Engine Combustion Network

ECN Home
Experimental Data
Constant-Volume Diesel Combustion
1 Experimental Data Search
2 Combustion Vessel Geometry
3 Ambient Conditions
4 Thermal & Velocity Distribution
5 Injector Characterization
6 Fuels
7 Definitions
8 Experimental Diagnostics
8.1 Soot
8.2 Jet Penetration
8.3 Liquid Penetration Length
8.4 Lift-Off Length
8.5 Ignition Delay
8.6 High-Speed Movies & Flow Visualization
Related Internet Sites
References
Tutorial: Diesel Spray Visualization

Injector Characterization

A common-rail fuel injector was used for the experiments. The fuel injector was a prototype, electronically controlled, common-rail, solenoid-activated injector designed by Diesel Technology Corporation. (Schematic of the injector, Fig. 2.4). Fuel is supplied to the injector from an accumulator located immediately upstream of the injector. The accumulator was sized to limit the pressure loss during injection to less than 2% for injections of up to 100 mg of fuel.

Several types of injector tips were used. For experiments after 1997, cylindrically-shaped, on-axis injector tips were used as depicted in Fig. 5.1.

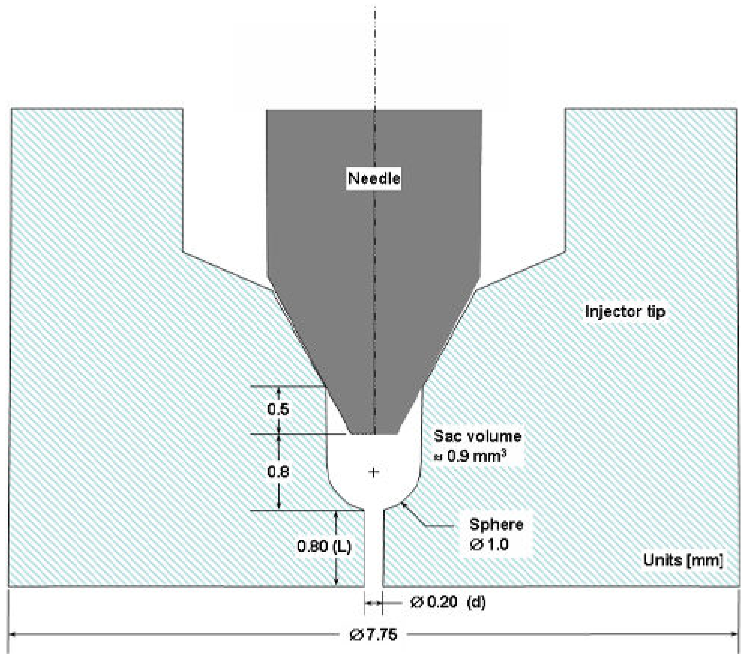

Figure 5.1

Important characteristics of the orifices used in the experiments are listed in Table 5.1. Values given in the table for each orifice are the nominal diameter (d), the discharge coefficient (C_d), the area-contraction coefficient (C_a) for two injection pressure differences across the orifice (72 and 138 MPa), and the length-to-diameter ratio (*L*/*d*). All the orifices had sharp-edged inlets and outlets and no hydro-grinding was performed. Orifices were slightly tapered with the diameter increasing by about 4% from inlet to outlet. Diameters listed in Table 5.1 are based on the *minimum* diameter. The sac-volume dimensions were preserved as orifice size or *L*/*d* ratio were varied (i.e., the dimension *L* was changed). Figure 5.1 shows a sample orifice with an *L*/*d* ratio of 4.

Table 5.1 Injector tip parameters for cylindrically-shaped tips used after 1997.

Orifice Diameter	Discharge Coefficient	Area-Contraction Coefficient		Length-to-Diameter
d	C_d	C_a	C_a	*L*/*d*
(mm)		(72 MPa)	(138 MPa)	
0.100	0.80	0.91	0.86	4.0
0.180	0.77	0.85	0.82	4.2
0.251	0.79	0.88	0.79	2.2
0.246	0.78	0.89	0.81	4.2

0.267	0.77	0.89	0.82	8.0
0.363	0.81	-	0.85	4.1
0.498	0.84	0.94	0.88	4.3

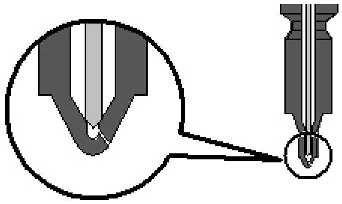

Figure 5.2

For experiments before 1997, three injector tips with an off-axis nozzle were used, as shown in Fig. 5.2. The spray remained directed into the center of the chamber, however. The nozzle tip sizes and coefficients are listed in Table 5.2, The coefficients given in Table 5.2 are based on the *minimum* diameter at the inlet for consistency with Table 5.1, unlike SAE 960034, which based coefficients on the exit diameter. Like the on-axis injector tips, the off-axis orifices were slightly tapered with the diameter increasing by 4-6% from inlet to outlet.

Table 5.2 Injector tip parameters for off-axis nozzles.

Orifice Diameter	**Discharge Coefficient**	**Area-Contraction Coefficient**	**Length-to-Diameter**
d	C_d	C_a	*L/d*
[mm]			
0.185	0.64	0.93	5.4
0.241	0.71	0.92	4.2
0.330	0.66	0.89	3.0

Injection rate profiles, and the discharge and area-contraction coefficients were measured by injecting onto a force transducer and simultaneously collecting and weighing injected fuel (Naber, SAE 960034 and Siebers, SAE 1999-01-0528). The experimental method and explanation of the orifice coefficients is discussed below.

As the development of a spray is dependent on both the mass and momentum flow rates from an orifice, two orifice coefficients are needed to characterize these flow rates. The discharge coefficient is the product:

$$C_d = C_a \cdot C_v \,. \qquad (3)$$

where C_v is the velocity coefficient. Using C_v and C_a, the mass flow rate (m_f) and momentum flow rate (M_f) from an orifice are given by the following:

$$\dot{m}_f = C_a \cdot A_f \cdot \rho_f \cdot C_v \cdot U_b \,, \qquad (4)$$

$$\dot{M}_f = \dot{m}_f \cdot C_v \cdot U_b \,, \qquad (5)$$

where U_b is given by Bernoulli's equation:

$$U_b = \sqrt{2 \cdot [P_f - P_a] / \rho_f} \,. \qquad (6)$$

The term ρ_f is the fuel density, A_f is the orifice exit area, and P_f and P_a are the fuel and ambient gas pressures, respectively. The velocity U_b is the maximum potential fluid velocity at the orifice exit, while the product $C_v \cdot U_b$ is the average velocity at the orifice exit over the area $C_a \cdot A_f$.

The orifice area-contraction coefficients were determined from the spray momentum measured with a force transducer and the following relationship derived from Eqs. (3-6):

$$C_a = 2 \cdot A_f \cdot C_d^2 \cdot [P_f - P_a] / \dot{M}_f \qquad (7)$$

The spray momentum was measured with a piezoelectric pressure transducer calibrated to measure the force (i.e., the momentum) induced by a spray impinging on the transducer diaphragm. The transducer was placed approximately 3 mm in front of the orifice. This distance was close enough to the orifice that the entire spray impinged on the central region of the transducer diaphragm, but far enough away that the flow through the orifice was not restricted.

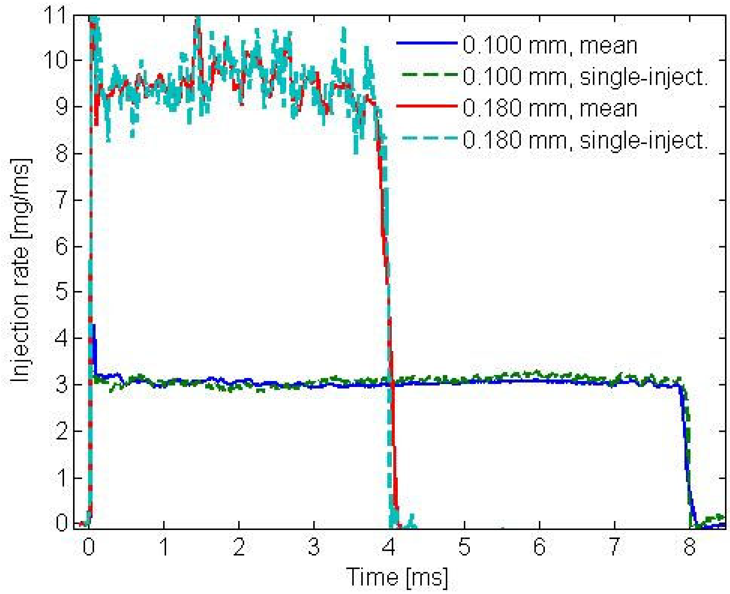

Figure 5.3

Figure 5.3 (0.100 mm data 0.180 mm data) shows injection rates for two orifices with an injection pressure above ambient of 138 MPa and using diesel fuel at room temperature (300 K). The injection period is much longer for the small orifice to inject approximately the same total mass. Injection rates are shown for a single injection, as well as the average of 60 injections. The injection rate profiles show that the opening and closing of the injector occurs in less than 0.1 ms. (The spike at the beginning of injection may be an artifact of mass accumulation at the head of the spray, as the force transducer was a finite distance away from the orifice.) The closing time is shorter for a single injection compared to the mean because of small injection-to-injection variability. Injection is nearly steady during the time of injection, creating a square-wave injection rate shape. The square-wave shape was also found for the off-axis injector tips (Naber, SAE 960034). As opening and closing times are small, the average momentum (M_f) during the steady-flow period was used to determine the orifice coefficients (e.g. Eq.7).

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