研究論文

Spray Angles of Gasoline Fuel Injector by Image Processing, Shadowgraphy, and Spray Patternator

Jae Ho Kim, Soo Young No and Byung Soo Moon
Chungbuk National University

Spray angle, a parameter which is most commonly used to evaluate spray distribution, is important because it affects the axial and radial distribution of the fuel. Spray angles were measured and compared for the pintle-type gasoline fuel injector with n-heptane as a fuel by three measuring techniques, i.e. digital image processing, shadowgraphy, and spray patternator, respectively. Fuel was injected with the injection pressures of 0.2-0.35 MPa into the room temperature and atmospheric pressure environment. In the digital image processing method, the transmittance level greatly influences the spray angle with the axial distance from the injector. From the experimental results by the shadowgraphy technique, it is obvious that the spray angle vary during the spray injection period. The results of spray angle from the spray patternator show that there exist the different spray angles in the different areas. The spray angles increase with the increase in the injection pressure for the three measurement techniques considered in this study. The spray angles obtained by shadowgraphy method and by digital image processing method revealed the big difference due to the inherent difference of images between instantaneous image of shadowgraphy and multiple images of digital image processing. The critical axial distance of about 60mm was found by comparing the results from the digital image processing method and those from the spray patternator method.
Keywords: Spray Angle, Pintle-type Injector, Digital Image Processing, Shadowgraphy, Spray Patternator

1. INTRODUCTION

The parameter most commonly used to evaluate spray distribution is spray angle (cone angle or spray dispersing angle). As one of spray characteristics, spray angle is important because it influences the axial and radial distributions of the fuel and ultimately, efficiency and emissions. Of interest is the dependence of spray angle on the geometry of the nozzle, the physical properties of fuel used and the ambient gas, the flow properties of both phases at the moment of injection.

A major difficulty in the definition and measurement of the spray angle is that the spray cone has curved boundaries, due to the effects of air interaction with the spray. Spray angle is commonly obtained by measuring the angle formed by two straight lines drawn from the nozzle tip to the outer periphery of the spray at some specified distance from the nozzle tip. The specified distance from the atomizer in diesel spray is, however, arbitrary and ambiguous. This may be due to that it is often hard to observe the spray boundaries, thus making an accurate estimate of the spray angle difficult.

The various methods of measuring spray angle have been developed for the years. One method is to project a silhouette at the spray onto a ground-glass screen at two or three magnifications. Alternative one is to use two probes equally spaced about the nozzle centerline that are moved until they contact the edges of the spray(1). However, the photographic method has been usually used for measuring spray cone angle. As a result of rapid development of computer-integrated systems and digital cameras, digital image processing has been developed as an alternative method to the conventional 35-mm still camera film system(2)-(5). The edge of the spray in this method was defined as a line of 80%(2) or 95%(3) transmittance of the back light. Recently, optical diagnostics instrumentation such as laser shadowgraphy technique(6), and schlieren imaging system(7) have been introduced for measuring the spray angle. In addition, the spray angle can be obtained from the measurement of spray pattern (8), (9).

The objective of this study is to measure and compare the spray angles resulted from digital image processing, shadowgraphy, and spray patternator, respectively and to suggest the guidelines for measuring the spray angles for the fuel injectors used in gasoline engine applications.

2. EXPERIMENTS

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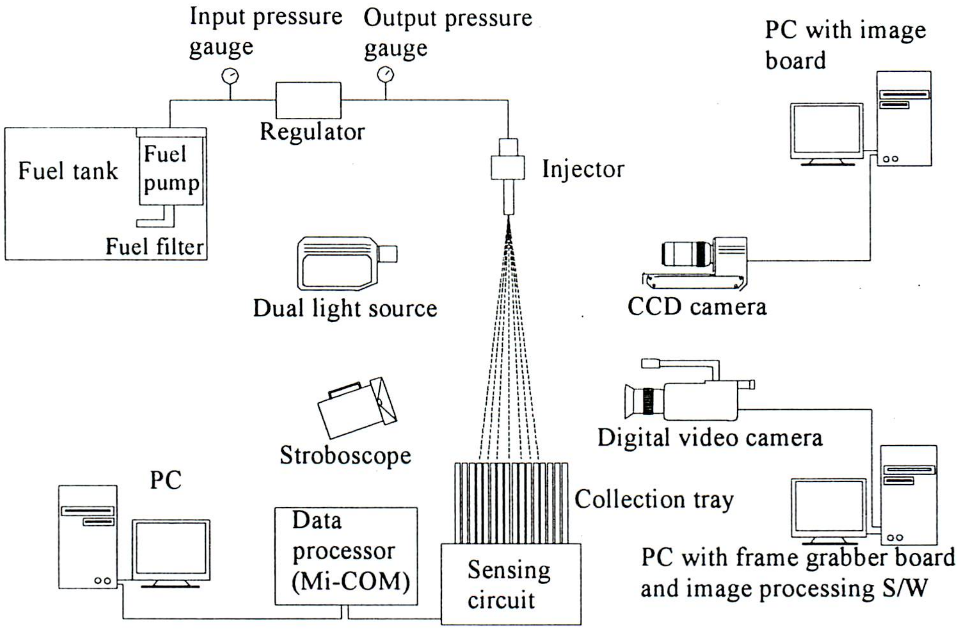

Fig. 1 Schematic of experimental setup

Figure 1 shows the schematic of the experimental setup used in this study. It consists of the fuel supply system, injector, and measurement system. The measurement system includes the three techniques, i.e. digital image processing , shadowgraphy , and spray patternator.

N-heptane as a test fuel was pumped by the fuel pump after passing the filter and was supplied to the injector through pressure regulator. The properties of n-heptane at 293K are shown in Table 1. Fuel was injected vertically downstream through an electromagnetic pintle-type injector(0.9 mm in hole diameter , 0.8 mm in pintle diameter, and 30 deg. in pintle angle) with the injection pressures of 0.2 – 0.35 MPa for 2.5 ms in injection duration except shadowgraphy method into the room temperature and atmospheric pressure environment. The injection duration of fuel in shadowgraphy method was set to be 6ms to get a long and clear spray for the comparison with other methods used in this study.

Table 1 Properties of n-heptane at 293K

Density	684 kg/m^3
Kinematic viscosity	0.61×10^{-6} m^2/s
Surface tension	20.9×10^{-3} N/m
Refractive index	1.385

Of three evaluation methods of spray angle, the digital image processing was performed by capturing multiple images of the spray with SONY 720 by 480 pixel 3-CCD digital video camera(DCR-VX1000) and a frame-grabber board. Direct lighting from the stroboscope was used to illuminate the spray field from a dark background. The captured spray images were stored in a PC for off-line analysis. Each spray image was processed with PHOTOSHOP image analysis software. The local spray angle is determined by taking the arctangent of the local spray width divided by the axial location of the spray width..

The shadowgraphy was based on the macroscopic spray measurement function of PMAS(Particle Motion Analysis System, V-tek Co., Korea). It consists of a spark light source of very short time duration (<50 ns), field lens, a CCD camera, and a PC with an image board. The shadowgraphy image passes through the diaphram of camera lens and is recorded on CCD. The qualitative observation and instantaneous images for a short period of time were obtained by the shadowgraphy technique.

The spray angle and axisymmetry of spray was also determined by a spray patternator. The spray patternator used here consists of 256, 5mm diameter cells arranged in square pattern. This technique gives the quantitative observation for the injection time of 1000 with injection pulse of 2.5 ms. The details of basic theory, operation, features of KEFICO patternator can be found in reference 10.

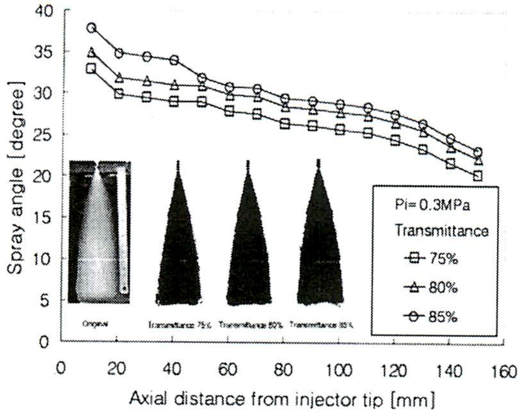

Fig. 2 Transmittance effect

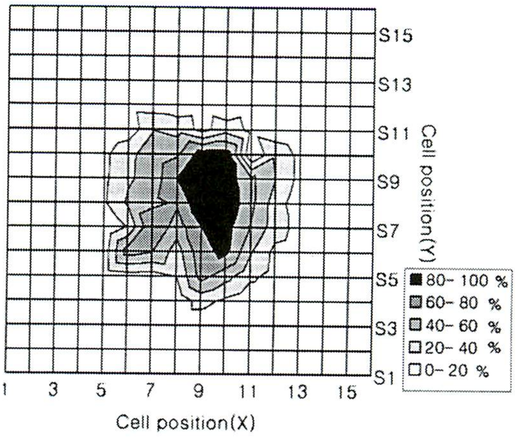

Fig. 4 Spray volume distribution in patternator

3. RESULTS AND DISCUSSION

In the digital image processing technique, the spray analysis began with selection of a threshold level to be used to separate the spray area from the background in a captured images. The threshold level is related to the transmittance of the backlight. The edge of the spray was usually defined by 80%[2] or 95% [3] transmittance criteria in the measurement of spray angle. Figure 2 shows the effect of transmittance level on the spray angle at Pi=0.3MPa. The original and the converted images with the different transmittance level are also included. It is clear that the selection of transmittance level affects the spray angle in the fixed axial distance from injector. The spray angle differed by 2~3 ° while the difference in the transmittance level was 5%. The spray angle is decreased monotonically with the increase in the axial distance from the injector. For the comparison of spray angles from the digital image processing with those from other techniques, the 80% transmittance level was selected.

The change in spray pattern by shadowgraphy images with Pi=0.3 MPa at the different times from the start of injection is shown in Fig.3. It is clear from the figure that the spray angle can be changed with time after the start of injection and with the different axial distance from the injector. For the comparison with spray angles resulted from other methods, the shawdowgraphy images at 6 ms after the start of injection was selected.

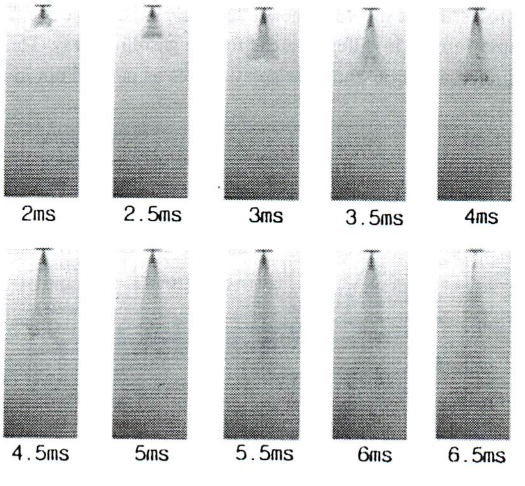

Fig. 3 Spray images by shadowgraphy (P_i=0.3MPa)

The individual cell volume collected in the spray patternator was transformed to Cartesian coordinate and is depicted in Fig. 4. The relative volumetric distribution is defined as the ratio of cell volume collected to the maximum cell volume collected and is also shown in Fig.4. Spray angle was obtained from the above data as the included angle where 80%, 90%, 95%, and 97.5% of the fuel spraying from the injector is contained. However, SAE recommended 95% of fuel distribution for a solid spray cone pattern[11] in the measurement of spray angle for gasoline spray. For the comparison of spray angles with those by other techniques in this study, the recommendation of SAE was therefore followed.

Figure 5 illustrates the variation of spray angle with the time after the start of injection at Pi= 0.3 MPa for the different axial distance from the injector by shadowgraphy technique. Spray angle is not widely changed between 3 ms and 6 ms at the all axial distances from the injector considered in this study. It can be found that there is difference for spray angle with the different axial distance at

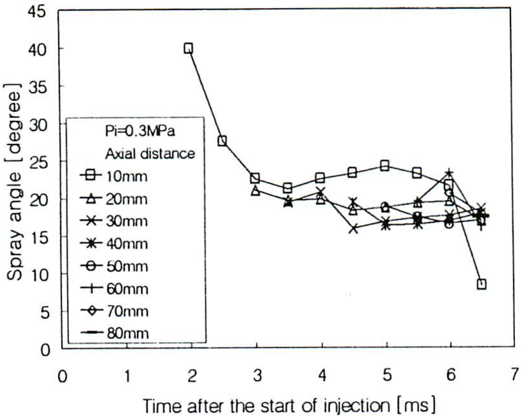

Fig. 5 Spray angle variation with time after injection by shadowgraphy

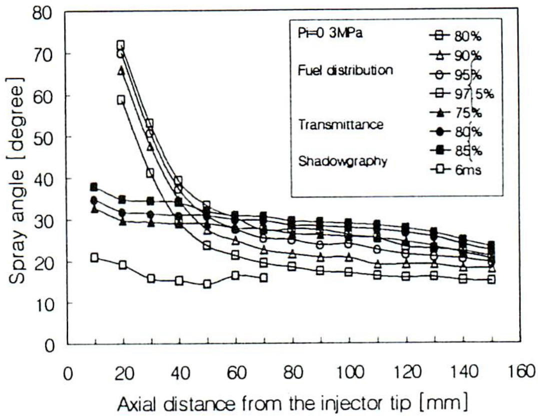

Fig. 6 Comparison of spray angles by measuring techniques

the same time after the start of injection.

Figure 6 displays the variation of spray angle with the axial distance from the injector for the different distribution of the fuel spraying from the injector from patternator method at Pi=0.3MPa. For the comparison, the results from the digital image processing method with the different transmittance levels and from the shadowgraphy method at 6ms after the start of injection are also included. The spray angles by the spray patternator is sharply decreased with the increase in the axial distance.

The increasing rate of spray angle with the increase in fuel volume distribution is remarkably increased. It is found that the spray angle by the fuel voume distribution of 95% is relatively well with those by the digital image processing techniques with 75% transmittance level from the axial distance of 60mm.

The results of spray angles from three measuring methods at Pi=0.2MPa are compared in Fig.7. As similar as in the case of Pi=0.3MPa in Fig.6, spray angles obtained from spray patternator decrease sharply up to 40 mm from the injector tip and are larger than those of other two methods. The larger spray angle in the near region from the injector is believed to be due to the effect of obstruction by spray patternator. In other words, the distance between injector tip and patternator is too close to get the influence of entrainment of the ambient air. It is found that the spray angles with 75~85% transmittance at Pi=0.2MPa are relatively independent of the axial distance from the injector. The spray angle by the shadowgraphy is decreased monotonically with the increase in the axial distance from the injector. It is clear that the spray angle is widely different according to the measurement techniques introduced in this study. However, it must be kept in mind that there is the inherent difference of images between instantaneous image of shadowgraphy and multiple images of digital image processing. It should be noted that there exist in the different spray angles in different areas for the gasoline spray. This is similar as a near and a far spray angles as pointed out in the

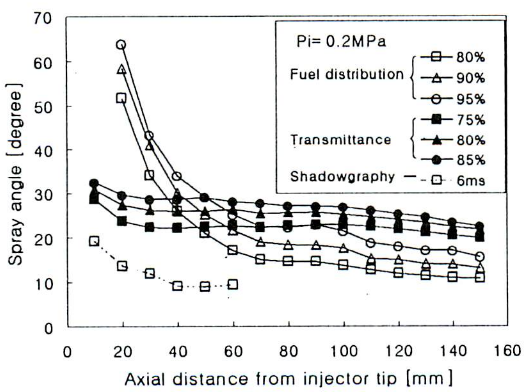

Fig. 7 Spray angles by different measuring method

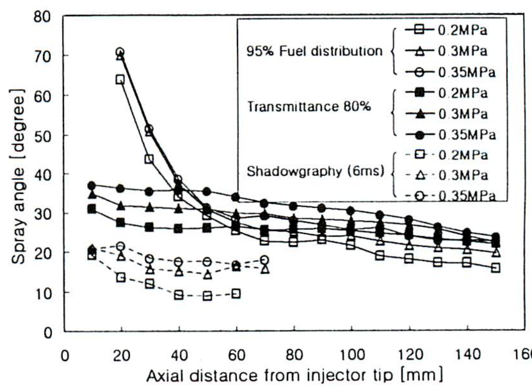

Fig. 8 Injection pressure effect

diesel spray by Dan et. al [2], Chang and Farrell [3].

Figure 8 displays the effect of injection pressure on spray angle with the axial distance from injector for three measurement techniques. Even though there is the difference in increasing rate of spray angle with the different measurement method, the spray angle increases with the increase in the injection pressure under the experimental conditions considered in this study. This is coincident with the results by Lai et. al[12] for the wide range of injection pressure. It should be noted again that the spray angle is considerably different, especially in the near region from the injector, even in the same injection pressure with the measurement techniques used in this study. From the above discussions, the optimal position for measuring the spray angle by the spray patternator seems to be 60mm from the injector tip.

4. CONCLUSIONS

Spray angles were measured and compared for the pintle-type gasoline fuel injector by digital image processing, shadowgraphy, and spray patternator, respectively. N-heptane as a test fuel was injected with the injection pressures of 0.2-0.35 MPa into the room temperature and atmospheric pressure environment.

In digital image processing approach, the selection of the transmittance level is critical to obtain the edge of spray and hence to measure the spray angle. From the measurement results by the shadowgraphy technique, it is clear that the spray angle vary during the spray injection period. The measurement results from spray patternator show that there exist the different spray angles in different region. Spray angle increases with the increase in the injection pressure. The spray angle is remarkably different, especially in the near area from the injector, according the measurement techniques introduced in this experimental work. The spray angles obtained by shadowgraphy method and by digital image processing method revealed the big difference due to the inherent difference of images between instantaneous image of shadowgraphy and multiple images of digital image processing.

The critical axial distance of about 60mm was found by comparing the results from the digital image processing method and those from the spray patternator method.

LITERATURE REFERENCES

(1) Lefebvre, A.H.:*Atomization and Sprays*, Hemisphere Pub. Co., New York, (1989), 275.

(2) Dan, T., Yamamoto, T., Senda J. and Fujimoto, H.: Effect of Nozzle Configurations for Characteristics of Non-Reacting Diesel Fuel Spray, SAE paper 970355, (1997).

(3) Chang, C.T. and Farrell, P.V.: A Study on the Effects of Viscosity and Nozzle Geometry on High Injection Pressure Diesel Spray Characteristics, SAE paper 970353, (1997).

(4) Hung, D.L.S. and Markle, L.E.: Macroscopic Spray Characterization of DI Gasoline Injectors Using Automatic Image Analysis, *Proc. of ILASS-Americas 99*, Indianapolis, USA, (1999), 439-431.

(5) Senda, J., Yamaguchi, M., Tsukamoto, T. and Fujimoto, H. : Spray Characteristics of a Pintle-type Injector in a Low-Pressure Gas Environment, *Atomization and Sprays*, vol.4, (1994), 237-251.

(6) Renoir, G. and Maly, R.R. : Spray Structures of Automotive Injectors, *Int'l Symp. on Advanced Spray Combustion*, Hiroshima, Japan, July 6-8, (1994), 45-53.

(7) Naber, J.D. and Siebers, D.L., : Effects of Gas Density and Vaporization on Penetration and Dispersion of Diesel Sprays, SAE paper 960034, (1996).

(8) Xu, M. and Markle, L.E. : CFD-Aided Development of Spray for an Outwardly Opening Direct Injection Gasoline Injector, SAE paper 980493, (1998).

(9) Parrish, S. and Evers, L. : Spray Characteristics of Compound Silicon Micro Machined Port Fuel Injector Orifices, SAE paper 950510, (1995).

(10) Kim, J.Y., Baik, S.K., Choi, S.Y., Lee, D.R., Yoon, : S.H. and Kang, K.K. : Development of Spray Patternator for Gasoline Fuel Injector, *4th Conf. of ILASS-Asia*, (1999), 93-98.

(11) SAE Highway Vehicle Recommended Practice, Gasoline Fuel Injector, SAE J 1832, Nov., (1989).

(12) Lai, M.C., Zhao, F.Q., Amer, A.A. and Chue, T.S. : The Structure of Por Injector Spray in Gasoline Engines, Int'l Symp. On Advanced Spray Combustion, Hiroshima, Japan, July 6-8, (1994), 79-89.

Dr. Jae Ho Kim
Keumwang Technical High School
Eumsung, Chungbuk,
369-900, Korea
Tel : +82-43-877-0367
Fax : +82-43-877-5717
e-mail : jeiho2000@hanmail.net

1980 BS in Industrial Education, Chungbuk Nat'l University, Korea
1995 MS in Mechanical Engineering, Chungbuk Nat'l University, Korea
2001 Ph.D. in Mechanical Engineering Chungbuk Nat'l University, Korea

His interests in research are the sprays in engines.

Prof. Byung Soo Moon
Dept. of Mechanical Engineering
Chungbuk National University
Cheongju, 361-763, Korea
Tel : +82-43-261-2444
Fax : +82-43-263-2441
e-mail : bsmoon@chungbuk.ac.kr

1965 BS in Mechanical Engineering, Hanyang University, Korea
1976 MS in Mechanical Engineering, Kyunghee University, Korea
1987 Ph.D. in Mechanical Engineering, Kyunghee University, Korea

His research area is in internal combustion engine

Prof. Soo Young No
Dept. of Agricultural Machinery Engineering
Chungbuk Nat'l University
Cheongju, 361-763, Korea
Tel : +82-43-261-2583
Fax : +82-43-271-4413
e-mail : sooyoung@chungbuk.ac.kr

1976 BS in Mechanical Engineering, Inha University, Korea
1980 MS in Mechanical Engineering, Inha University, Korea
1990 Ph.D. in Mechanical Engineering and Energy Studies, University of Wales, College of Cardiff, U.K.
1999- Secretary of ILASS-Asia and ILASS-Korea
2000- Editorial board member of Korea Society of Automotive Engineers

He is actively pursuing research in atomization and sprays, CFD modeling and combustion.