An Investigation of Design Parameter and Atomization Mechanism for Air Shrouded Injectors

Ki-Hyung Lee*, **Chang-Sik Lee**
Department of Mechanical Engineering, Hanyang University, 1271 Sa-1 dong, Ansan, Kyunggi-do 425-791, Korea
Bong-Gyu Kim
BK21 Research center, Hanyang University, 17 Haengdang-dong, Seongdong-gu, Seoul 133-791, Korea
Hae-Young Jeong
Department of Mechanical Engineering, Graduate School of Hanyang Univevrsity, 1271 Sa-1 dong, Ansan, Kyunggi-do 425-791, Korea

With increasing requirements for the less harmful exhaust emissions and the better fuel economy, the conventional injectors in gasoline engines can be replaced by the air shrouded injector in order to provide improved combustion in engine operations. To find out the optimal shape of air shrouded atomizer attached to the conventional injector nozzle, the critical design parameters such as droplet size, fuel and air inlet angles, and injection angles were investigated based on experimental analyses. To explain the characteristics of fuel atomization, these experimental approaches were carried out using a Phase Doppler Particle Analyzer (PDPA) system. The droplet sizes of injected air fuel mixture were obtained by using the beam diffraction phenomenon. In order to improve the atomization effect, the various atomizers were investigated. The Sauter Mean Diameter (SMD) measured at the predetermined locations outside the atomizer represented the performance of fuel atomization. The experimental results show that the design factors and atomization mechanism needed for developing air shrouded injectors. The suggested design parameters in this paper can be a useful reference in the early design stage.

Key Words: Air Shoruded Injector, SMD(Sauter Mean Diameter), Weber Number, Atomizer

Nomenclature

n : Number of holes of atomizer
ϕ : Hole diameter of atomizer (mm)
θ : Hole angle of atomizer (deg.)
p : Inlet air pressure of atomizer (bar)

1. Introduction

With increasing demands of high quality and low emissions, automobile industries have focused on the comfortable and low fuel-consumption engines. In addition, the regulation of exhaust emission is getting stricter due to environmental policy. For this reason, the Gasoline Direct Injection (GDI) system is one of the solutions to reduce the hydrocarbon emissions. However, the application of GDI engine is at an early development stage because of the high internal pressure, the pulse-noise, and the vibration obstacles, etc (Zhao et al., 1997).

As an alternative of the GDI, the air shrouded injector can be applied to the conventional gasoline engine without a major change of an engine or the engine management system. Compared with conventional injectors, the air shrouded injector provides a benefit to minimize exhaust

* Corresponding Author,
E-mail : hylee@hanyang.ac.kr
TEL : +82-31-400-5251; **FAX** : +82-31-406-5550
Department of Mechanical Engineering, Hanyang University, 1271 Sa-1 dong, Ansan, Kyunggi-do 425-791, Korea. (Manuscript **Received** July 31, 2002; **Revised** January 24, 2003)

emission and to improve the cold start performance (Shayler, 1989 ; Saikalis et al., 1993 ; Brown and Lodommatos, 1991 ; Harada and Shimizu, 1992). Therefore, the application of air shrouded injector will be a promising one to achieve lower fuel consumption. In general, the capability of the air-fuel mixture in gasoline engine has dominant influence on the engine operations. Currently, the most popular injection system in gasoline engines is an electronic fuel injection (EFI) system. In EFI system, the spray injected from the nozzle is a combination of the vapor and the liquid. The spray can easily impinge to the wall of an intake port, intake valve and/or to the combustion chamber. This wall-wetting ratio depends on the ambient temperature, the injection timing, the geometry of an intake system, and the engine driving conditions. In addition, the injection characteristics such as spray angle and droplet diameters are significant factors for the wall-wetting ratio.

There are two types of air assisted injectors. The first type is the pulsed-pressurized internal mix air assisted (PPAA) injector, which uses high-pressure air produced by the mechanical pump or compressor. However, the PPAA injector has high fuel consumption due to mechanical loss and weight. The second type is the vacuum driven air assisted (VDAA) injector. This type can atomize fuel droplets efficiently without engine power loss by using natural airflow created from pressure difference between front and rear of throttle valve (Ikeda et al., 1997 ; Zhao et al., 1995).

In this paper, experimental analyses using a PDPA system were performed to design the better VDAA injector and to investigate the atomization mechanism of a shrouded injector.

2. Experimental Procedures

To measure atomization performance of the air shrouded injector, a PDPA system (Fig. 1) was used for the measurement of droplet size and velocity. This system consists of 5W Ar-ion laser, transmitter, optical receiver and signal processor. When fuel droplets sprayed from injector were measured, 10000 or more sampling data were acquired at each measurement point. Moreover, ensemble average was calculated.

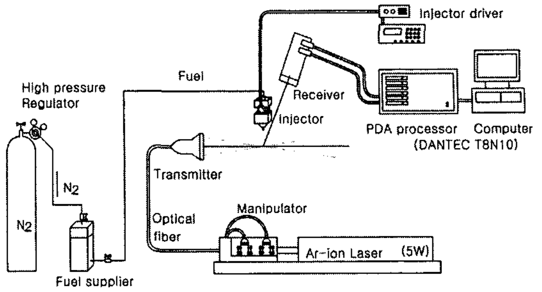


Fig. 1 The schematic diagram of PDPA system

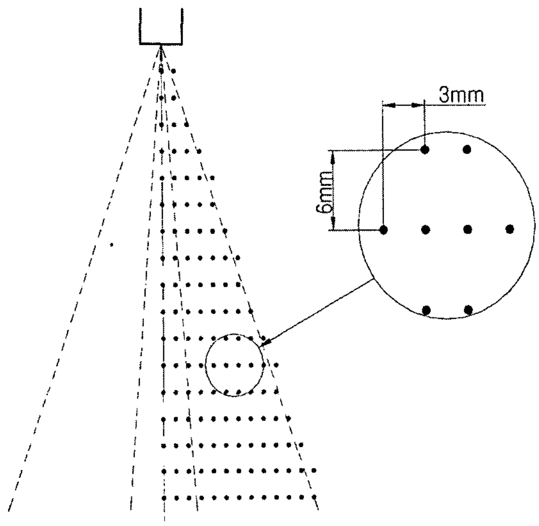


Fig. 2 The position of measurement points

Shrouding air pressure was varied in four conditions of 0, 10, 30 and 50 kPa. All pressure conditions are limited within the range of real engines. Test fuel was gasoline, which was sprayed into ambient air while fuel injection pressure was 0.3 MPa. Measuring points are shown in Fig. 2. Each measurement points were arrayed at an interval of 3 mm horizontally and 6 mm perpendicularly. To investigate the atomization mechanism, on the other hand, measurement positions were located at 100 mm vertically below the nozzle to compare the SMD between design parameters.

In this study, a test injector, shown in Fig. 3, was taken as a base for the air shrouded injector with modified design. Air shrouded injectors can be divided into two categories depending where the mixing process of the air and fuel takes place. One is the internal mixing type where, the mixing takes place within the atomizer and then the mixture is injected into the atmosphere. The other is the external mixing type where the fuel is first injected into the atmosphere and then the atomization is caused by collision with the shrouded air. For this study, the internal mixing type was chosen which has a better atomization effect and is known to have lower distortion of the injection pattern by the shrouded air.

The diameter (ϕ), the number (n) of the holes and the angle (θ) of the inflow passage are major parameters for introducing the shrouded air that influence the spray atomization. Various shapes of air shrouded injectors are shown in Fig. 4.

Table 1 Design parameter of atomizer

Number of holes (n)	Hole diameter (ϕ)	Air supply angle (θ)
2	0.5	0°
3	1.0	15°
4	1.2	20°
6	1.5	30°
		45°

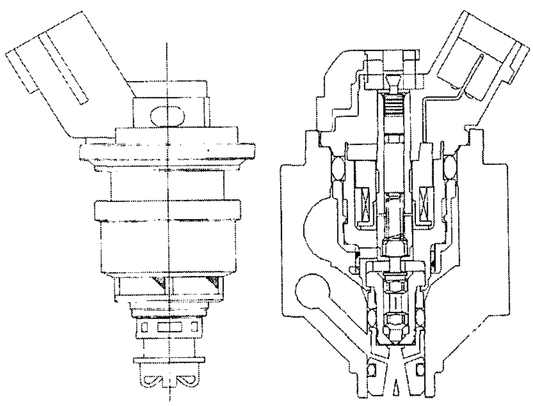


Fig. 3 The test injector

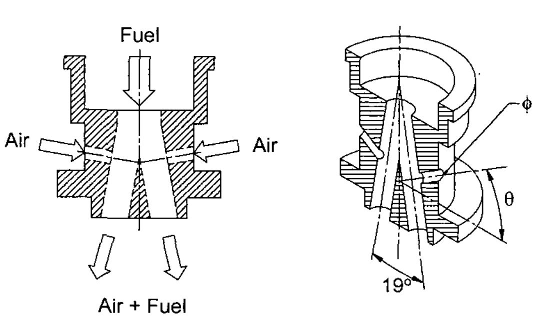


Fig. 4 The shape of atomizer

Atomizers were designed as shown in Table 1. The effect or tendency of each design factor on the atomization could be analyzed.

3. Results and Discussion

3.1 Characteristics of shrouding air flow rate for various atomizers

For the results in Fig. 5, the hole diameter was held constant at 1 mm and only the number of holes was changed, where the difference of air flow rate between 2 and 3 holes is greater than the others but when the number of holes is over 3, the increasing rate of air flow rate becomes smaller.

The effects of diameter of holes on the shrouded airflow rate are shown in Fig. 6. It can be found that there is almost no difference in the airflow rate for holes with 1 mm and 1.2 mm diameter. Figure 7 shows the effect of air supply angle on the airflow rate. The maximum airflow rate is achieved with an inlet angle of 30°. If only the increase of the air flow rate is considered, it can be concluded from these three results that the atomizer, which is similar to the shape as shown in Fig. 4, should have at least more than 3 holes of approximately 1 mm diameter with an inlet angle of 30° for the optimal design of air shrouded atomizer.

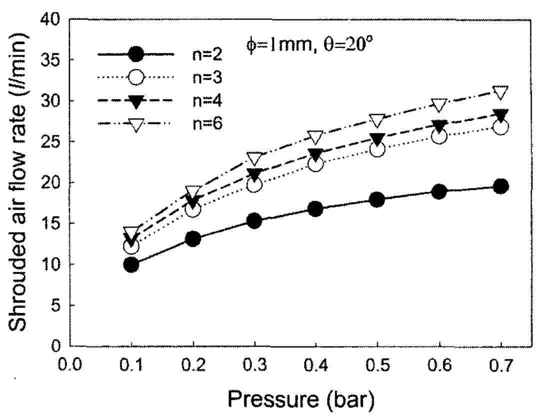


Fig. 5 Effect of hole number on the shrouded air flow rate at $\varphi=1$, $\theta=20°$

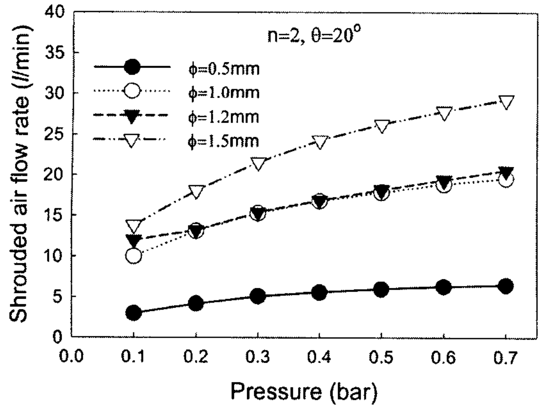


Fig. 6 Effect of hole diameter on the shrouded air flow rate at n=2, θ=20°

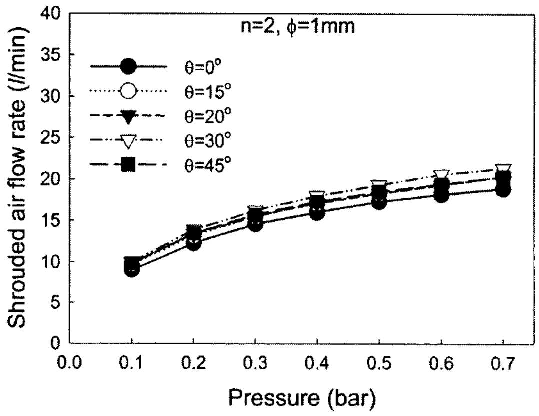


Fig. 7 Effect of hole angle on the shrouded air flow rate at n=2, ϕ=1 mm

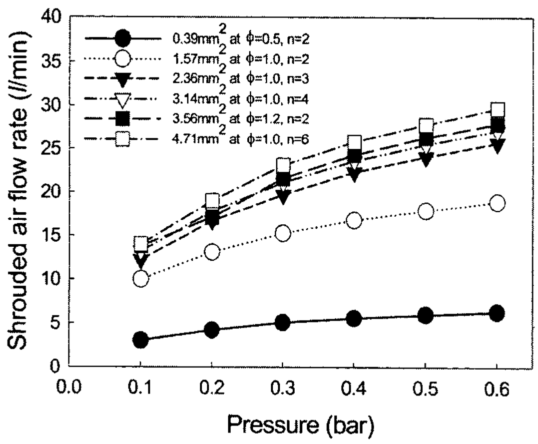


Fig. 8 Shrouded air flow rate vs. hole section area at θ=20°

Furthermore, the results of the air flow rate corresponding to the sectional area of holes that are calculated by considering the variation of the number and the diameter of the holes were shown in Fig. 8. These results show that the sectional area should not be smaller than 2.36 mm^2.

3.2 The relation between the airflow rate and the atomization

In order to investigate the airflow rate on the atomization, the SMDs with regards to the airflow rate and the sectional area of holes are shown in Fig. 9 and Fig. 10. SMD is averaged for all measuring points at 5 ms of elapsed time.

As the airflow rate increases, it can be seen that the atomization is proportionally increased and

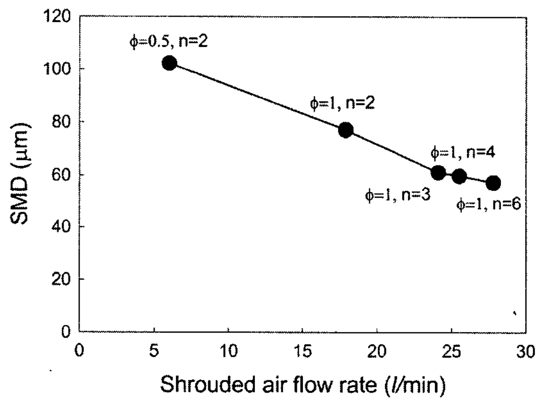


Fig. 9 SMD vs. shrouded air flow rate at 6 ms and 0.5 bar (air pressure)

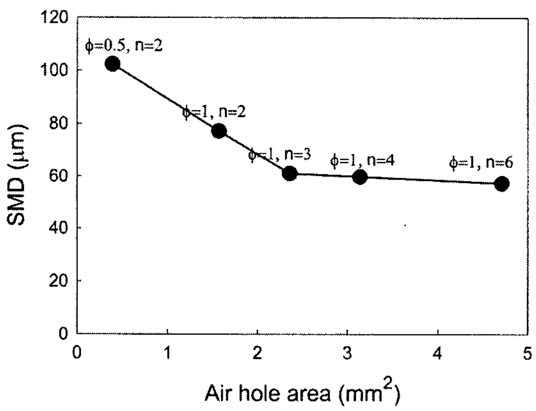


Fig. 10 SMD vs. shrouded hole section area at 6 ms and 0.5 bar

that, for sectional areas of holes greater than 2.5 mm^2, SMD reduction is weakened. From these results, the sectional area of holes should not be smaller than 2.36 mm^2 can be confirmed.

3.3 The influence of each design factor on atomization

Twelve experimental conditions listed in Table 1 were performed with three design parameters (the number of hole, hole diameter, and air supply pressure) affecting the performance of injectors. To find the atomization parameters, the SMD results corresponding to each design parameter are shown in Fig. 11 and Fig. 12.

The results of SMD have a big difference for holes with a diameter of 0.5 mm and 1 mm, but, on the other hand, the atomization hardly increases for holes with diameters larger than 1 mm.

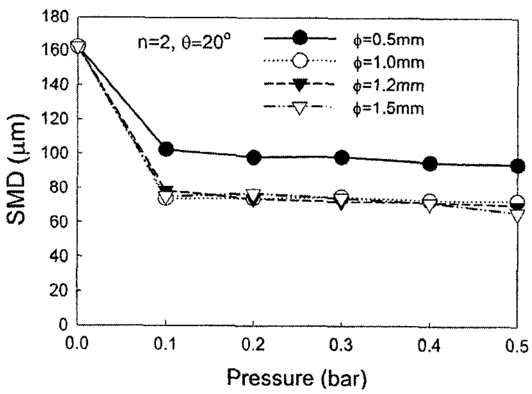


Fig. 11 Effect of hole diameter on the droplet size at n=2, $\theta=20°$

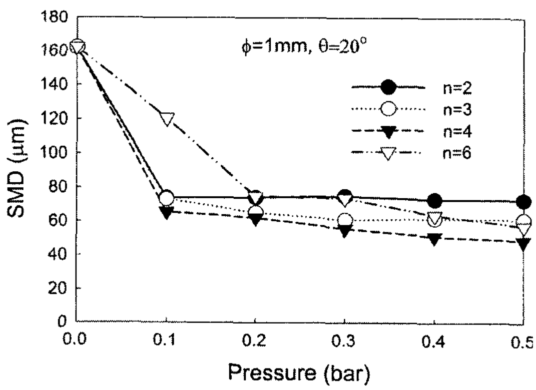


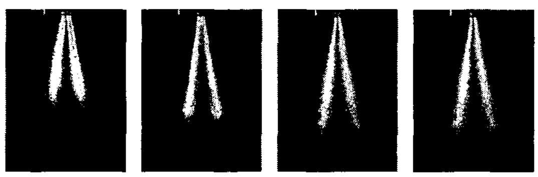
Fig. 12 Effect of hole diameter on the droplet size at n=2, $\theta=20°$

This result means that if the number of holes is held constant and the diameter of the holes surpass a certain size, in spite of the larger hole size, the atomization is not improved, and this result was also shown in Fig. 10. Based on these results, the optimal diameter of hole is 1 mm.

From the results of Fig. 12, it can be seen that, by increase of the number of holes, the effects of atomization is not improved in accordance. That is, as the number of holes is increased, SMD decreases but in the case of 6 holes, the atomization tends to become worse, especially in the case of low shrouded air pressure. Therefore, it is estimated that a number not greater than 4 holes is adequate.

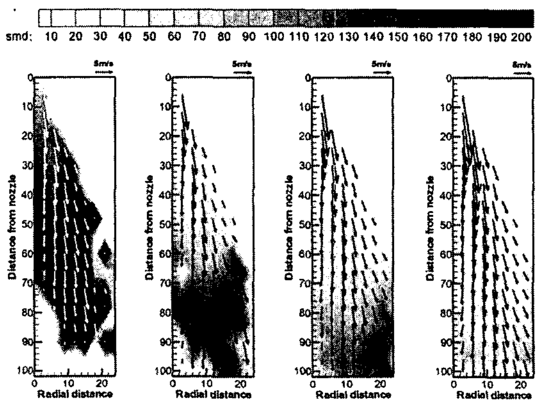
3.4 The atomization mechanism of air shrouded injector

In order to analyze the atomization mechanism of the air shrouded injector, the atomization characteristics of fabricated atomizer (n=2, $\theta=20°$, $\phi=1.0$) was investigated by using PDPA. Weber



(a) 0 bar (b) 0.1 bar (c) 0.3 bar (d) 0.5 bar

Fig. 13 The spray pattern with shrouding air pressure at 6 ms



(a) 0 bar (b) 0.1 bar (c) 0.3 bar (d) 0.5 bar

Fig. 14 The distribution of droplet velocity and SMD

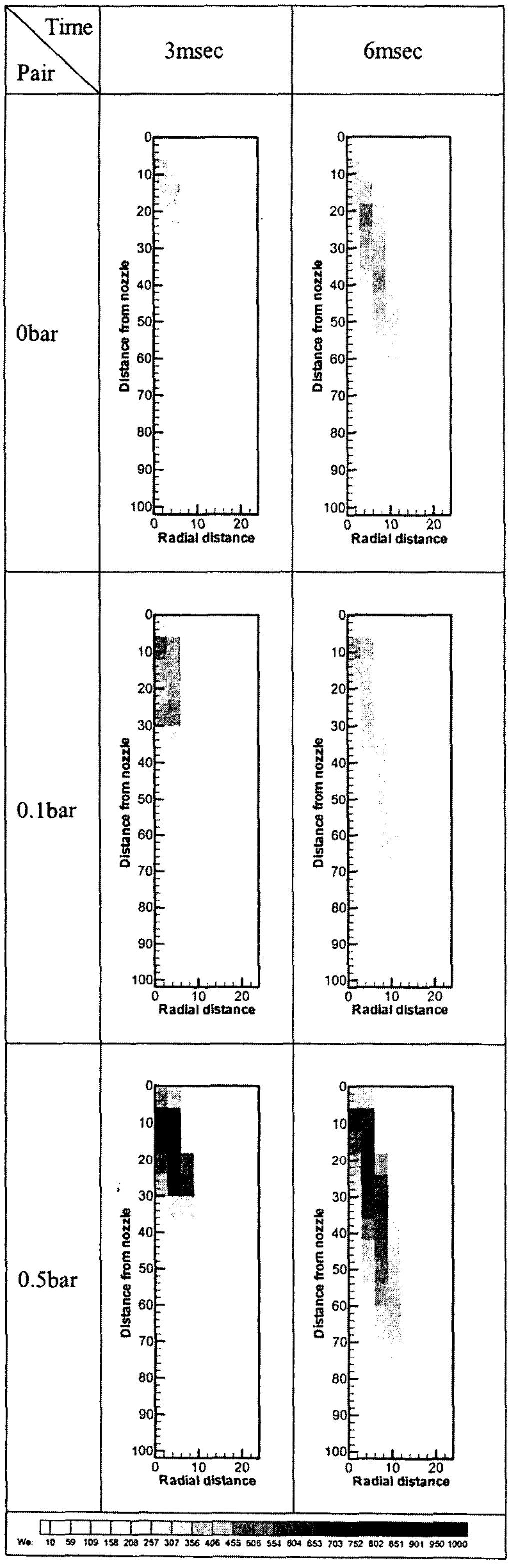


Fig. 15 The distribution of Weber number

number was calculated from the size and the velocity of fuel droplets measured by PDPA.

The penetration was enlarged in proportion with air pressure as shown in Fig. 13. The SMD and velocity distributions with elapsed time are displayed in Fig. 14, SMD decreased while droplet velocity increased with air pressure. There fore, shrouding air was certificated to have a great effect on the fuel atomization and the spray characteristics.

Weber number is representative dimensionless number to represent atomizing performance. Therefore, in order to measure the local atomizing performance, local Weber numbers were calculated at each measuring point as time elapsed. Weber number is the ratio of surface tension to viscous force. Thus if the number is larger than one, droplets start to break-up, and atomization is promoted in proportion to the number. Consequently, the velocities and the diameters of droplets decease according to time, and break-up is reported to continue until the number is one.

The distribution of Weber numbers with time and the introducing air pressure is shown in Fig. 15. As shown in this figure, Weber number increased with shrouding air pressure, and maintained a high value near the nozzle regardless of elapsed time. From these results, fast airflow was found to play a great role in atomizing the droplets.

4. Conclusions

In this work, the effects of design parameters on the atomization characteristics of air shrouded injectors are investigated. The experimental results show the optimal design factors and atomization mechanism of the air shrouded injector. From the results of this study, the following conclusions are obtained.

(1) In experimental analyses, the SMD of hole diameter of 0.5 mm is higher than that of the other cases. The SMD of $\phi=1$ mm or larger is not changed significantly. In addition, the increase of air pressure brings about the decrease of drop size.

(2) For the design of the air shrouded injector,

the most important design factor to influence atomization is the shrouded airflow rate. As the airflow rate is increased, the SMD is decreased.

(3) The decreasing rate of air flow is significantly reduced above 6 holes for air inflow passage. It is found that the number of airflow holes should be efficient less than four.

(4) The results of Weber number show that break up mechanism were brisk near nozzle where large Weber number was distributed owing to rapid air velocity.

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