

LPG

A Study On The Characteristics of Direct Injection LPG Spray

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ABSTRACT

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ABSTRACT

Liquefied petroleum gas (LPG) has been used as motor fuel due to its low emissions and low cost. The fuel feeding system has been improved with stringent requirement for exhaust emissions. LPG carburetion system was first introduced, then the system has been changed to a precisely controlled gas injection system, but this gas feeding system has a limitation on improving power output. In order to improve an engine performance, a multi-point port injection system was introduced recently, and a liquid direct injection system into a cylinder was suggested as a next generation system to maximize a fuel economy as well as a power.

This study addresses the analysis of the LPG spray from single hole injector. The spray images are visualized and compared with diesel or gasoline sprays in a wide injection and ambient gas pressure ranges. A short arc strobo having flashing duration of 20micro-s and CCD camera of Pulnix are used to take the images. The injection pressure is generated up to 150MPa by Haskel air driven pump. And the ambient pressure is adjusted by pumping air into a constant volume chamber. Three different test conditions are given, which are the continuous injection case with various injection pressures, the spray development case with various injection pressures and the spray development case with ambient pressure variation. The LPG spray photographs are compared with sprays of gasoline and diesel fuel at the same conditions, and the spray angles and penetration lengths are also compared, then the spray behavior is analyzed.

The LPG spray photos show that the dispersion characteristics depends very sensuously on the ambient pressure soon after injection. The spray angle is very wide in the low ambient pressure conditions until 0.3MPa, but the angle value is quickly reduced at the condition over the pressure. However the down stream of the LPG spray still shows much wider dispersion and less penetration than those of gasoline and diesel sprays due to fast evaporation. That says the LPG fuel in liquid phase by high injection rail pressure at the nozzle tip is quickly evaporated into gas phase in the low ambient pressure cases, but the spray leaving the nozzle is remaining as liquid phase in the high ambient pressure cases. Therefore the spray is dispersed widely with low penetration like LPG gas injection in the low ambient pressure case, and the spray is less dispersed and longer penetrated like liquid gasoline spray in the high ambient pressure cases, but the behavior at the spray tip is much wider and less penetrated than those of gasoline and diesel. It indicates that the behavior of LPG spray might be more dependent on the gas flow motion in cylinder than the spray injection velocity. Therefore, the chamber and intake port shape might be careful to get a suitable flow motion for designing direct injection LPG engines.

1.

1.1

가

LPG 70

가

가

가

가

LPG

LPG-MPI

LPG

LPG

가

Table 1.1

LPG

가

가

[1]. Fig. 1.1

LPG

LPG

70%

30%

가

가

20

8Kg/cm²

Table 1.1 Properties of LPG, diesel, gasoline

Fuel	Formula	Mol.wt (Kg/kmol)	Boiling pt. ()	Ignition pt. ()	Autoignition pt. ()
Propane	$C_3 H_8$	44.096	-42.1	-104	481
Butane	$C_4 H_{10}$	58.123	-0.5	-60	441
LPG(used) propane(30%)+ butane (70%)		54.915	-12.98	-30.78	453
Diesel	$C_{10.8} H_{18.7}$	148.6	180 360	65 80	350 450
Gasoline	$C_{8.26} H_{15.5}$	114.8	27 225	-42.8	500 550
	$C_{7.76} H_{13.1}$	106.4			

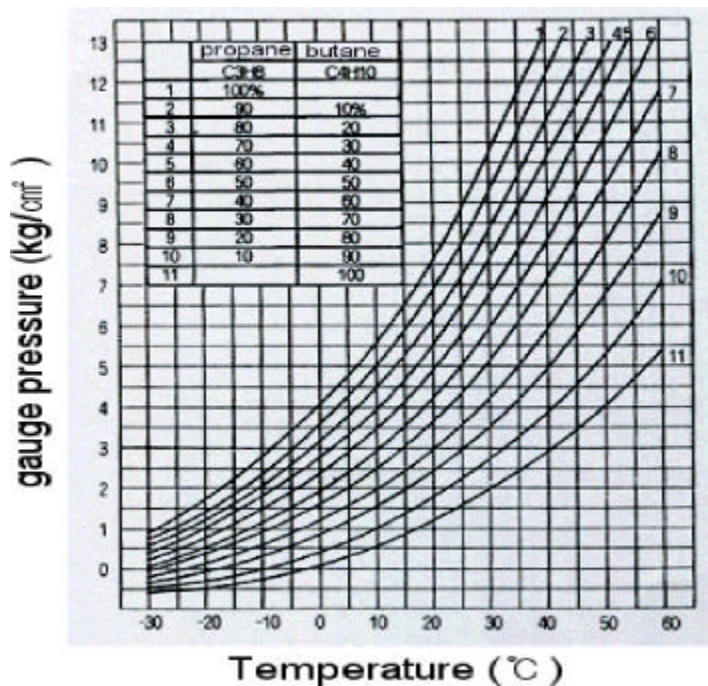


Fig. 1.1 Vapor pressure variation as temperature

LPG 가 ,

가 . Brown York

LPG (flashing) Kitamura Wildgen

Straub [2] [4].

가 LPG , Lowi Jr.

가 가

20 60% [5]. Hollemans LPG

가 ,

가 , LPG 가

가 [6] [12].

Rushmoor Borough

CO

NOx 80% , 100% .

95% NOx

[13] [15].

가 , Sierens

MPI , LPG 15%

가

가 [16].

LPG 가

LPG

[17] [20].

Poulton , LPG

가 가

[21] [22].

LPG, LPG 가 가

,

.

1.2

- 5 . , 1 .
- 2 . LPG 가 .
3 가 .
- 3 .
0.9MPa 0.22mm LPG
가 .
- 4 . 가 ,
LPG 10MPa 0.0, 0.3, 0.6MPa
가 .
- 5 .

2.

2.1

LPG

가

Fig. 2.1

LPG

가

200MPa

DC 48V

3

1.5J,

50ns

가

768 × 484 CCD

가

Table 2.1

LPG

0.22mm, 0.30mm

가

5MPa

50MPa

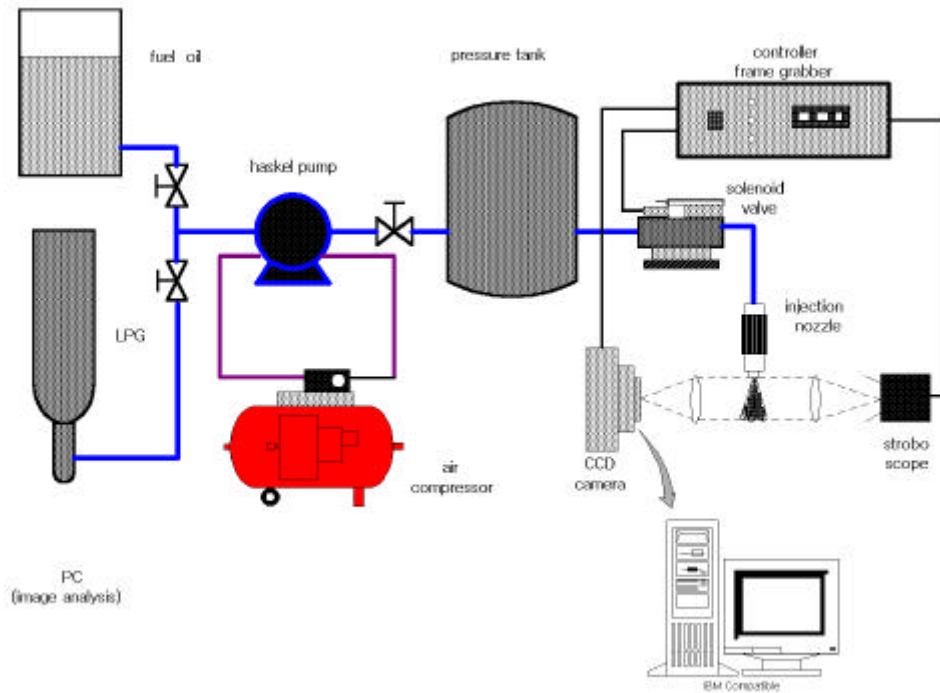


Fig. 2.1 Experimental setup

Table 2.1 Test cases

Fuel	noz. hole dia. (mm)	Nozzle type	Rail pressure (MPa)
LPG	0.22	Automatic close (Single hole)	5, 10, 15, 20, 25, 30, 40, 50
	0.30		
Diesel	0.22		
	0.30		

2.2 가

Fig. 2.2 (a), (b), (c), (d) LPG 0.22mm, 0.30mm
가 150mm
가 LPG 75mm 가 . Table 2.2 Fig. 2.4,
Fig. 2.5 , LPG
가

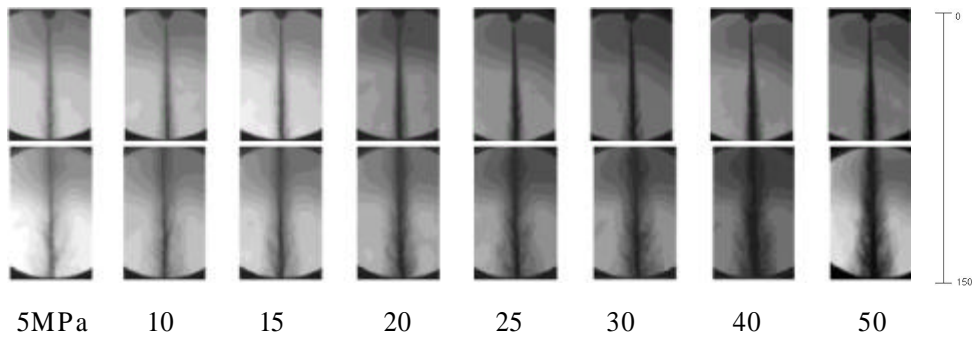
2.2.1

0.22mm 가 5MPa

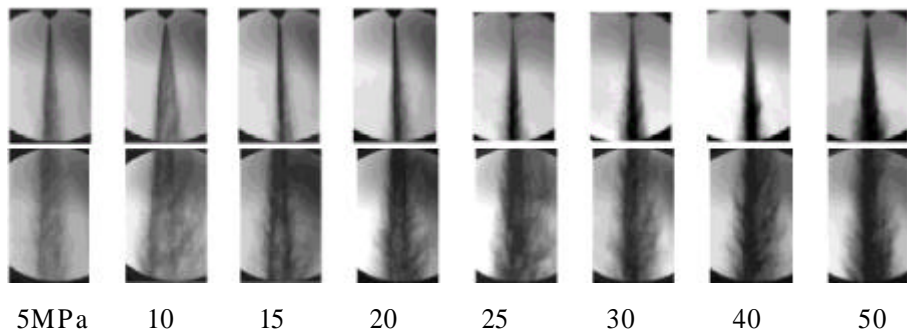
가 50MPa가
150mm

(Fig. 2.3). Table 2.2

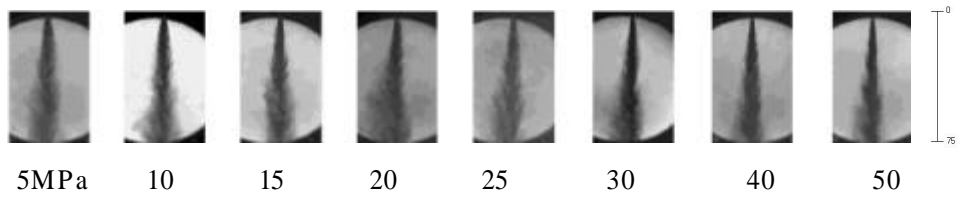
가
. 0.30mm 0.22mm
가 가 . 0.22mm
4 5° 0.30mm 8 11°
가 가
10MPa
가 가



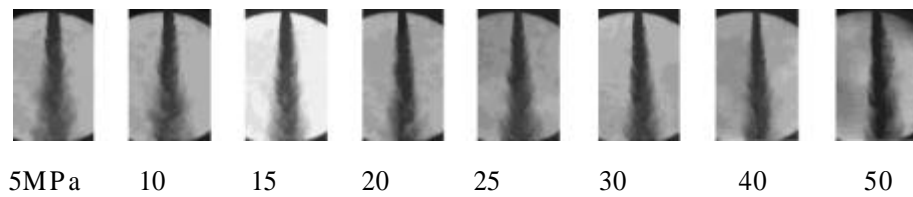
(a) 0.22mm nozzle hole diameter diesel injection



(b) 0.30mm nozzle hole diameter diesel injection



(c) 0.22mm nozzle hole diameter LPG injection



(d) 0.30mm nozzle hole diameter LPG injection

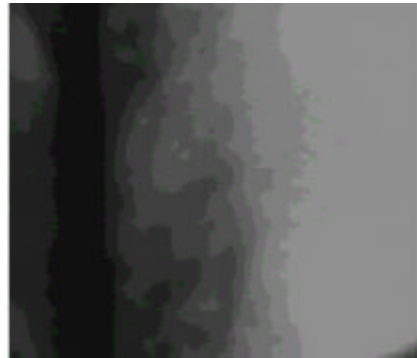
Fig. 2.2 Spray shapes with injection pressure variation

Table 2.2 Spray angles with test conditions

	Measuring Position from nozzle tip(mm)	Nozzle hole dia. (mm)	Rail Pressure(MPa)							
			5	10	15	20	25	30	40	50
Diesel	35	0.22	4	5	5	4	5	5	6	7
		0.3	9	11	8	8	8	10	10	11
	70	0.22	13	14	13	13	13	14	14	14
		0.3	15	17	18	18	19	19	19	20
LPG	35	0.22	22	22	20	18	17	13	11	9
		0.3	26	26	22	20	18	17	15	12
	70	0.22	23	23	20	22	21	20	19	19
		0.3	24	23	21	24	23	23	20	20



(a) 5MPa



(b) 50MPa

Fig. 2.3 Comparison of diesel sprays around 140mm from injector

2.2.2 LPG

LPG
5MPa
가
가
40mm
(Fig. 2.4, Fig. 2.5, Fig. 2.6). LPG
가 가
가 가

2.2.3 LPG

5MPa 가
가
LPG Fig. 2.7
가 5 가
가 가
가 가 LPG
가
LPG , 50MPa
150mm 가
LPG 40mm 가
가 가 LPG

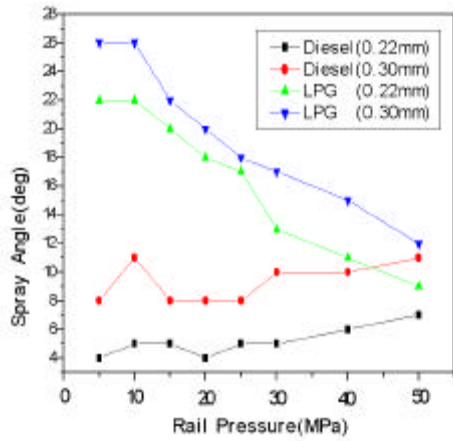


Fig. 2.4 Spray angles measured at 35mm from the nozzle tip

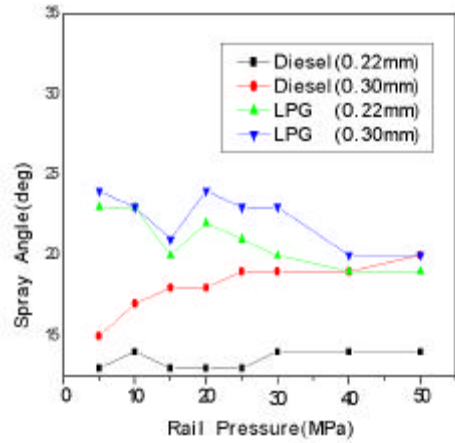
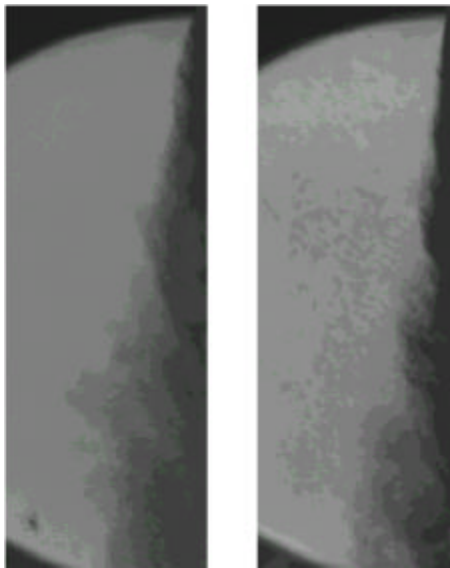
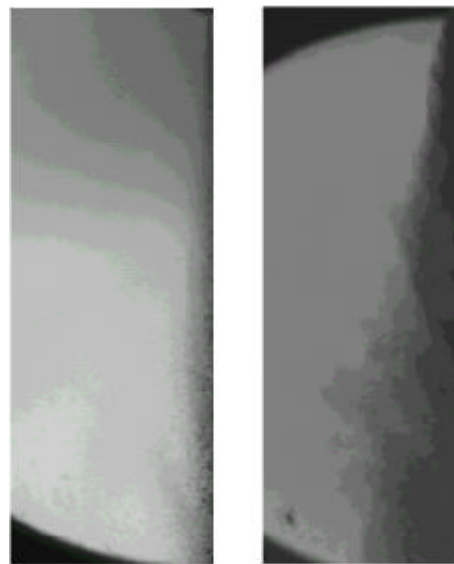


Fig. 2.5 Spray angles measured at 70mm from the nozzle tip



a) 5MPa b)50MPa

Fig. 2.6 Comparison of sprays



(a) Diesel (b)LPG

Fig. 2.7 Comparison of spray at 5MPa

가 , 가
가 가
LPG 150
가 -50 가
가 가
가
가 ,
가
[19] LPG
가
LPG가
LPG

3.

3.1

2

. DC 48V

ms

(synchronizer)

가

1 1.6J/F,

0 60Hz,

18 23 μ s

Short Arc Strobo (SA-100A)

Lamp(LH-SA 1M)

sheet beam

가

가 1/60 1/16,000sec

768(H) \times 484(V)

PULNiX

TMC-970 CCD

가

Table 3.1

LPG

0.22mm

15MPa

150MPa

, LPG

15MPa

100MPa

0.9MPa

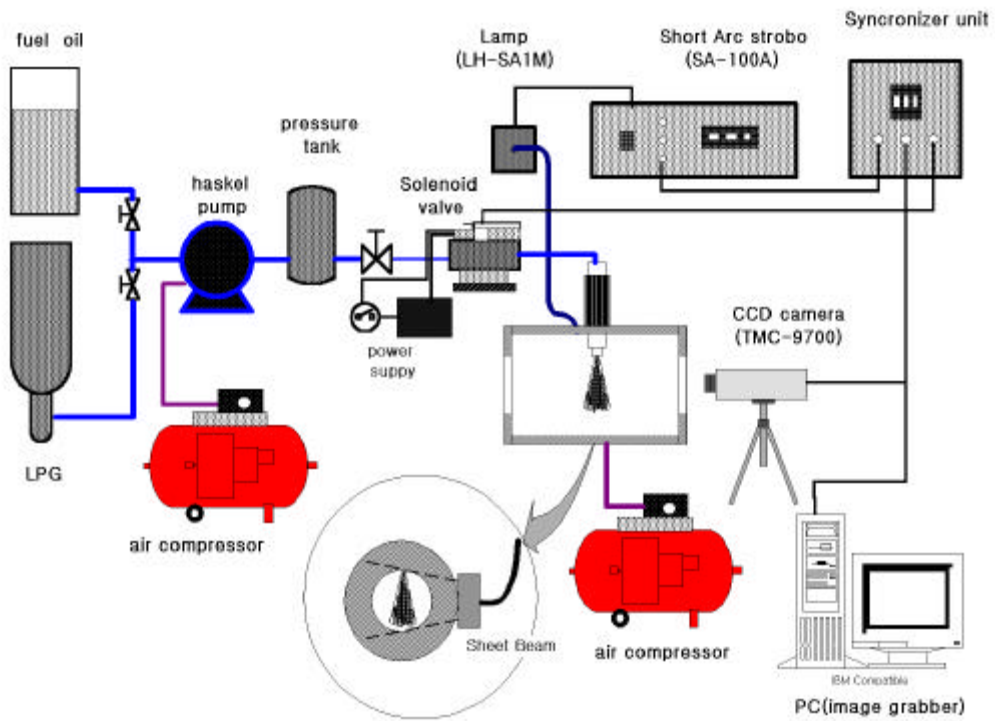
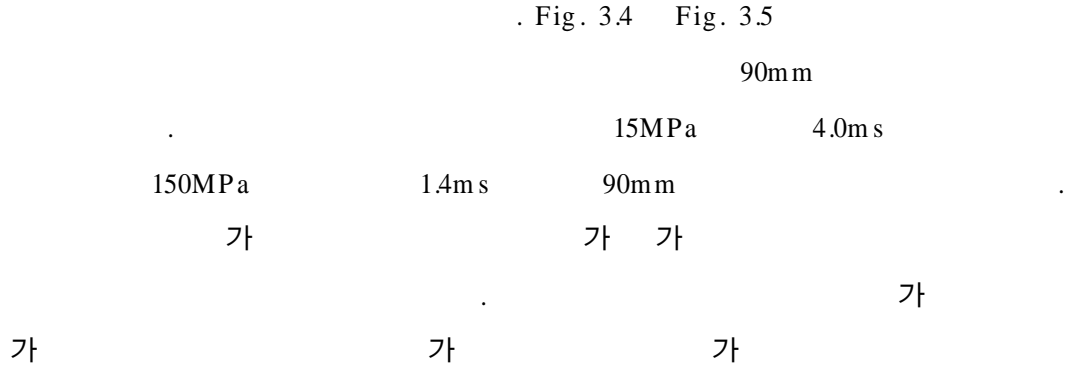
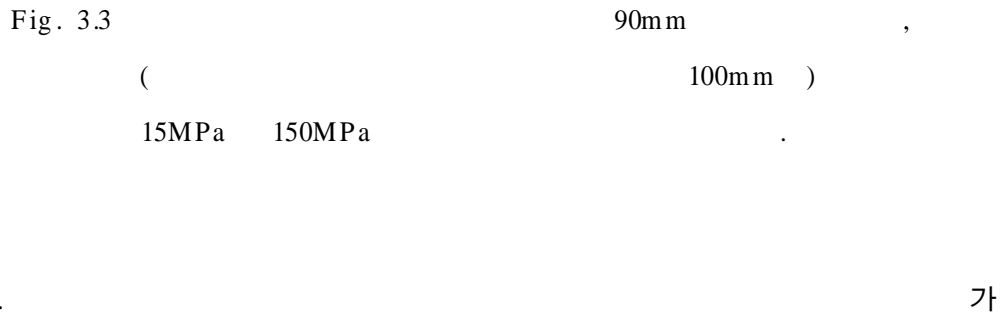
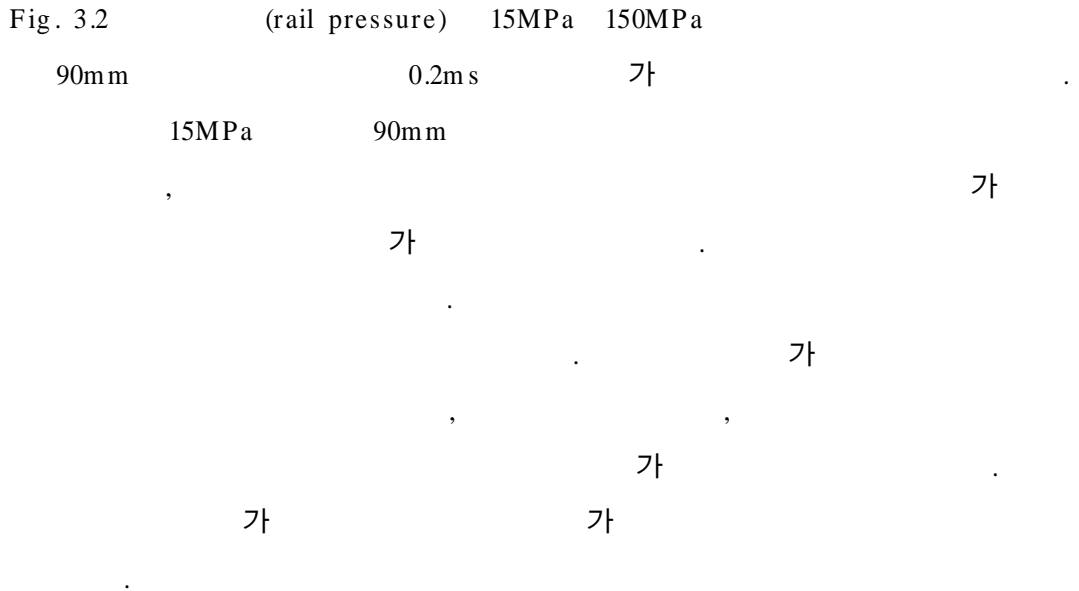


Fig. 3.1 Experimental setup

Table 3.1 Test cases

Fuel	noz. hole dia. (mm)	Nozzle type	Rail pressure (MPa)
Diesel	0.22	Automatic close (Single hole)	15, 25, 50, 75, 100, 150
LPG	0.22		15, 25, 50, 75, 100

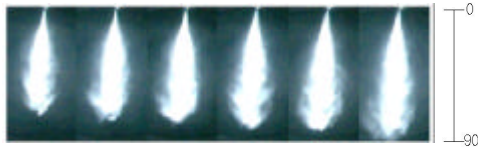
3.2



가 가 가

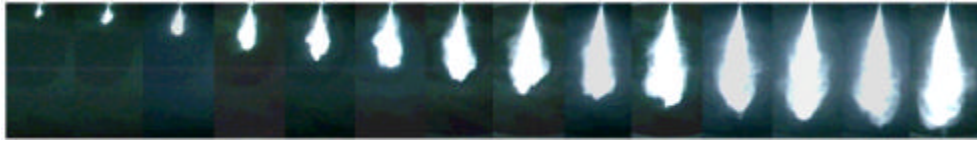


0.1ms 0.3 0.5 0.7 0.9 1.1 1.3 1.5 1.7 1.9 2.1 2.3 2.5 2.7



2.9 3.1 3.3 3.5 3.7 3.9

(a) 15MPa



0.2ms 0.4 0.6 0.8 1.0 1.2 1.4 1.6 1.8 2.0 2.2 2.4 2.6 2.8

(b) 25MPa



0.2ms 0.4 0.6 0.8 1.0 1.2 1.4 1.6 1.8 2.0 2.2 2.4

(c) 50MPa



0.2ms 0.4 0.6 0.8 1.0 1.2 1.4 1.6 1.8

(d) 75MPa

Fig. 3.2 Diesel spray developments with injection pressure variation

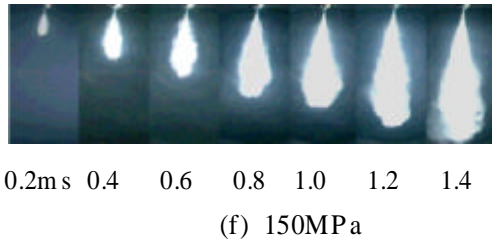
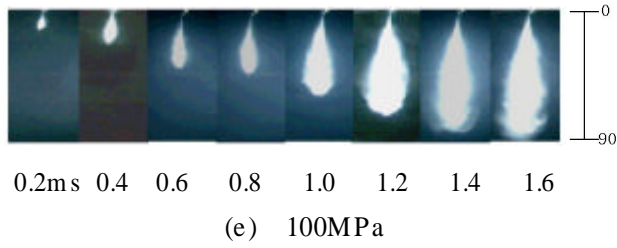


Fig. 3.2 Diesel spray developments with injection pressure variation - continued

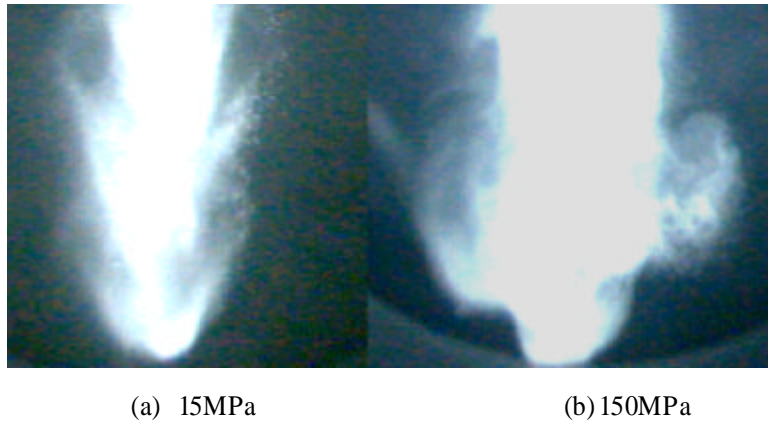


Fig. 3.3 Comparison of diesel sprays near wall

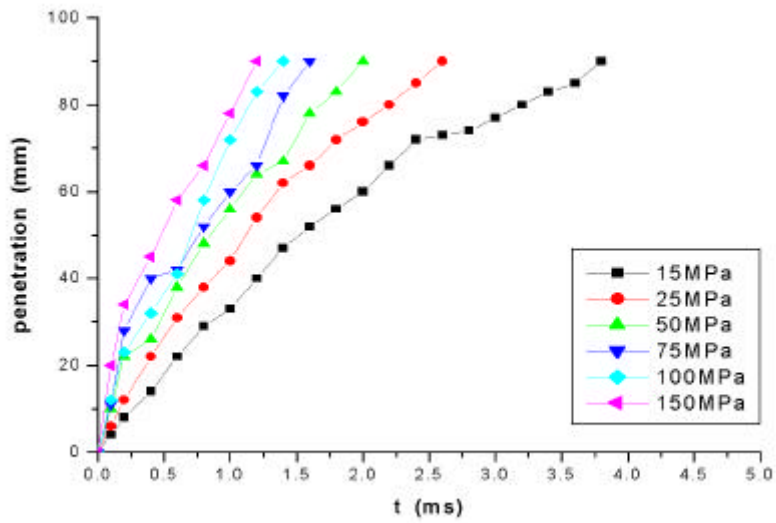


Fig. 3.4 Diesel spray penetration with time from injection start

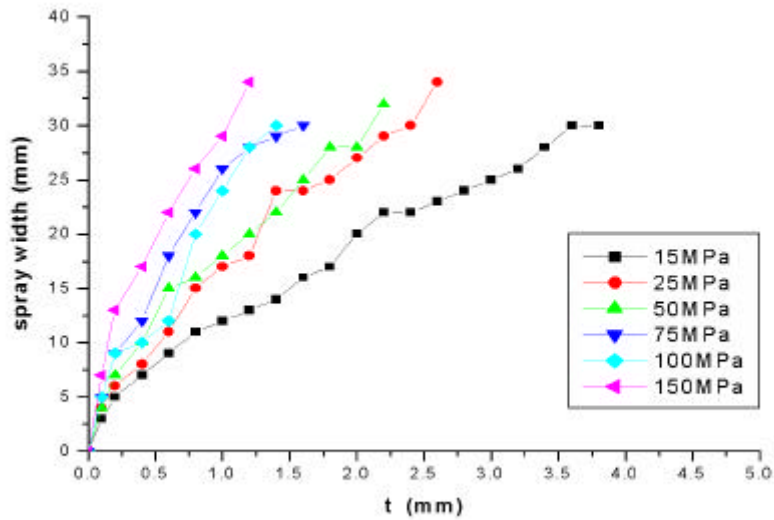


Fig. 3.5 Diesel spray width with time from injection start

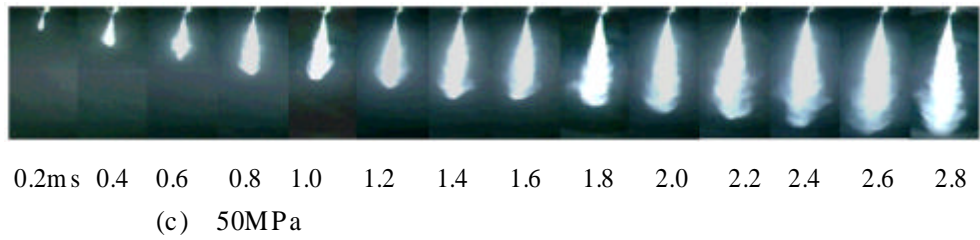
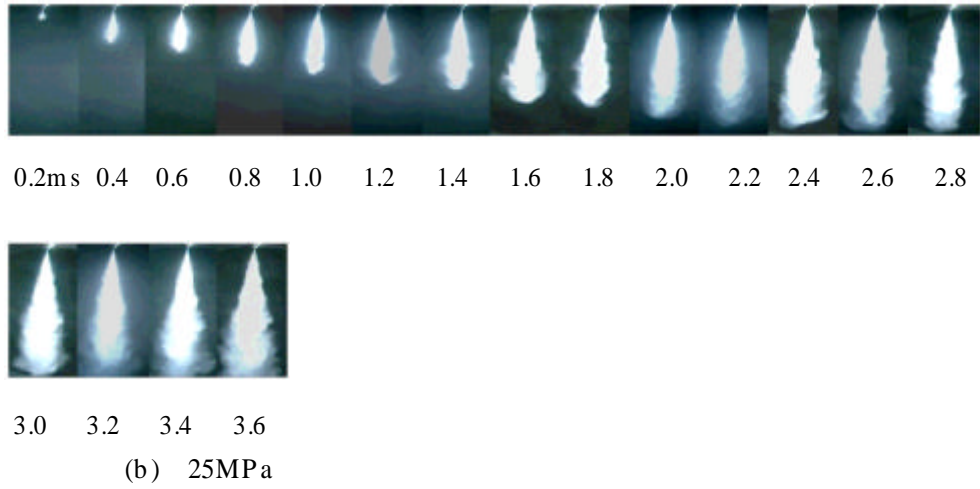
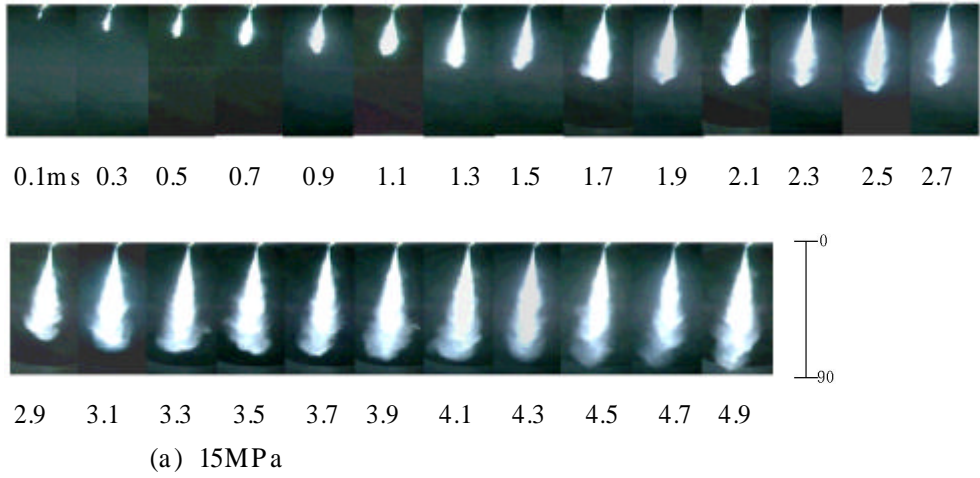


Fig. 3.6 LPG Spray developments with injection pressure variation

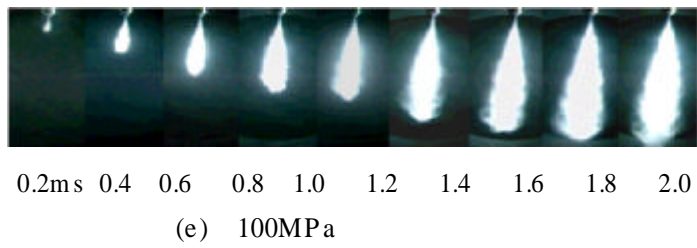
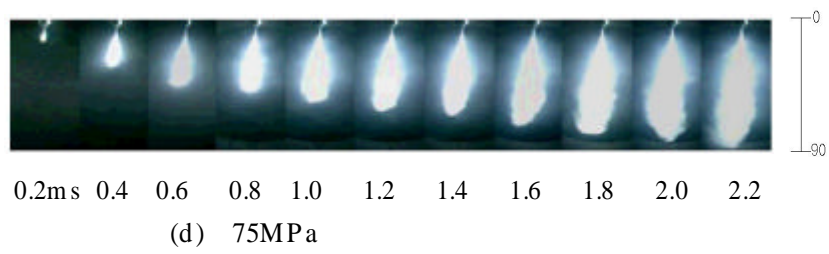


Fig. 3.6 LPG Spray developments with injection pressure variation - continued

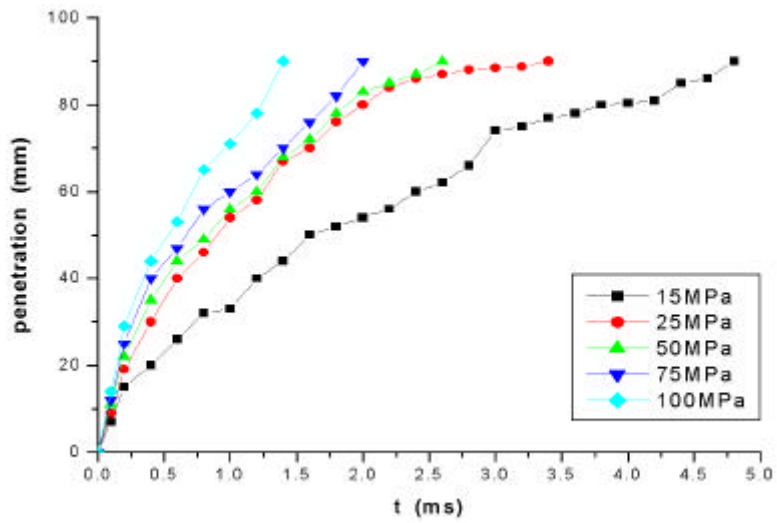


Fig. 3.7 LPG spray penetration with time from injection start

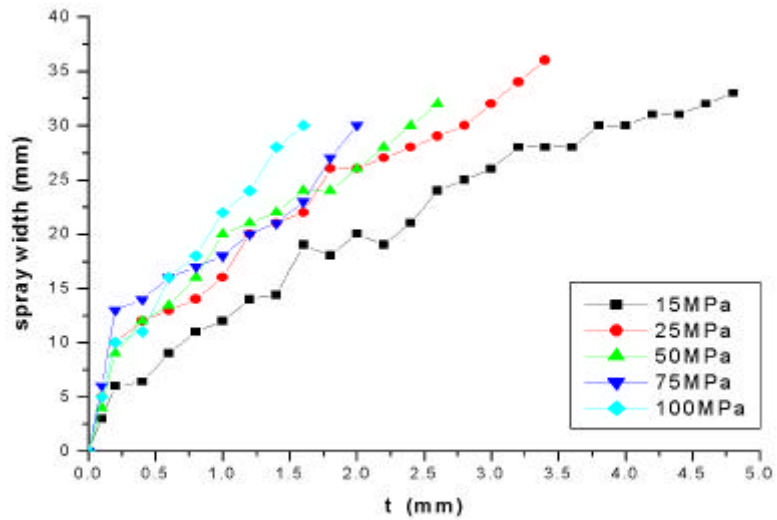


Fig. 3.8 LPG spray width with time from injection start

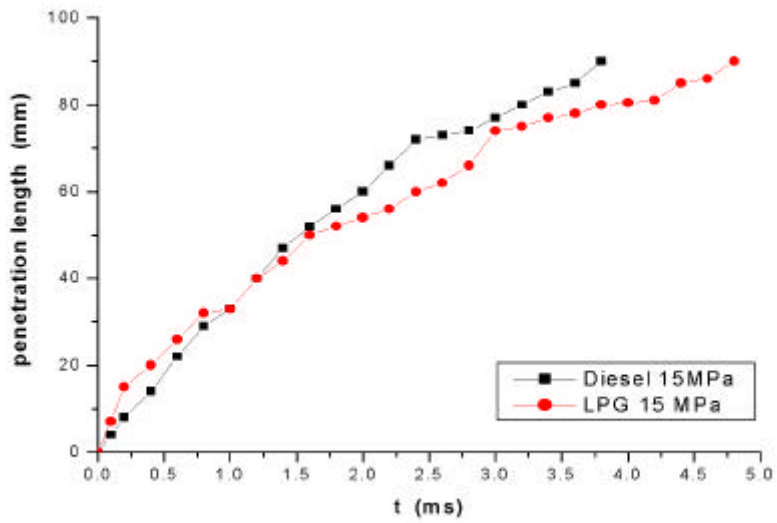


Fig3..9 Comparison of diesel/LPG spray penetration at rail pressure 15MPa

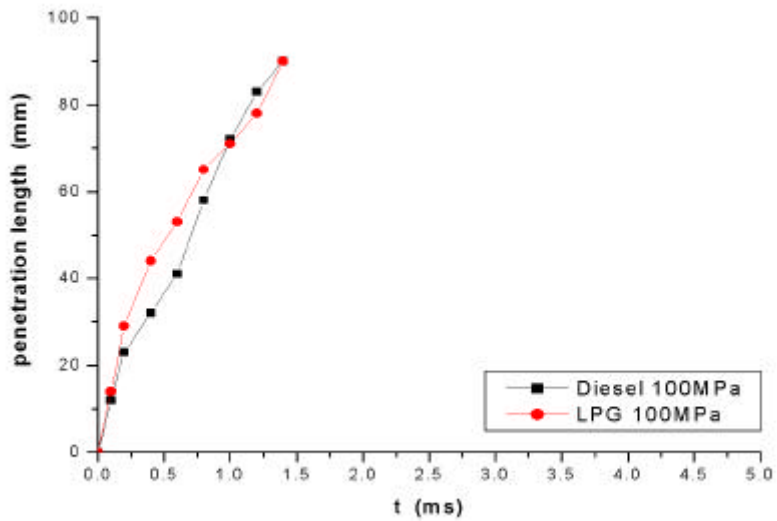


Fig. 3.10 Comparison of diesel/LPG spray penetration at rail pressure 100MPa

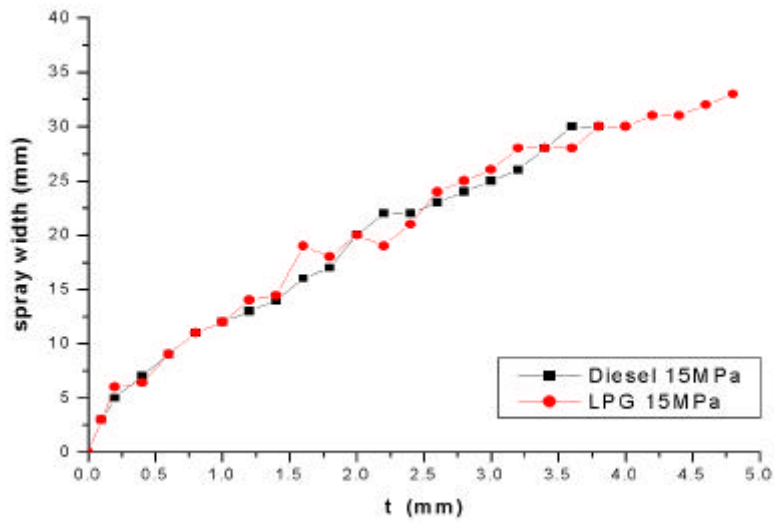


Fig3.11 Comparison of diesel/LPG spray width at rail pressure 15MPa

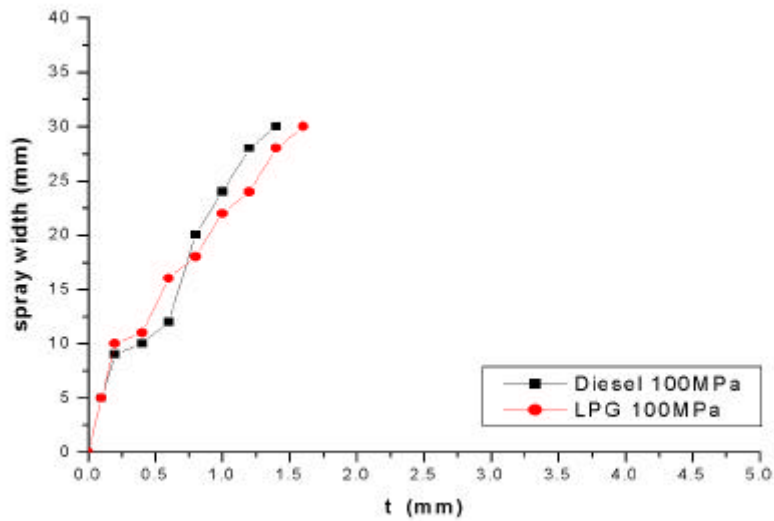


Fig3.12 Comparison of diesel/LPG spray width at rail pressure 100MPa



(a)

(b)

(c)

(d)

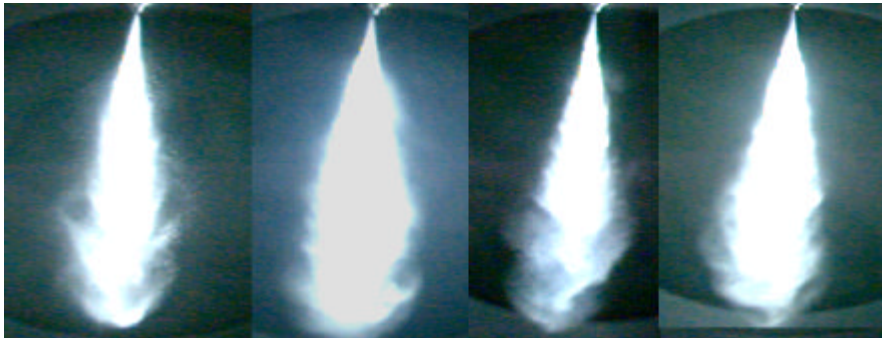
(a) Diesel 15MPa,

(b) Diesel 100MPa

(c) LPG 15MPa

(d) LPG 100MPa

Fig. 3.13 Spray comparison at about 20mm length



(a)

(b)

(c)

(d)

(a) Diesel 15MPa

(b) Diesel 100MPa

(c) LPG 15MPa

(d) LPG 100MPa

Fig. 3.14 Spray comparison at about 100mm length

4.

4.1

3 Fig. 3.1 Table 4.1
 . LPG , 가
 0.22mm . , LPG, 가 10MPa
 0.0MPa, 0.3MPa, 0.6 MPa .

Table 4.1 Test cases

FUEL	noz. hole dia. (mm)	Nozzle type	Rail pressure (MPa)	Surround pressure (MPa)
LPG	0.22	Automatic close (Single hole)	10	0.0, 0.3, 0.6
Diesel				
Gasoline				

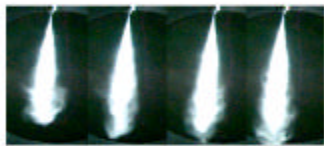


0.1ms 0.3 0.5 0.7 0.9 1.1 1.3 1.5 1.7 1.9 2.1 2.3

(a) Rail pressure 10MPa - Surround pressure 0MPa

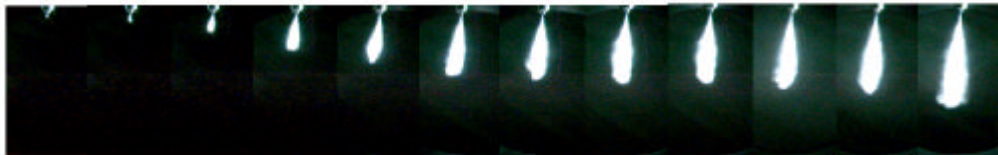


0.1ms 0.3 0.5 0.7 0.9 1.1 1.3 1.5 1.7 1.9 2.1 2.3

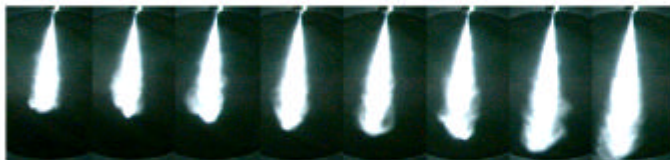


2.5 2.7 2.9 3.1

(b) Rail pressure 10MPa - Surround pressure 0.3MPa



0.1ms 0.3 0.5 0.7 0.9 1.1 1.3 1.5 1.7 1.9 2.1 2.3



2.5 2.7 2.9 3.1 3.3 3.5 3.7 3.9

(c) Rail pressure 10MPa - Surround pressure 0.6MPa

Fig. 4.1 LPG Spray developments with surround pressure variation

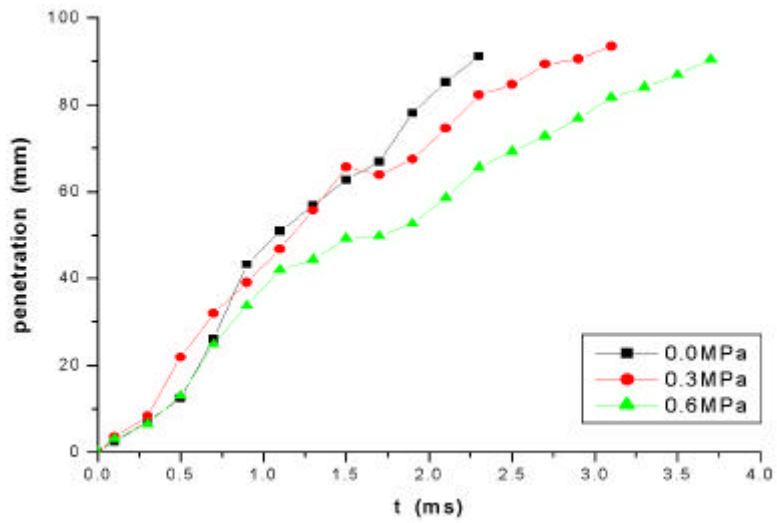


Fig. 4.2 LPG Spray penetration with time from injection start

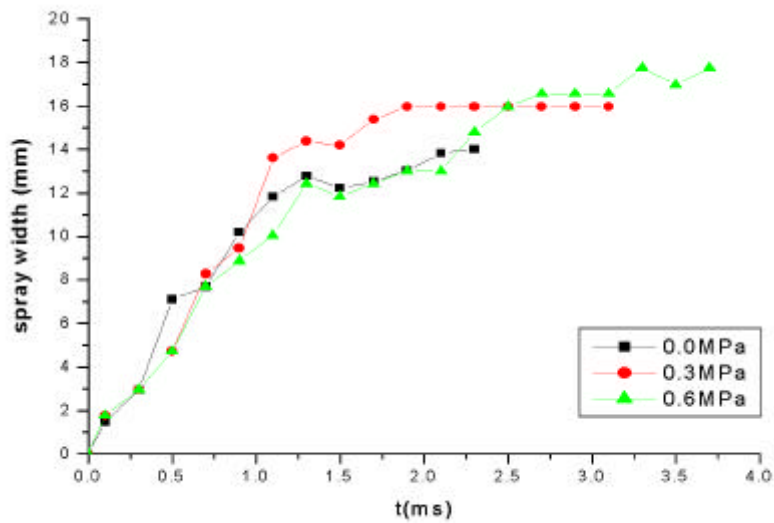
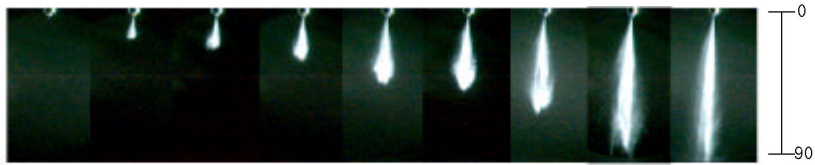


Fig. 4.3 LPG spray width with time from injection start



0.1ms 0.3 0.5 0.7 0.9 1.1 1.3 1.5 1.7

(a) Rail pressure 10MPa - Surround pressure 0.0MPa

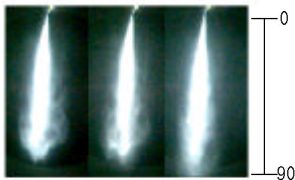


0.1ms 0.3 0.5 0.7 0.9 1.1 1.3 1.5 1.7 1.9 2.1 2.3

(b) Rail pressure 10MPa - Surround pressure 0.3MPa



0.1ms 0.3 0.5 0.7 0.9 1.1 1.3 1.5 1.7 1.9 2.1 2.3



2.5 2.7 3.1

(c) Rail pressure 10MPa - Surround pressure 0.6MPa

Fig. 4.4 Diesel Spray developments with surround pressure variation

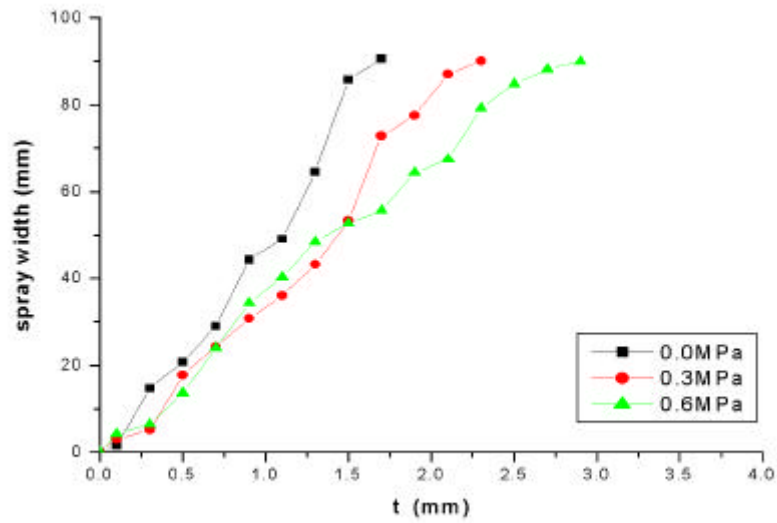


Fig. 4.5 Diesel spray penetration with time from injection start

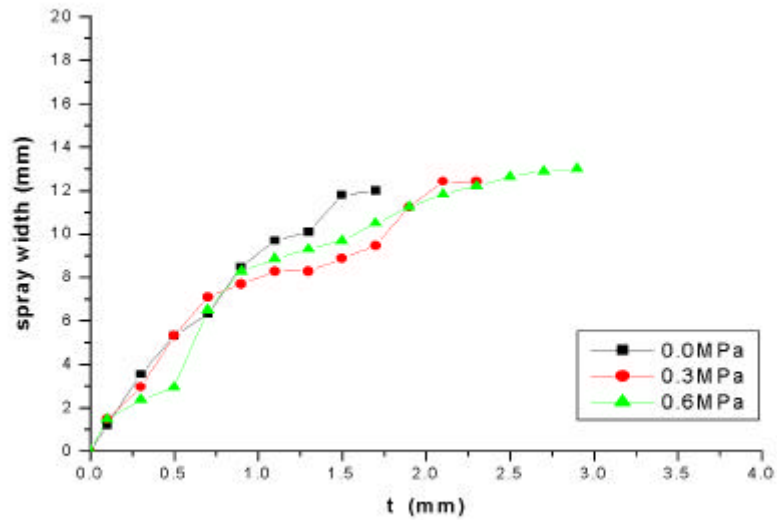


Fig. 4.6 Diesel spray width with time from injection start

4.4 가

Fig. 4.7 10MPa 0.0MPa, 0.3MPa, 0.6MPa

. 가

가 ,

가 .

Fig. 4.8, Fig. 4.9 10MPa 0.0MPa, 0.3MPa,
0.6MPa . 가

.

0.0MPa, 0.3MPa,

0.6MPa 가 .

가 .

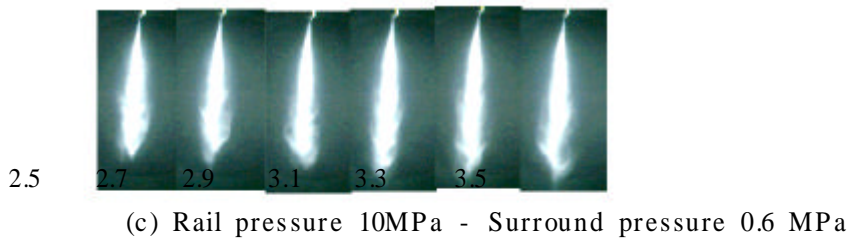
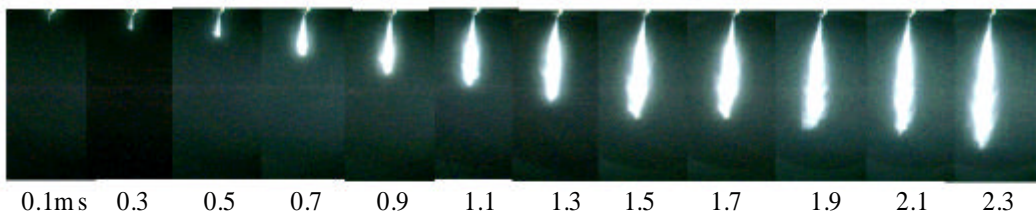
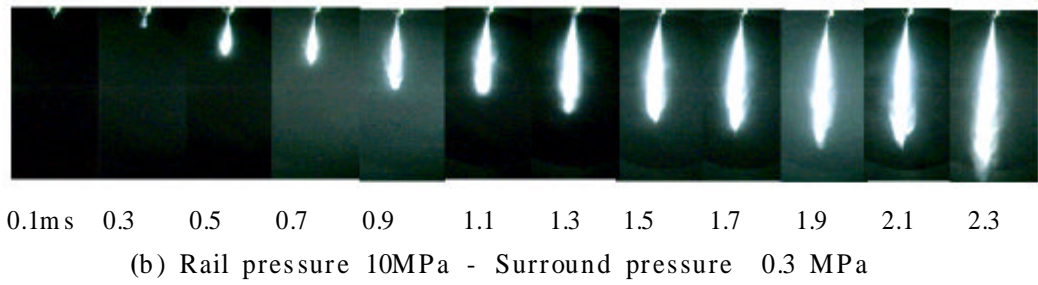
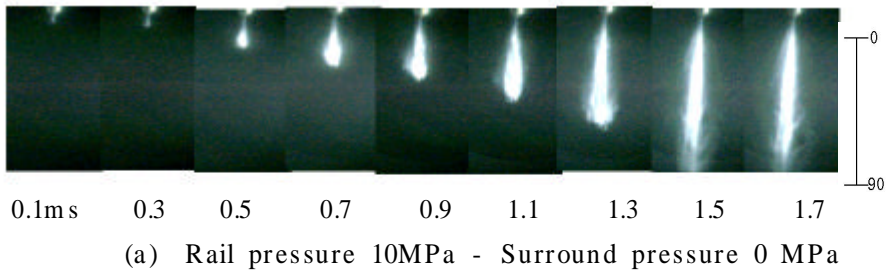


Fig. 4.7 Gasoline Spray developments with surround pressure variation

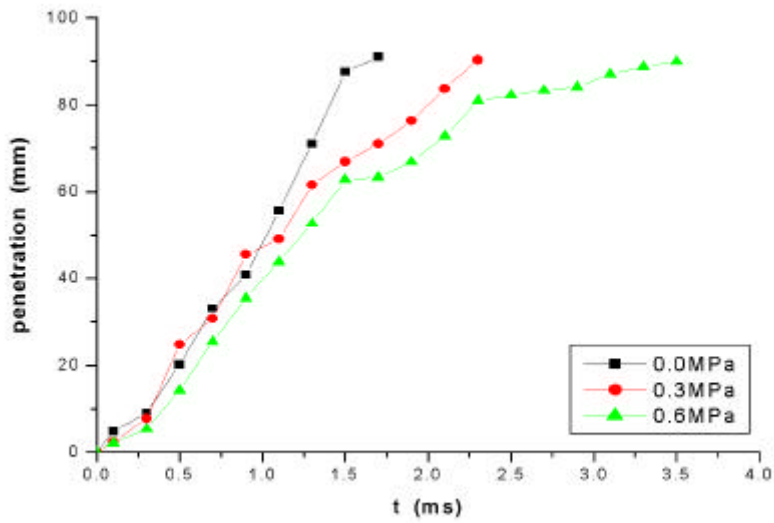


Fig. 4.8 Gasoline spray penetration with time from injection start

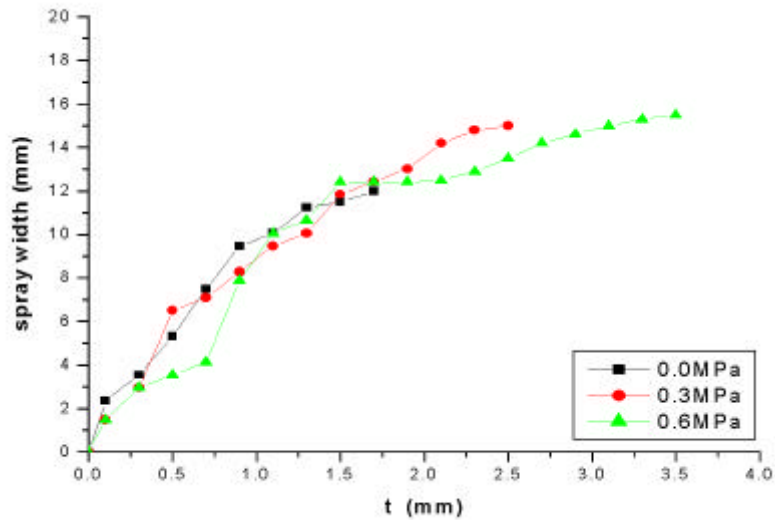


Fig. 4.9 Gasoline spray width with time from injection start

4.5 LPG, 가

4.5.1

Fig. 4.10, Fig. 4.11, Fig. 4.12 10MPa LPG, 가
0.5ms . LPG 0.0MPa 가
가 , 가
. , 0.0MPa LPG
. 0.0MPa LPG
가 , 가 .
가 LPG ,

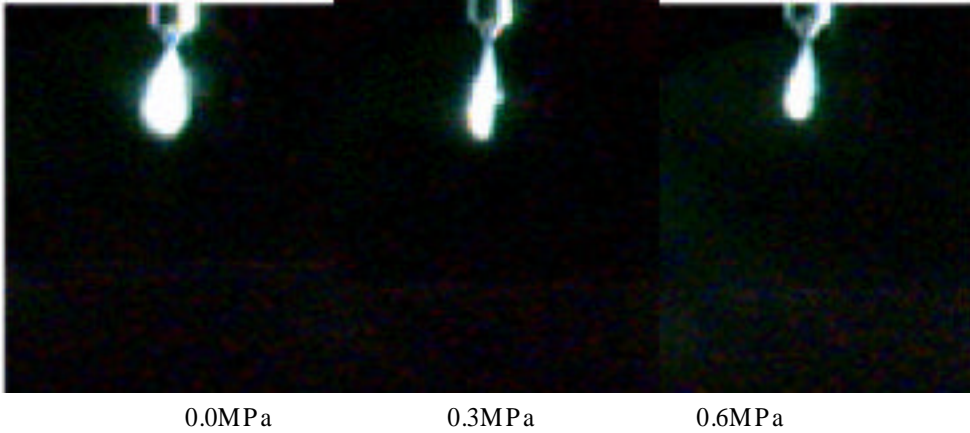


Fig. 4.10 Spray of LPG at 0.5ms after injection

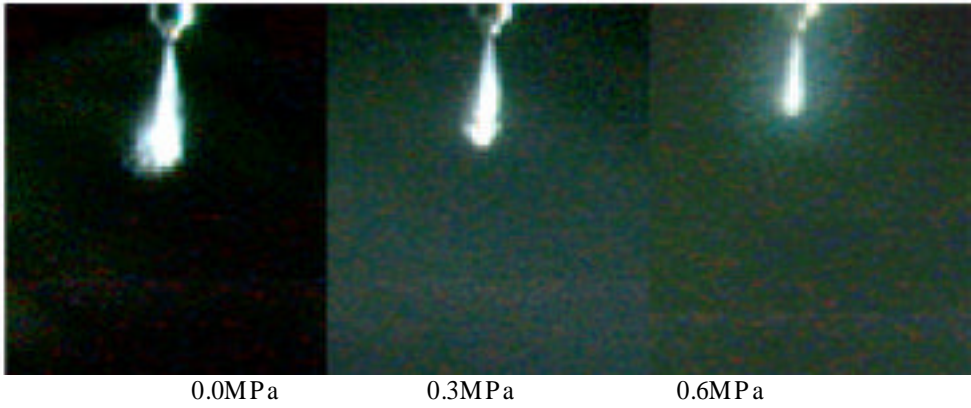


Fig. 4.11 Spray of diesel at 0.5ms after injection

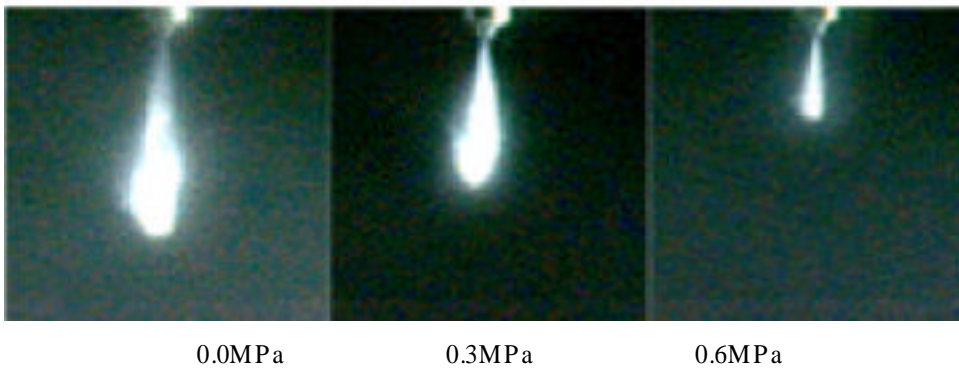


Fig. 4.12 Spray of gasoline at 0.5ms after injection

4.5.2

85 mm

Fig. 4.13, Fig. 4.14, Fig. 4.15 10MPa LPG, 가

가 85mm

. LPG 0.0MPa

가 가 .

. LPG . 가

0.0MPa 가 , 0.6MPa

.

.

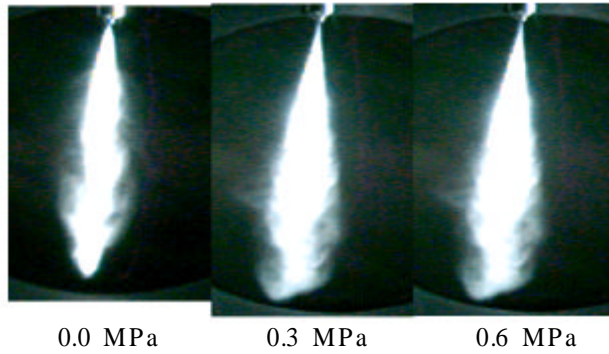


Fig. 4.13 Spray of LPG at tip penetration 85mm

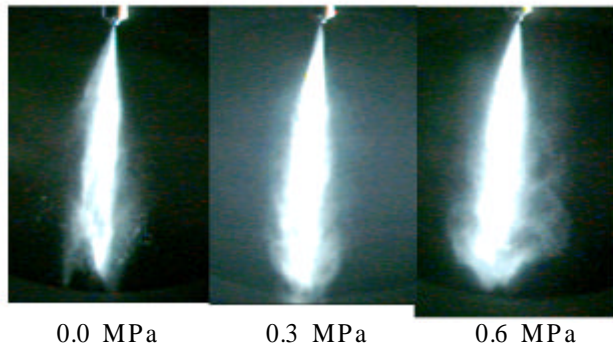


Fig. 4.14 Spray of diesel at tip penetration 85mm

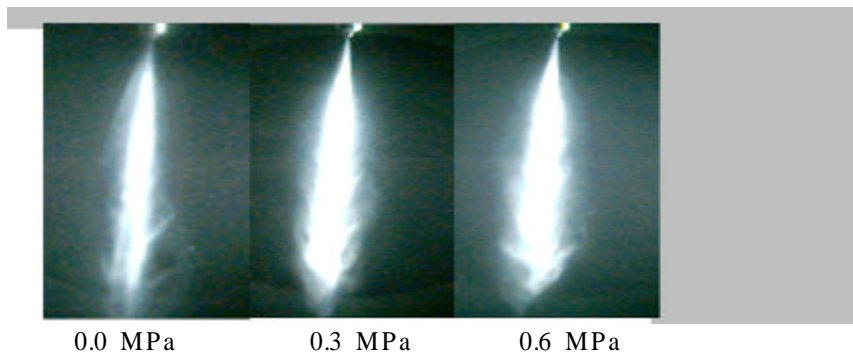


Fig. 4.15 Spray of gasoline at tip penetration 85mm

4.5.3

Fig. 4.16, Fig. 4.17 Fig. 4.18 10MPa LPG, 가

가

가

가

가

가

,

, LPG

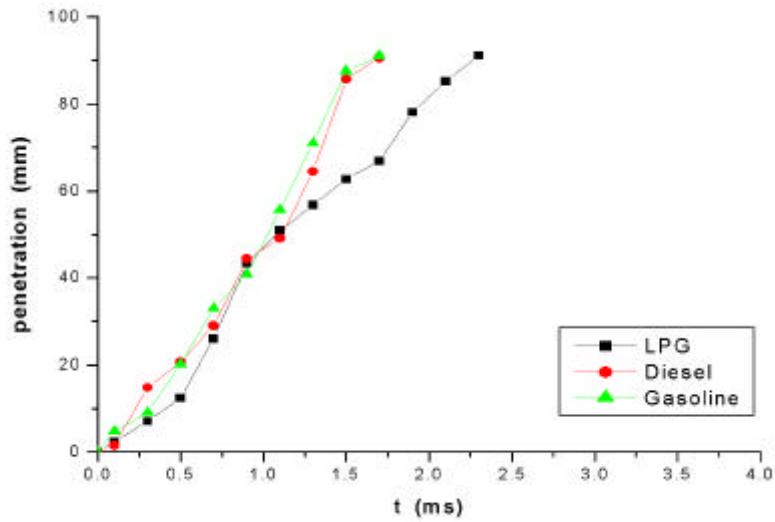


Fig. 4.16 Comparison of spray penetration of LPG, diesel, gasoline at surround pressure 0.0MPa

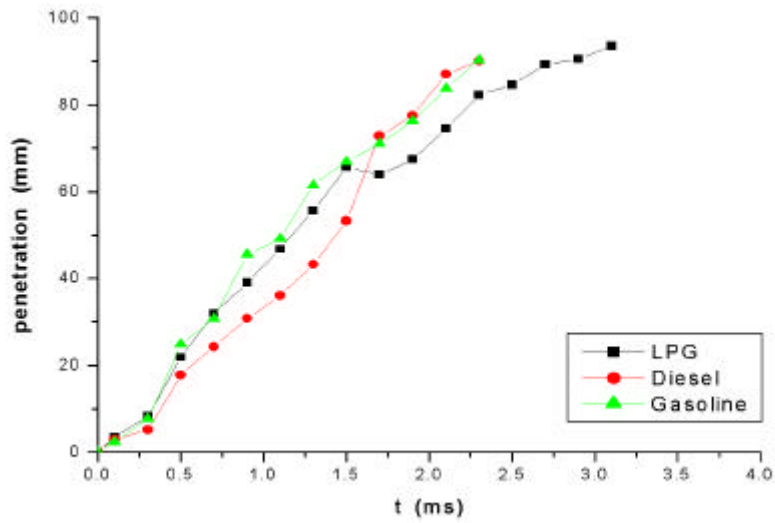


Fig. 4.17 Comparison of spray penetration of LPG, diesel, gasoline at surround pressure 0.3MPa

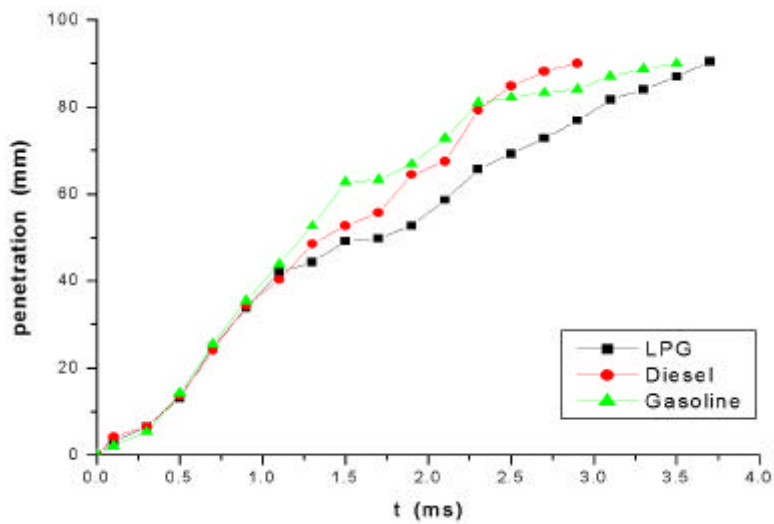


Fig. 4.18 Comparison of spray penetration of LPG, diesel, gasoline at surround pressure 0.6MPa

Fig. 4.19, Fig. 4.20, Fig. 4.21

10MPa LPG, 가

LPG가 가

0.0MPa LPG

가 , 0.3MPa

, Fig. 1.1

3:7 LPG , 25 0.35MPa

가

0.6MPa 가

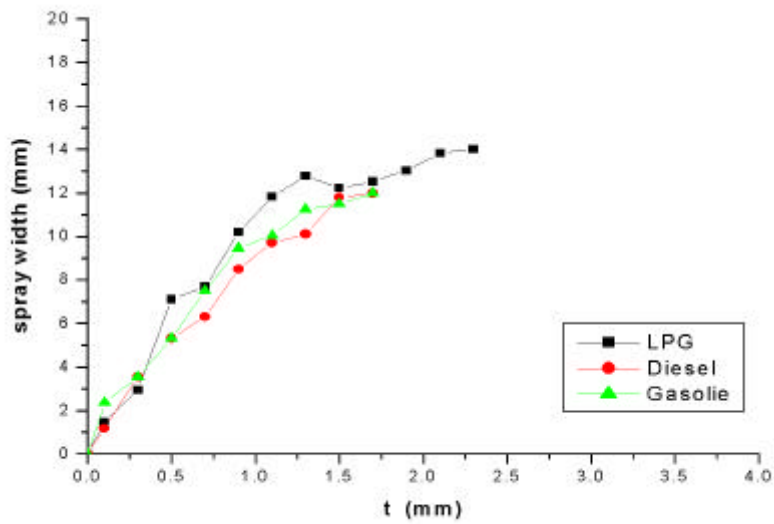


Fig. 4.19 Comparison of spray width of LPG, diesel, gasoline at surround pressure 0.0MPa

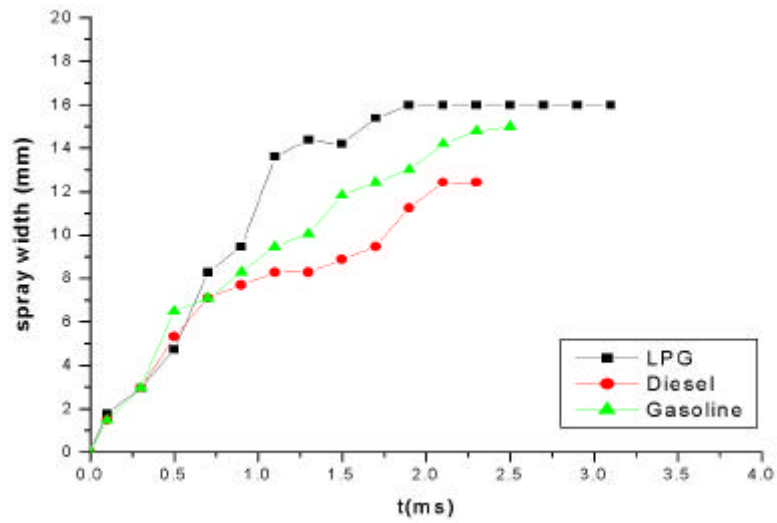


Fig. 4.20 Comparison of spray width of LPG, diesel, gasoline at surround pressure 0.3MPa

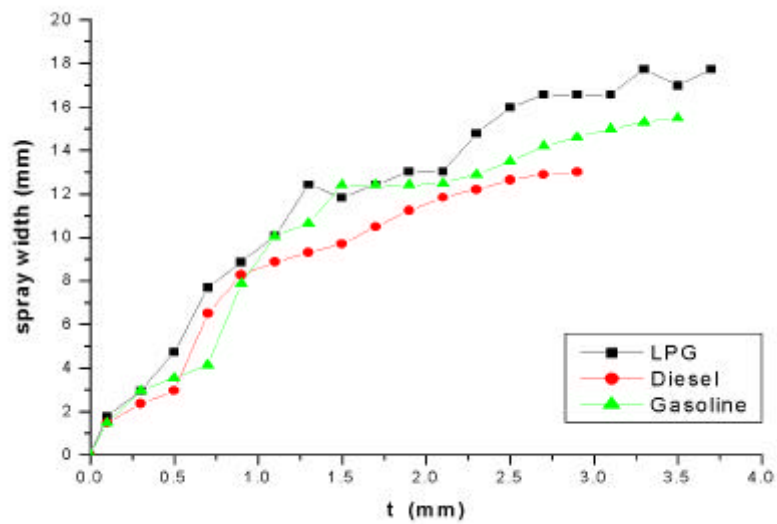
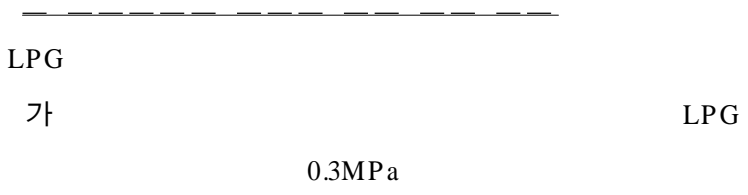
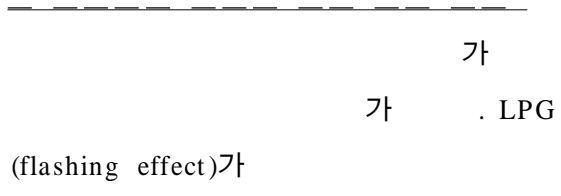
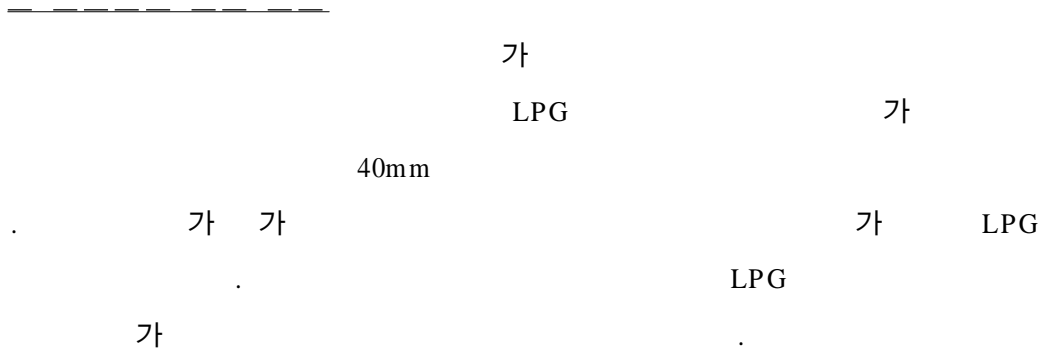


Fig. 4.21 Comparison of spray width of LPG, diesel, gasoline at surround pressure 0.6MPa

5.

0.9MPa



가

가

가

.

LPG

,

가

가

.

LPG

5MPa

LPG

가

가

가

.

LPG

, LPG

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