The Effects of Injector Nozzle Geometry and Operating Pressure Conditions on the Transient Fuel Spray Behavior

Ja Ye Koo*

School of Aerospace and Mechanical Engineering, Hankuk Aviation University, Kyunggi-do 412–791, Korea

Effects of injector nozzle geometry and operating pressure conditions such as opening pressure, ambient pressure, and injection pressure on the transient fuel spray behavior have been examined by experiments. In order to clarify the effect of internal flow inside nozzle on the external spray, flow details inside model nozzle and real nozzle were also investigated both experimentally and numerically. For the effect of injection pressures, droplet sizes and velocities were obtained at maximum line pressure of 21 MPa and 105 MPa. Droplet sizes produced from the round inlet nozzle were larger than those from the sharp inlet nozzle and the spray angle of the round inlet nozzle was narrower than that from the sharp inlet nozzle. With the increase of opening pressure, spray tip penetration and spray angle were increased at both lower ambient pressure and higher ambient pressure. The velocity and size profiles maintained similarity despite of the substantial change in injection pressure, however, the increased injection pressure produced a higher percentage of droplet that are likely to breakup.

Key Words: Nozzle Geometry, Operating Pressure, Spray Development, Droplet

1. Introduction

The distribution of fuel in the combustion chamber at the start of combustion is critical to the subsequent combustion. Fuel efficiency and exhaust emissions depend on fuel spray atomization and mixture formation. Better understanding of atomization process and break-up mechanism is necessary to achieve optimum fuel distribution in the combustion chamber for the low pollutant emissions and high engine performance. In the quest for improved emissions, fuel distribution strategies have been changed. Certain techniques have been shown to be effective in reducing certain emissions, for example, high pressure injection in diesel engines is useful for simultaneous reduction of NOx and particulate emissions (Oblander et al, 1989). The break-up of liquid jet is the result of competing unstable hydrodynamic forces acting on the liquid jet as it exits the nozzle (Reitz and Bracco, 1979; Shimizu et al., 1990). The behavior of spray, for example, penetration rate, spray angle, and mean drop diameter is governed by the nozzle geometry and up-stream injection conditions as well as relative velocities between liquid and ambient gas, viscous forces, and surface forces (Koo and Martin, 1995; Ohrn, 1989). External conditions alone may not be sufficient to explain external spray characteristics. The nozzle geometry and up-stream injection conditions affect the characteristics of flow inside the nozzle, such as turbulence and cavitation bubbles (Ruiz, 1981; Wang et al., 1989; He and Ruiz, 1995). The cavitation bubbles inside nozzle, which can be produced when the pressure of fuel is lower than the vapor pressure of fuel, is thought to improve atomization efficiency. However, there is lack of knowledge of integrated understanding of internal flow inside nozzle and external spray
behavior. In this work an integrated study is carried out, considering nozzle geometry, internal flow inside nozzle and operating pressure conditions.

2. Experiment Setup and Computer Simulations

Two sets of simplified plain orifices were made for the investigation of the effect of internal flow on external spray. One set is actual scale model of 0.3 mm hole diameter and the other is 100 times scale model of 30.0 mm hole diameter. In the scale model needle was not considered in the orifice, but in the actual nozzle calculation needle was considered. Round and sharp shape of inlet nozzle with various length to diameter (L/d) were tested as shown in Fig. 1. A phase/Doppler Particle analyzer (PDPA) was used in the velocity only mode to measure the fluid velocity at various axial and radial positions inside nozzle. For the external spray, PDPA was also used for the measurement of droplet sizes and velocities. Valid data obtained at each locations were 3000 samples. For the external spray visualization pulsed laser sheet photography system was used as shown in Fig. 2. Computations for the internal flows inside nozzle were carried out for all three geometries- the single-hole diesel injector (L/D=3.3), the simplified single-hole nozzles used in the PDPA and visualization tests, and the corresponding scaled up nozzle. Details for computations are shown in reference (Koo, 1996).

In order to investigate the effect of opening pressure and ambient pressure a single shot injection system was made using solenoid valve as shown in Fig. 3. The opening pressure of dummy injector is 1.1 MPa and the opening pressure of main injector is 20.1 MPa or 40.1 MPa. When the solenoid valve is closed by the solenoid driving pulse fuel is injected through the main injector. The Z-pulse with 5 volts is generated in the rotary encoder that is connected to the shaft of the injection pump every revolution of injection pump. The Z-pulse is the reference pulse in this system. Figure 4 shows Z-pulse signal, external clock, solenoid driving pulse, needle lift and light duration.

In comparing data from two different injection pressures, two different injection systems were used. One is CAV-Lucas injector with a static popping pressure of 15.2 MPa. The nozzle and