Advances and Applications in Fluid Mechanics

Published Online: September 2015
http://dx.doi.org/10.17654/AAFMOct2015_213_222
Volume 18, Number 2, 2015, Pages 213-222 **ISSN: 0973-4686**

ANALYTICAL STUDY ON SPRAY CHARACTERISTICS OF AN INJECTOR FOR GDI ENGINE

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Abstract

This study conducted the spray analysis for gasoline direct-injection multihole injector. When the injection pressure was changed to 75 bar, 100 bar and 125 bar under atmospheric pressure condition, change in spray penetration length, spray angle, and spray was obtained, which was compared and analyzed with test results. Spray penetration length, spray angle, and spray shape from spray analysis exhibited similar behavior to existing test results. Certain results of spray penetration length had a considerable deviation, which could be result of settings of analytical conditions.

Received: March 17, 2015; Accepted: June 3, 2015
2010 Mathematics Subject Classification: 76-XX.
Keywords and phrases: GDI, CFD, injector, penetration length, spray angle.
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Communicated by Shahrdad G. Sajjadi

1. Introduction

Global warming and environmental pollution due to burning of fossil fuels, which is the major driving factor for increase in global warming, have become globally serious environmental problems. Consequently, the requirements for developing economically feasible and environmental friendly engines are increasing in automobile industries. Automobile engineers are working hard to improve the fuel consumption rate and to satisfy environmental regulations for emissions, which is gradually strengthening [1, 2]. Apparently, numerous carmakers have manufactured various Gasoline Direct Injections (GDI) engines. GDI engine is the engine to inject directly and combust gasoline fuel in the combustion chamber. As it injects directly the fuel into the combustion chamber, the responsibility of engine becomes faster and accurate fuel supply is able to control the fuel quantity rather than the engine of port injection. In addition, vaporized latent heat of fuel injected into the combustion chamber has high cooling effect for the sucked air so that an increase in its compression ratio is available. This increase in the cooling effect and the compression ratio can improve volumetric efficiency and heat efficiency of the engine. Gasoline direct-injection engines are significantly dependent on spray atomization feature and mixture flow characteristics within the combustion chamber as compared with port injection engine. Therefore, for the development of engine performance, the study for injection properties of the injector has to be preceded [3, 4].

Based on the injection test results [5] of injector for GDI engine, which are applicable to mass produced automobiles, this study aimed to analyze the injection properties analytically according to the spray pressure changes through CFD simulation. Figure 1 represents gasoline GDI engine of 2400 cc applied to the injector that has been employed in this study.

Figure 1. 2400 cc GDI engine.

2. Injector Modeling and Analytical Method

The injector used in this study is shown in Figure 2, which is the six-hole injector of Continental Automotive. The injector is the gasoline direct-injection injector in the form of a solenoid and can be installed in GDI engine of 2400 cc. The specifications of the injector are shown in Table 1.

Figure 2. GDI injector.

Table 1. Specifications of injector

Variable	Value
Total spray angle	33° ± 5°
Total bent angle	13° ± 5°
Mass flow rate	14.7 g/s @100 bar
SMD	< 20 μm @75 mm from injector tip

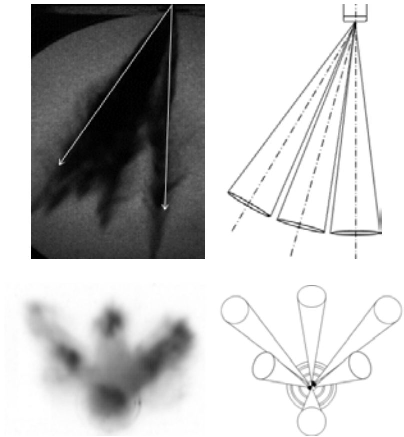


Figure 3. Spray angle and bent angle of the GDI injector.

STAR-CCM+ [6], which is the commercial software was used for the injection analysis. The direction of injection and angle of each inject hole were applied in analytical model and the results of spray visualization (Figure 3) were analyzed with respect to existing paper [5]. The material properties of injected fuel, which are necessary for analysis, are described in Table 2. The calculation mesh used for the analysis was trimmed mesh of a rectangular parallelepiped, and its number was about 260,000.

Table 2. Properties of gasoline

Feature		Value	
		Liquid	Gas
Vaporization temperature	K	352	-
Density	kg/m^3	830	-
Molecular weight	kg/kmol	221.16	
Latent heat	kJ/kg	180	-
Saturation pressure	Pa	1,875	-
Specific peat	J/kgK	2,050	2,430
Droplet surface tension	N/m	0.019	-
Viscosity	Pa-s	-	7×10^{-6}
Thermal conductivity	W/m-K	-	0.0178

The segmentation of fuel particles is actively processed as long as the relative velocity between air and fuel particles gets elevated under same condition [7]. Spray penetration length, which is the standard of spray penetration in injector spray, is sensitively affected by the spray pressure and with change in ambient pressure in the combustion chamber. There are various measuring methods according to spray shapes, as the one depicted in Figure 4 for spray penetration length, and the measurement for maximum penetration length in this study was based on Figure 4c that is the same with existing test measurements.

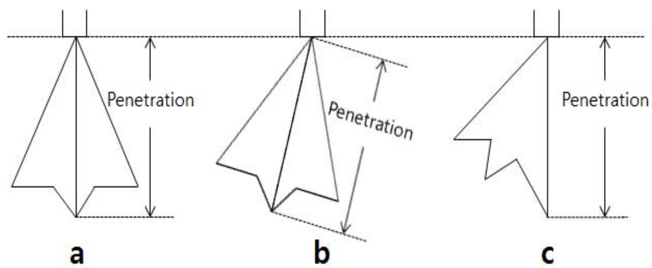


Figure 4. Penetration length measurement.

3. Result

The analytical results of SMD for injected fuel particles are shown in Figure 5, and in the present case, SMD signifies mean of total spray. A sudden atomization generated around 0.15ms of spray time for all spray pressures and atomization stabilized from 0.2ms of spray time. In 0.46ms of spray time, SMD values were 20μm for $P_{inj} = 100$ bar, 26μm for $P_{inj} = 75$ bar, and 18μm for $P_{inj} = 125$ bar. This result was due to setting of GDI injector model to value less than SMD = 20μm for $P_{inj} = 100$ bar.

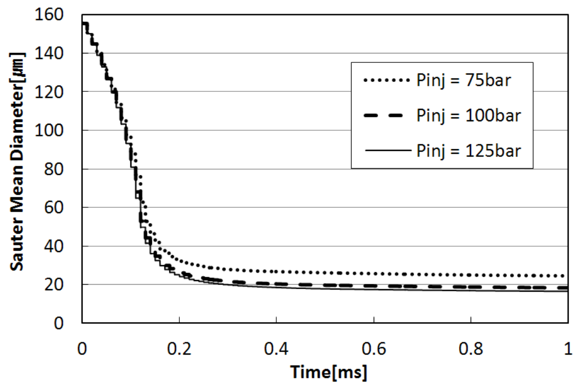


Figure 5. SMD variation according to time.

Figure 6 shows the example of spray angles, and Figure 7 represents results of comparative analysis between spray angles and spray pressures after 1ms of injection. The spray angle in test results was consistent to 33° and irrelevant to the change in spray pressure. The analysis revealed spray angle as 37°, which was also irrelevant to the change in spray pressure. Even the spray angle was 10% higher than the test results, which belonged to error range specified in the injector specification $(33^\circ \pm 5^\circ)$.

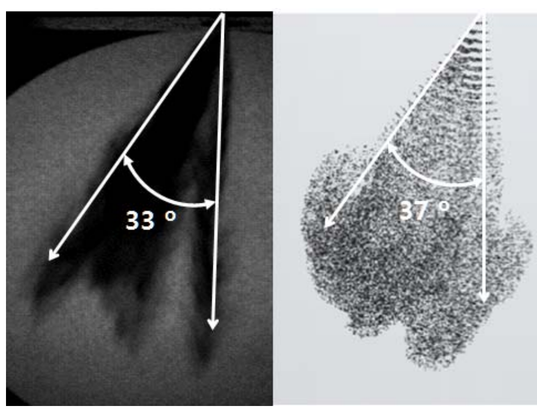


Figure 6. Spray angle measurement.

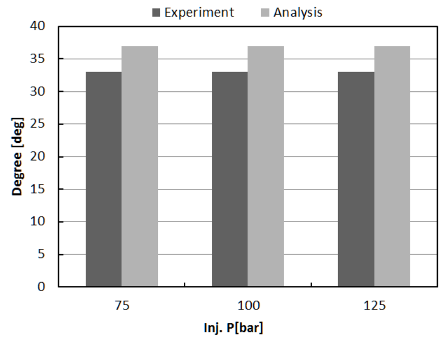


Figure 7. Comparison of spray angle.

Figure 8 indicates change in spray shape according to the change in injection pressure $(P_{inj} = 75\,\text{bar},\ 100\,\text{bar and } 125\,\text{bar})$ and time. In 1ms of spray time, the test results were very similar to the spray types as per visualization results. Nevertheless, an initial spray penetration length was confirmed to be overestimated from the picture when compared to test results, and this symptom could be more clarified from Figure 9. Figure 9 also shows spray penetration lengths according to spray pressure and time. As long as the spray pressure increased, we could confirm an increase in spray penetration lengths. This can be considered from the momentum increase of spray particles. The spray penetration lengths between test results and analytic results indicate a considerable deviation. Especially the analytic result of spray penetration length in 0.2ms of spray time is overestimated by maximum 2.8 times than the test result. There is a possibility of overestimation of the particle size in initial sprays because the initial particle size was set proportional to the injector hole. Also due to setting of final particle size as 20μm, the spray might be rapidly processed than the test result. Therefore, the velocity of sprayed particle after 0.2ms experienced a rapid decrease when compared to the result shown in Figure 9 and it could be due to decrease in particle momentum (Figure 5). The rapid decrease in particle size drives towards decreasing the momentum of particles so that the velocity is decreased and the spray penetration length is reduced. Consequently, it may be considered that the limitation of settings for the analysis led to the observed difference between the results of analytic and test.

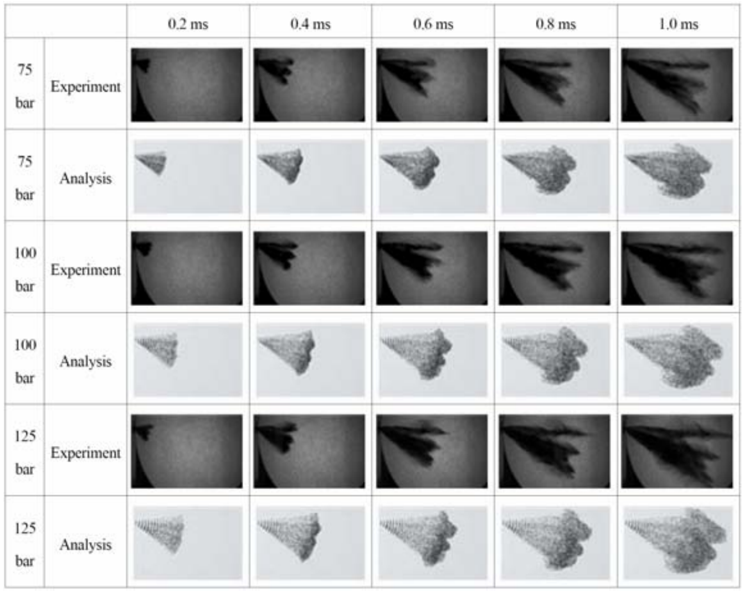
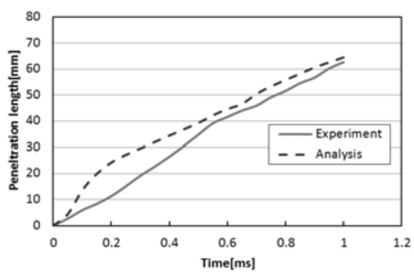
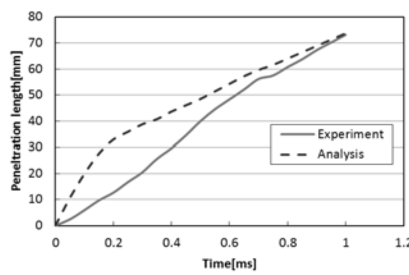


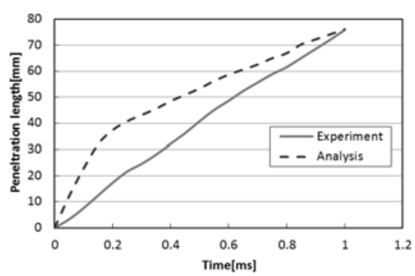
Figure 8. Change in spray shape according to the change in injection pressure.



(a) $P_{inj} = 75\,\text{bar}$



(b) $P_{inj} = 100\,\text{bar}$



(c) $P_{inj} = 125\,\text{bar}$

Figure 9. Comparison of penetration length.

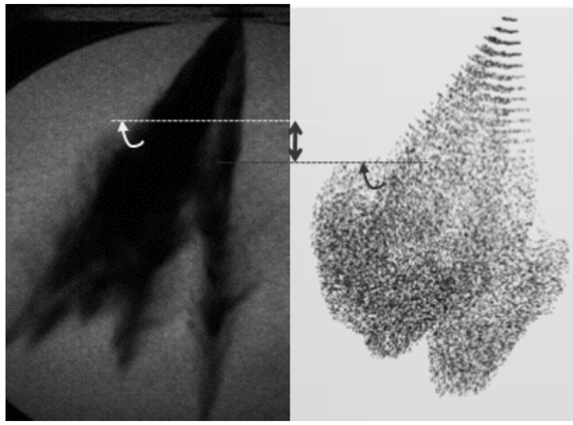


Figure 10. Comparison of air entrainment $(P_{inj} = 100\,\text{bar},\ 0.6\,\text{ms})$.

Figure 10 shows spray shapes of test and analysis in 100 bar of spray pressure and 0.6ms of the spray time. Air entrainment, the phenomenon by which air can penetrate in the side of spraying by the shearing force, can be visualized in the figure. Air entrainment in analytical result was generated later than in test results. This phenomenon resulted from setting the initial particle size proportional to injector hole size. That is due to set excessive initial spray momentum compared with those of test results. In addition, as the final average particle size in the late sprayings was regulated, it is considered that the spray was rapidly generated than in test results.

4. Conclusion

This study tested the spray properties of the injector for GDI engine through the analysis. We tried to obtain the reliability of spray analysis by comparing injector specification and existing visualization results. The following conclusions could be obtained based on comparison of spray test and analysis results.

(1) Using visualization results from the existing papers and the injector specification, the similar spray shapes with test results were obtained by achieving injector modeling for GDI engine and spray analysis. The spray analysis was conducted by changing spray pressure and time. In addition, individual spray shape was compared and analyzed with test values.

(2) As a result of spray analysis, as long as the injection pressure of injector $(P_{inj} = 75\,\text{bar},\ 100\,\text{bar and } 125\,\text{bar})$ increased, the size of spray particles decreased and the spray penetration lengths were longer. The comprehensive tendencies between results of spray analysis and test are consistent each other; however, considerable deviation was observed in a specific time, which could be due to two settings for the spray analysis. First, because the spray particle size in early sprayings was set proportional to the injector hole size, it could be considered that particle sizes were set oversize. Second, because of setting the final particle size to 20μm, the spraying was rapidly processed when compared to test results.

(3) In future studies, if the setting of analytical conditions could be made up for spray particle size and its movement after obtaining additional data, more reliable results will be generated from the analysis.

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