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An investigation on the spray characteristics of an 800kPa CNG injector

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Abstract. This paper investigated the spray characteristics of an 800 kPa compress natural gas (CNG) injector which was developed in the domestic Korea. The CNG injector with multi-holes, employed in this experiment, was designed to inject CNG in manifold at high pressure of 800 kPa. The spray macroscopic visualization test was carried out via Schlieren photography to study fuel-air mixing process. The fundamental spray characteristics, such as spray penetration, spray cone angle and spray velocity, were evaluated in the constant volume combustion chamber (CVCC) with varying the constant back pressure in CVCC from 0 to 1.8 bar. For the safety reason, nitrogen (N_2) and an acetone tracer were utilized as a surrogate gas fuel instead of CNG. The surrogate gas fuel pressures were controlled at 3, 5.5 and 8 bar, respectively. Injection durations were set at 5 ms throughout the experiment. The simulating events of the low engine speed were arranged at 1,000 rpm. The spray images were recorded by using a high-speed camera with a frame rate of 10,000 f/s at 512 x 256 pixels. The spray characteristics were analyzed by using the image processing (Matlab). The results showed the significant difference that higher injection pressure had more effect on the spray shape than the lower injection pressure. When the injection pressure was increased, the longer pray penetration occurred. Moreover, the linear relation between speed and time are dependent on the injection pressure as well.

1. Introduction

Due to concerning energy crisis and the air pollution and exhaust emission control, natural gas is the one of the most important alternative fuel and also consider as the cleanest fossil fuel. The abundance of natural gas has become a attracting factor for the wider usage of the fuel in the internal combustion engine [1]. Therefore, many engine scientists are interested to research on the natural gas engine. However, there are a few studies focusing on the mixture formation of gas jet.

This paper studied the spray characteristics in CVCC by varying the injection pressure of an 800 kPa CNG injector developed in the domestic Korea. To understand the spray behaviours, macroscopic spray visualization was investigated via Schlieren photography technic [2,3]. The spray penetration and cone angle, and speed of spray were analysed for studying the fuel-air mixing process.

2. Methodology

2.1. *Experimental setup*
The 800 kPa CNG injector as shown in Figure 1 was a solenoid injector. The general specification showed in Table 1. The diameter of nozzle exit is 6 mm. and its maximum injection pressure was 8 bar. It was mounted on the constant volume combustion chamber (CVCC) to evaluate the spray characteristics as well as injection mass flow rate with mass flow meter. For the safety reason, nitrogen (N_2) mixed with acetone tracer was utilized as a surrogate gas instead of CNG [4–7].

The injection pressure was set at 3, 5.5 and 8 bar. The back pressure in CVCC was varied with 1.0, 1.4 and 1.8 bar. The injection duration was controlled by supplying electrical on 5 ms. throughout the experiment. The spray cone angle and penetration, and speed of spray were assessed by using image processing [8,9].

2.2. *spray visualization*
The Schlieren photography technic arranging in z-type as shown in Figure 2 was employed in the whole experiment. The spray images were recorded by using a high-speed camera, Photron model S3, with a frame rate of 10,000 f/s. The resolution was selected at 512 x 256 pixels. All of The spray images were saved in a personal computer via Protron FASTCAM Viewer (PFV) software. The spray characteristics were analyzed by using the image processing (Matlab).

Figure 1. The 800 kPa CNG injector.

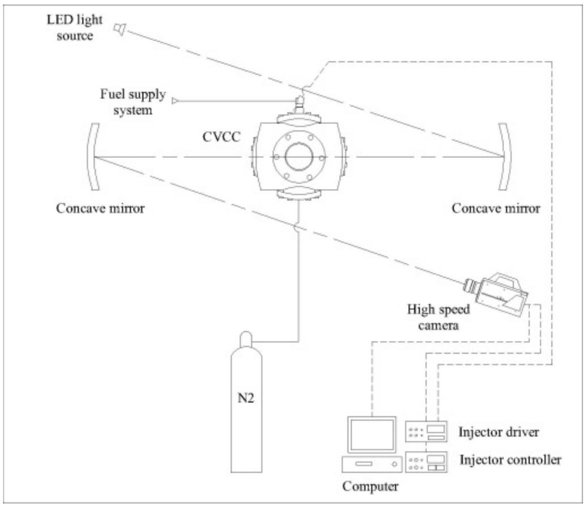


Figure 2. The spray visualization setup with the Schlieren photography technic (Z-type).

Table 1. General data of 800kPa injector.

Description	Value
Model	800 kPa (Prototype)
Type	Solenoid injector
Number of hole	4 holes
Tip diameter	6 mm.
Max. operating pressure	8 bar
Input voltage	10-14 V.

3. Results and Discussions

The definitions of spray cone angle and penetration length as shown in Figure 3 were declared as following [10]; spray cone angle (θ) was measured the angle from the end of nozzle edge and following along the edge of spray penetration length and spray penetration length (L) was measured the distance from the end of nozzle tip to the end of spray tip where the last pixel is located. Figure 4 showed mass flow rate of the 800 kPa injector that the higher injection pressure increases, the higher mass flow rate increases. The maximum mass flow rate at 8 bar was 36 slpm approximately. The spray developed patterns of injection pressure of 8 bar as shown in Figure 5 exhibited that mixing process of the gas jet was significantly different when the back pressure was changed. Figure 6 showed the spray cone angle with a variation of injection pressure and back pressure. The results showed that the spray cone angle was reduced by 24-27° approximately. In addition, the higher injection pressure led to convert the spray cone angle to narrow angle.

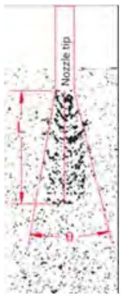
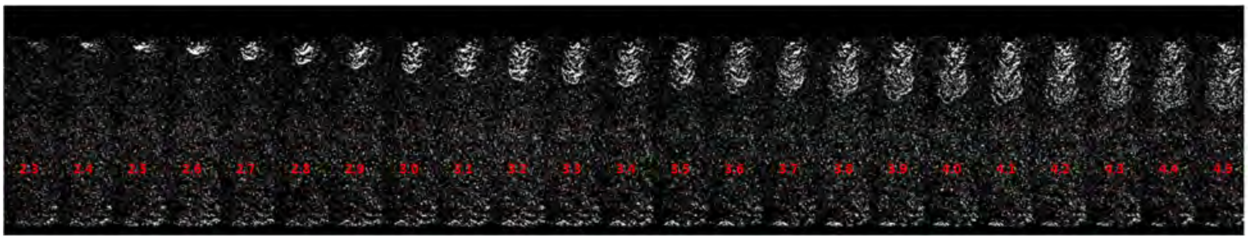
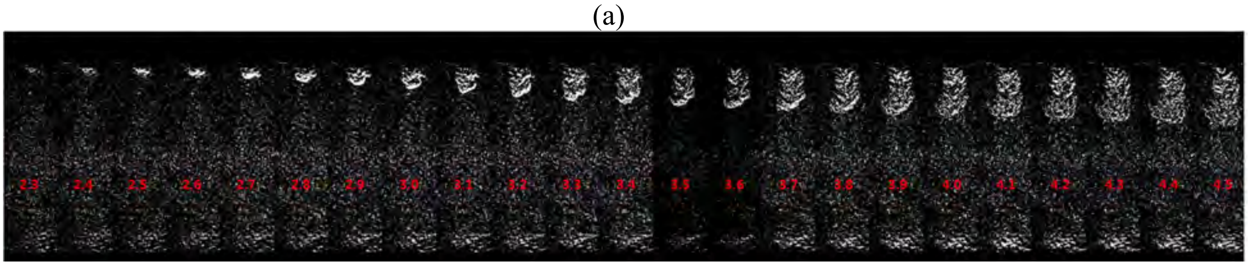


Figure 3. The definition of spray cone angle and penetration length.

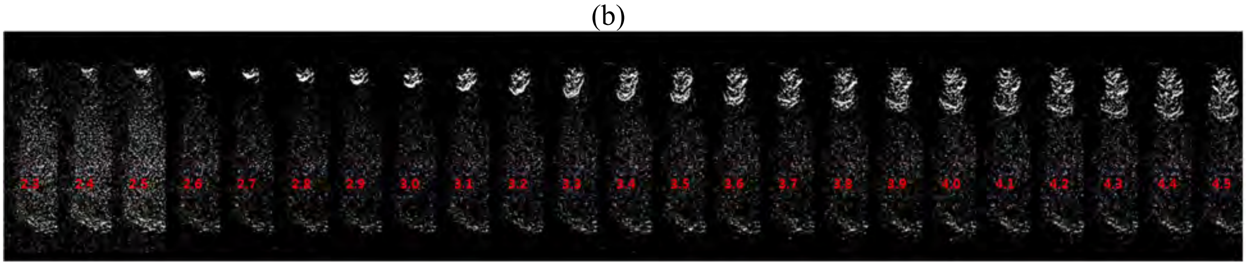
Figure 4. The injection mass flow rate with N_2 at the variation injection pressure.



(a)



(b)



(c)

Figure 5. The spray developed patterns of (a) injection pressure 8 bar and back pressure 1.0 bar, (b) Injection pressure 8 bar, back pressure 1.4 bar and Injection pressure 8 bar, back pressure 1.8 bar

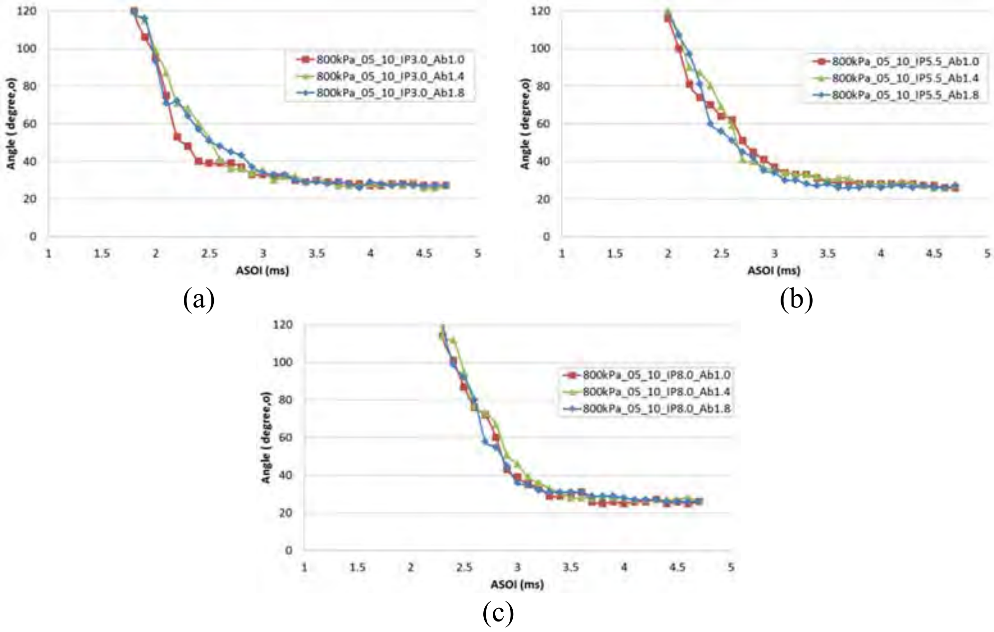


Figure 6. The spray developed patterns of (a) injection pressure 8 bar and back pressure 1.0 bar, (b) Injection pressure 8 bar, back pressure 1.4 bar and Injection pressure 8 bar, back pressure 1.8 bar.

Figure 7 illustrated the spray penetration with the variation of injection pressures and back pressure. The results showed that the back pressures of 1.4 and 1.8 bar effect the spray penetration length which was shorter than the back pressure of 1.0 bar and their penetration length not too much different with each other. Moreover, at high injections, it also affected on the injection delay.

Figure 8 showed the speed of gas jet that at the low back pressure, the speed of gas jet was faster than high back pressure due to low ambient density. In addition, the speed of gas jet was sharply increased after injection a few millisecond.

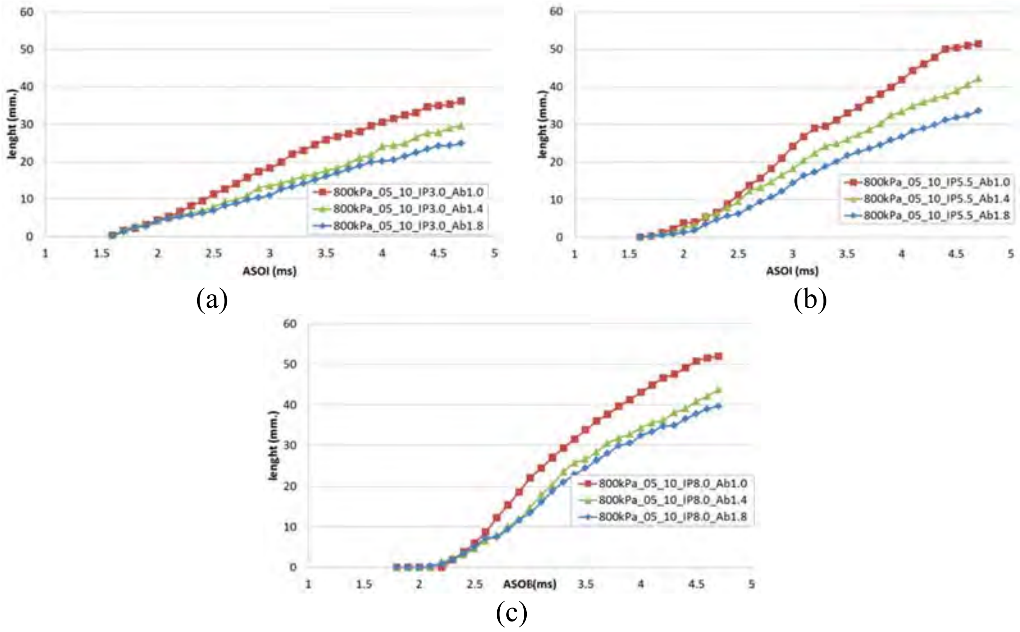


Figure 7. Effect of the injection pressure on the spray penetrations at (a) 3, (b) 5.5, and (c) 8 bar with the variations of the back pressure.

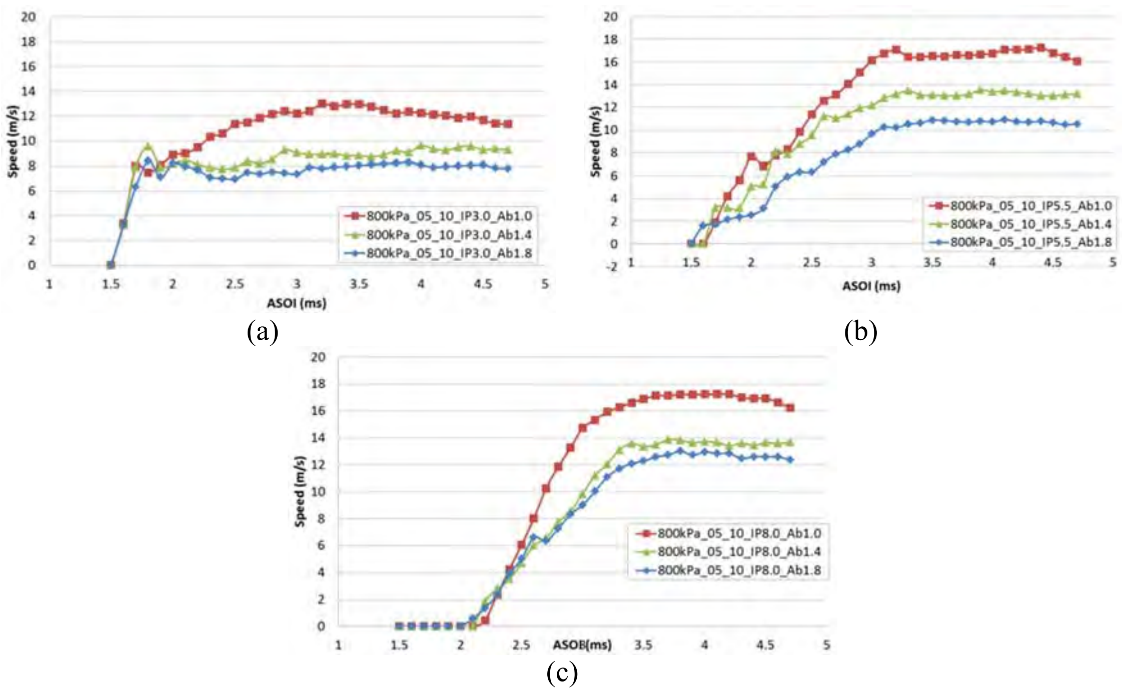


Figure 8. Effect of the injection pressure on the spray speed at (a) 3, (b) 5.5, and (c) 8 bar with the variations of the back pressure

4. Conclusion

This paper focused on the spray characteristics of the 800kPa CNG injector. The mass flow rate, the spray cone angle and penetration length, and the speed of gas jet are investigated. To analysis the spray behaviors, Schlieren photography technic and image processing are employed throughout the experiment. The results are compared with each other. The important conclusions are summarized as follows:

1. The higher injection pressure increases, the higher mass injection flow increases.
2. The higher injection pressure had more effect on the spray shape than the lower injection pressure. When the injection pressure is increased, the longer spray penetration occurs.
3. The higher back pressure has also effect on the spray form. However, at the back pressure of 1.4 and 1.8 bar, the spray characteristics are quite similar.
4. The linear relation between speed gas jet and time are dependent on the injection pressure as well.

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