. less than 10 ms for the combustion phase when rpm goes beyond 3,000 rpm, so that longer stroke pulse width may leads to insufficient mixture and combustion time in cylinder chamber when cam timing is fixed. While under 3,000 engine rpm, fueling injection time is relatively short so that injector #2 can still warrant enough mixture and combustion time in chamber. In the case of combustion with injector #1, it may result in lower temperature or lower explosion pressure due to much better fuel distribution and much small fuel particulates SMD, as a result of that, the NO_x concentration in tailpipe is lower.

It has to be pointed out that the original EMS system used in dynamometer test is specially designed and calibrated based on only one of these injectors, the air–fuel (AF) ratio in the tests still exists minor differences even though deliberated calibration and adjustment have been carried out. As it is well known, minor air–fuel ratio differences could still cause noticeable changes in THC/CO/NO_x emissions.

Considering the critical impact of AF ratio, even though injector #1 consumes more fuel in low engine rpm regime, it is still picked for the engine development based on its comprehensive performance as shown above.

4 Conclusions

An experimental method is setup from component characteristics identification to engine dynamometer test and CAE verification, in order to optimize and select a best performance injector. Through the tests, it can be concluded that component test results of injector #1 are better in combustion atomizing and emission output, while injector #2 are worse in the SMD of mist particles which is bad for mixing of fuel and air.

Injector #1 is chosen for the 1.5 L engine.

Acknowledgments Many thanks go to Professor Yuying Zhang and Mr. Hui Lin in the Institute of Automotive Engineering, Shanghai Jiao Tong University for their great support during the components test and CAE analysis.

References

1. J Ni (1996) Automobile internal combustion engine principle. Publishing of Tongji University, Shanghai
2. Ding N, Gao W, Ping Y (2010) CFD and visualization research on spray characteristics of direct injection engine. Tongji University
3. Chen H, Xu M, Zeng W (2009) An improved monisize droplet generator for SMD calibration. Shaihai Jiaotong University
4. SAE J1832 (2000) Low pressure gasoline fuel injectors. SAE International, Warrendal
5. Das S, Chang S-I, Kirwan J (2009) Pattern recognition for multi-hole gasoline direct injectors using CFD modeling. SAE 2009-01-1488
6. SAE J2715 (2007) Gasoline fuel injector spray measurements and characterizations. SAE International, Warrendale