Evaluation of Common Rail Injector and Engine Tail Pipe Emissions of Clean Diesel

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HONDA

Honda R&D Co., Ltd.

Today's Topics

1. Background and Objectives

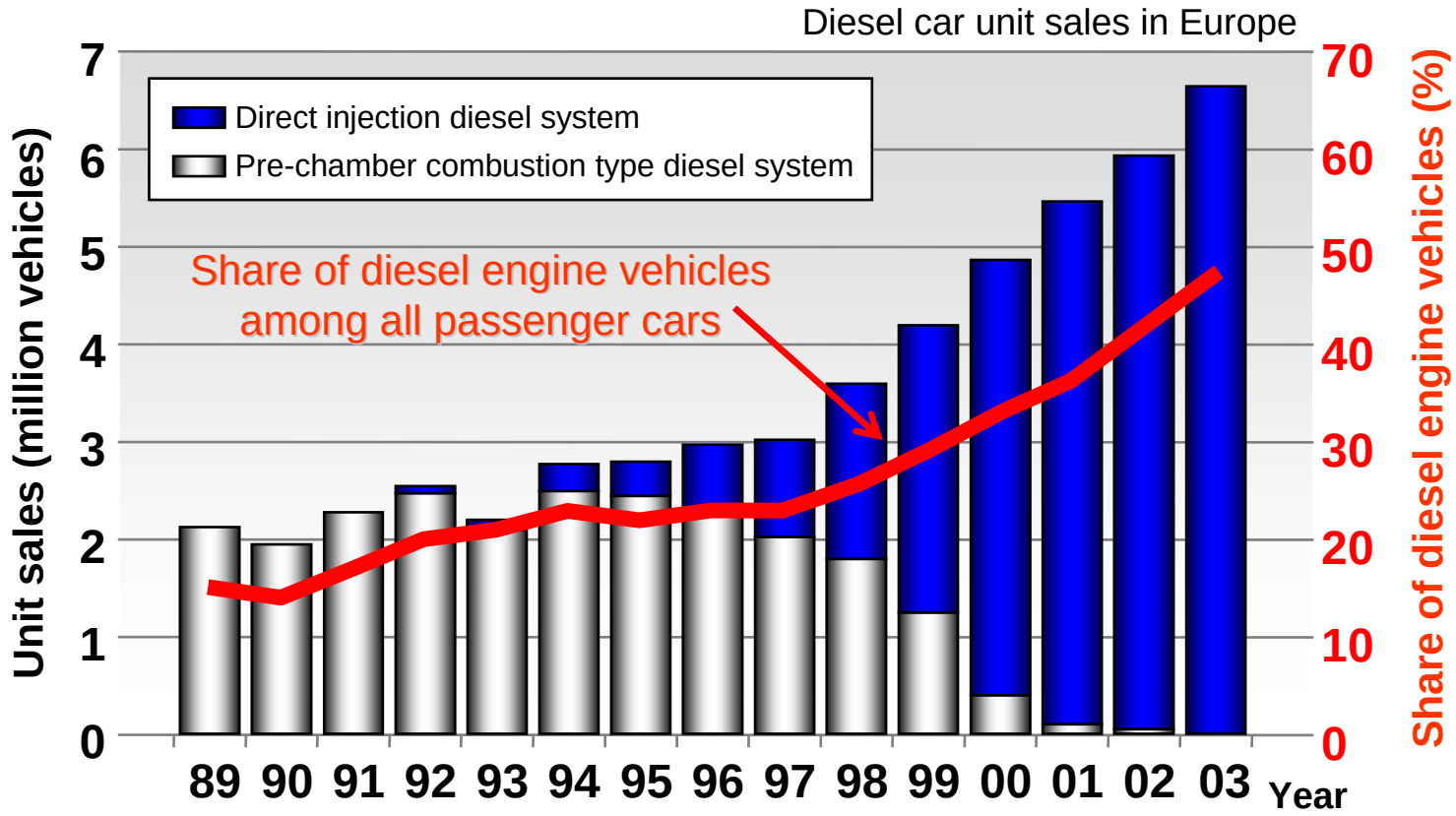
2. Influence of injector-tip performance to spray characteristics and combustion

3. Effect of injector specifications to spray characteristics and combustion

4. Summary & Future work

Background 1

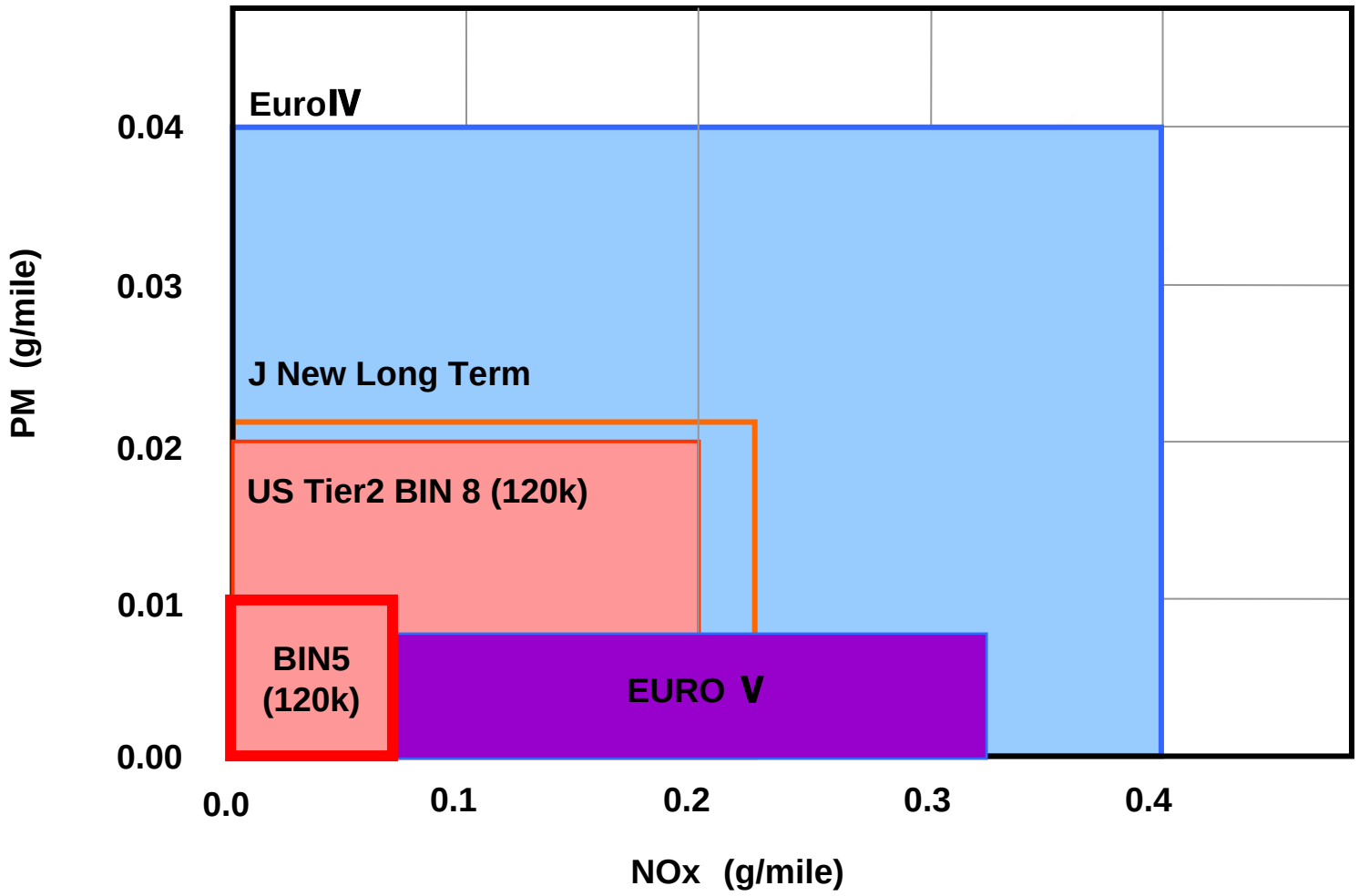
Use of diesel engines in Europe Market



Since the late 90's, there has been a large increase in the share of diesel engine vehicles.

Background 2

Emission Target of Clean Diesel



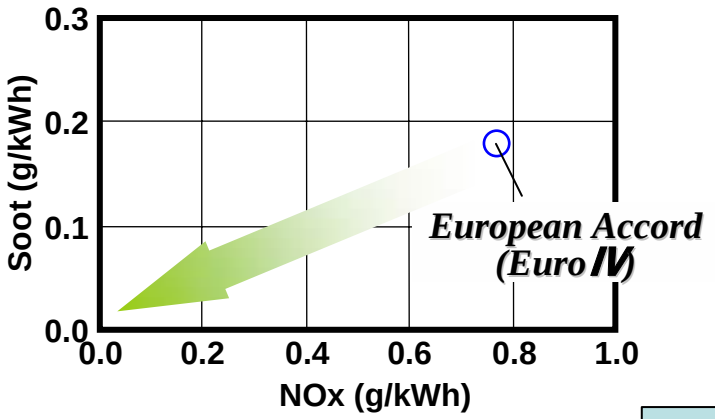
From the viewpoint of global warming,

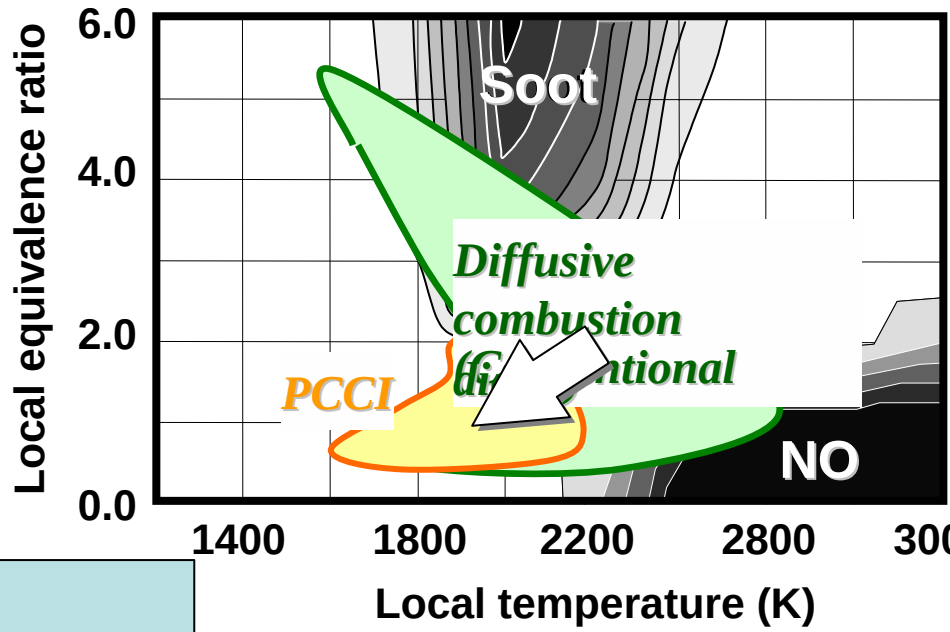
cleaner emissions for diesel engines are required

Background 3

Premixed charge compression ignition (PCCI)

=> significant reduction of NOx and soot





We achieve the clean diesel engine using new after treatment technology, and new combustion with cooled EGR and Diesel FIE improvement,

1. Higher Injection Pressure
2. Higher Injection Response
3. Smaller Nozzle Hole

for Lower Local Equivalence Ratio.

Objectives

To meet upcoming more stringent emission regulation, Advanced FIE system is a must item.

This presentation reports two topics as follows

1. Influence of injector-tip performance to spray characteristics and combustion

2. Effect of injector specifications “ injection pressure, hole diameter, response of injector ” to spray characteristics and combustion

Today's Topics

1. Background and Objective

2. Influence of injector-tip performance to spray characteristics and combustion

3. Effect of injector specifications to spray characteristics and combustion

4. Summary & Future work

Contents

Objective

To evaluate engine out emissions of 7 same spec. nozzles by a single cylinder engine and items regarding spray and R.O.I. likely to affect emission by correlation coefficient .

Contents

Test menu & experimental apparatus

1)Engine out emission
; Single cylinder engine

2) Spray form
; Hi-Speed digital video camera

3) Rate of injection
; Injection test stand

Test engine

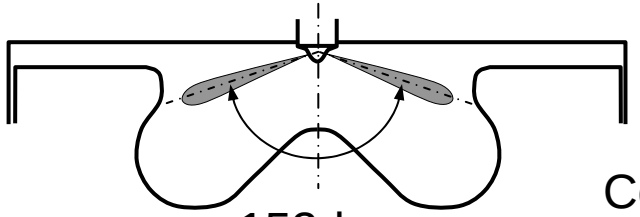
Engine specifications

Engine Type	4-stroke single cylinder direct injection diesel engine
Displacement volume	550 (cm^3)
Bore× Stroke	85.0 (mm)×97.1 (mm)
Fuel injection system	Common rail
Injection nozzle	Φ0.139 (mm)×6 holes
Swirl control valve	Continuously variable

Test fuel specifications

Fuel cetane index	52.0
Density at 15 (℃)	839 (kg/m^3)
Viscosity at 40 (℃)	2.833 (mm^2/s)

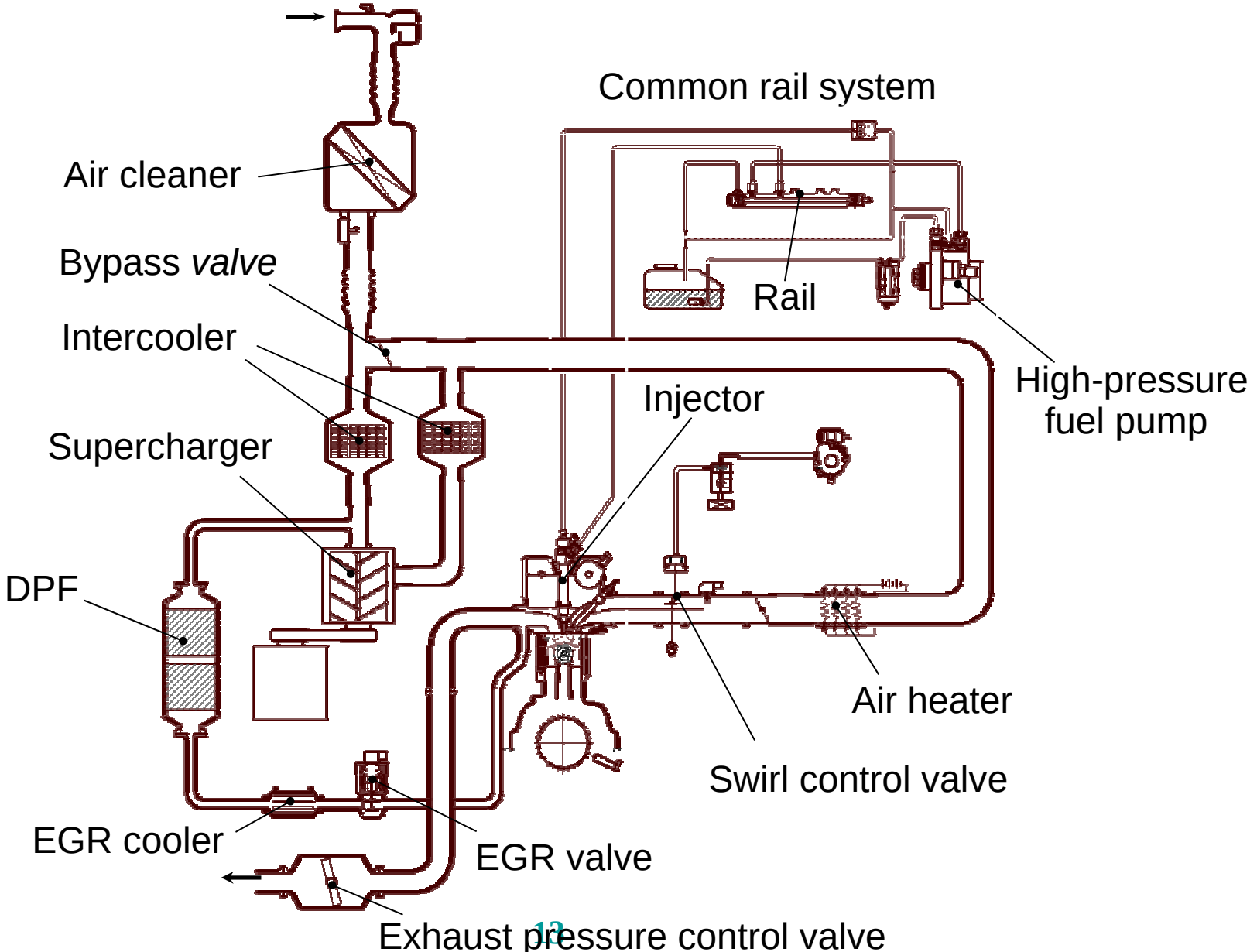
Outline of piston bowl and nozzle cone angle



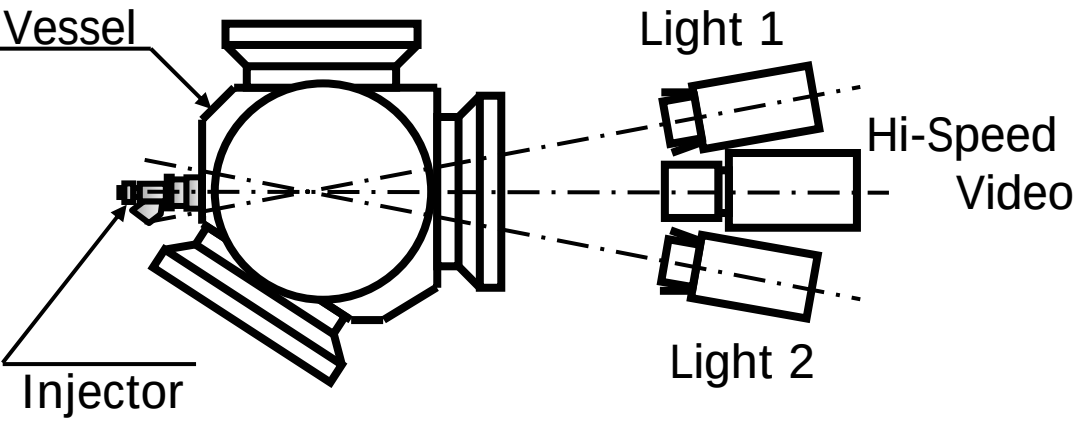
Compression ratio ; 16.7

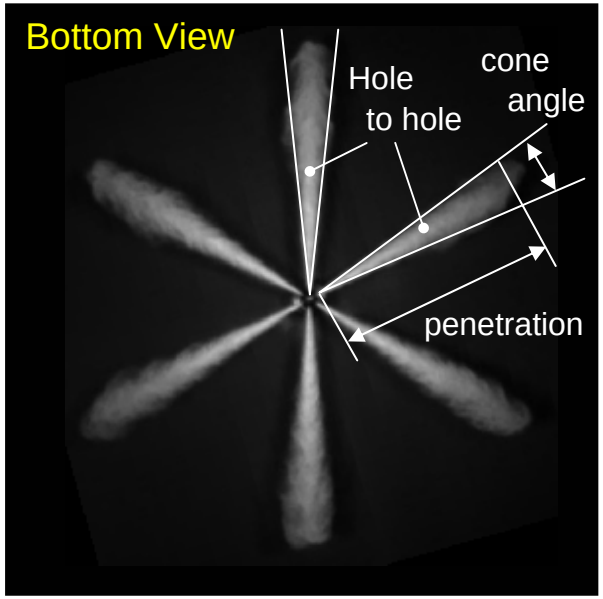
Aspect ratio ; 2.9

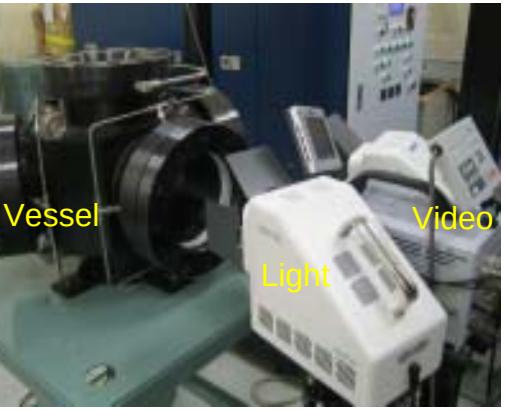
Test engine system



Hi-Speed image recording system





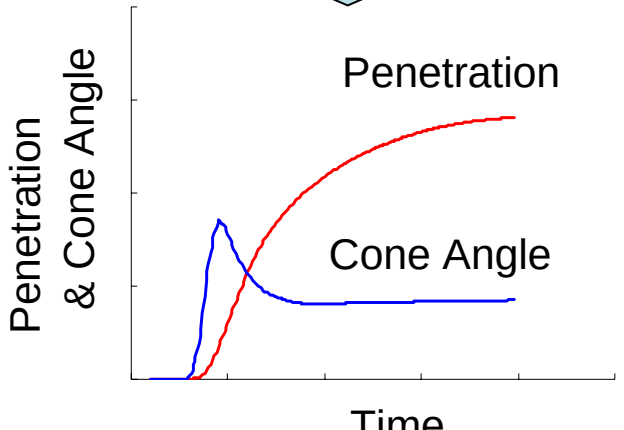


Hi-Speed Digital Video
- 10000FPS / 512×512pix
- Shutter Speed；2μsec

Lighting
- Metal halide;150 W×2

Vessel
- Window ; φ200mm ×3
- Pmax ; 2.0 MPa
- Ambient gas ; N2

Image processing



Injection test stand

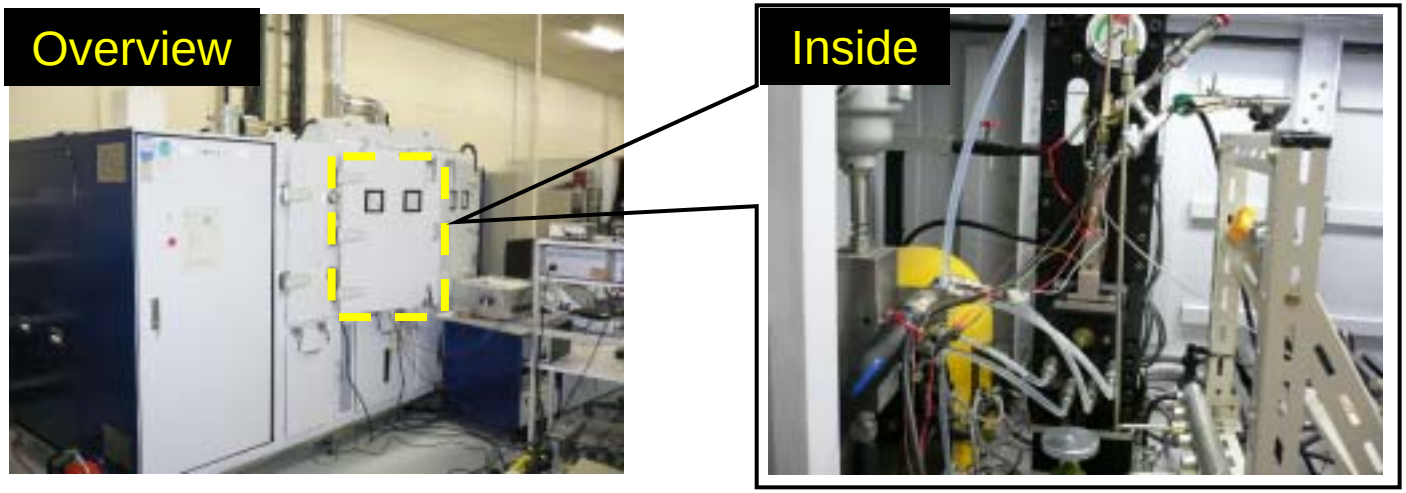
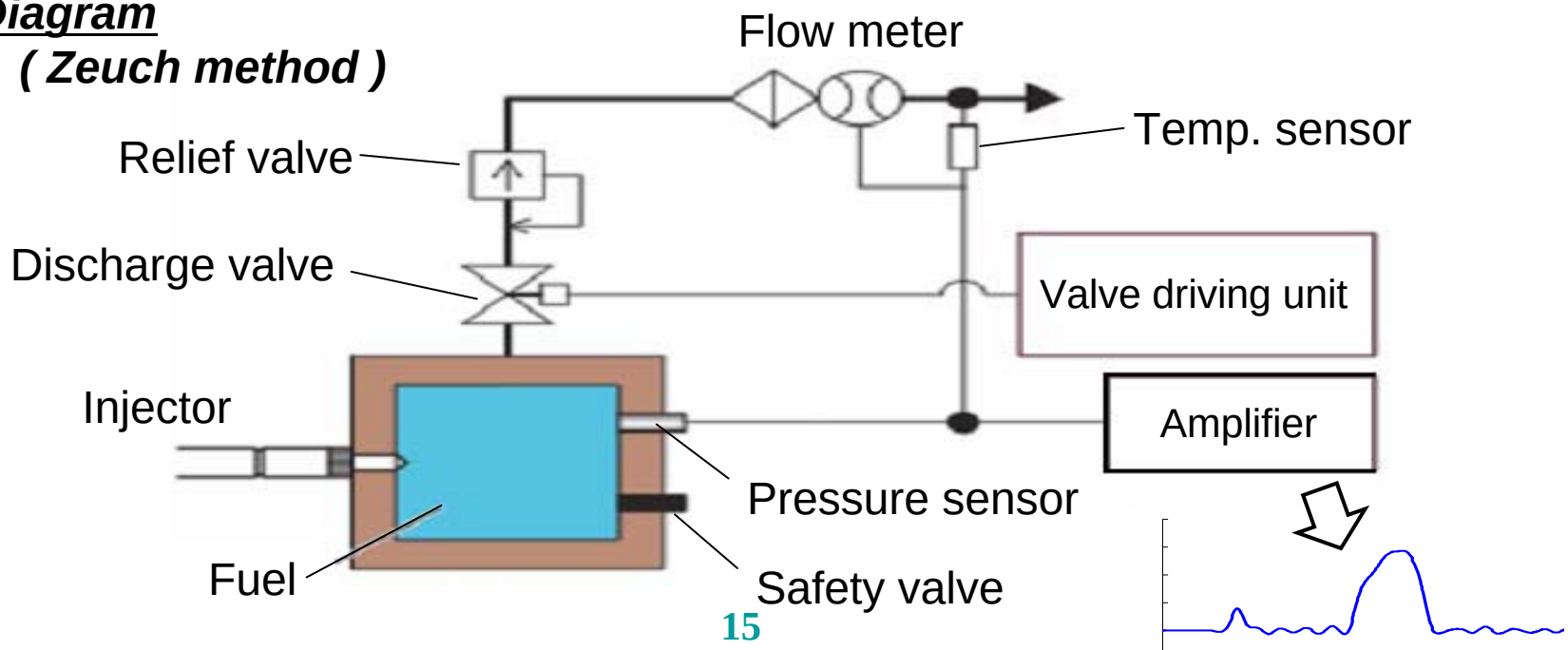
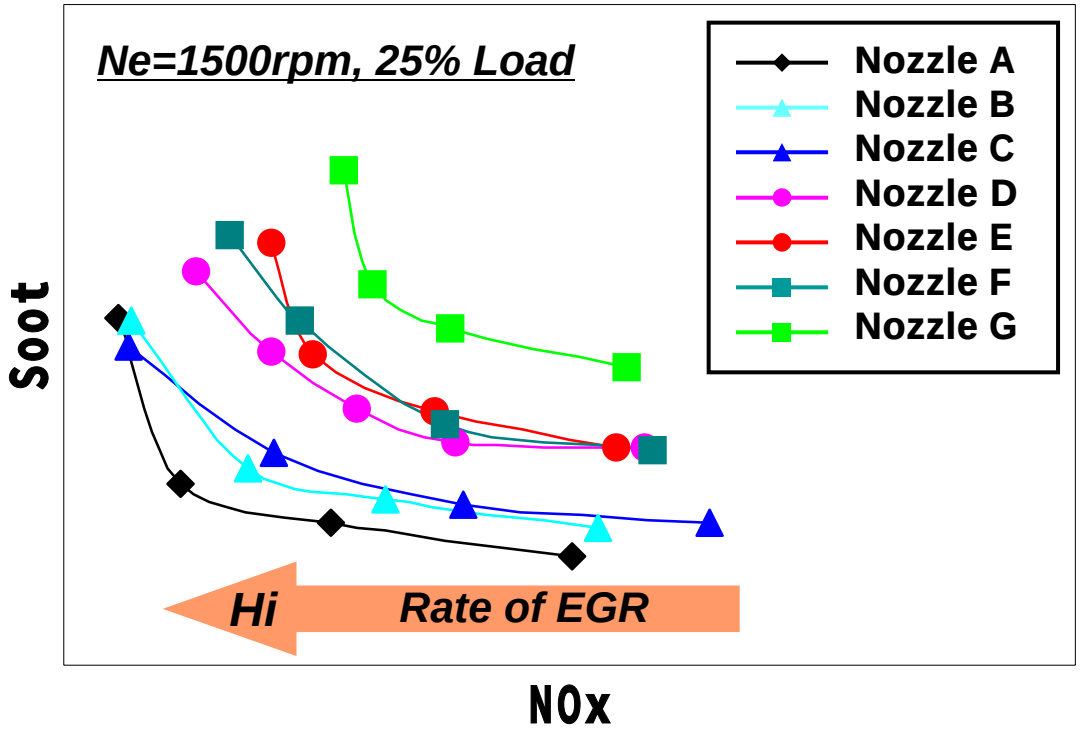


Diagram
(Zeuch method)

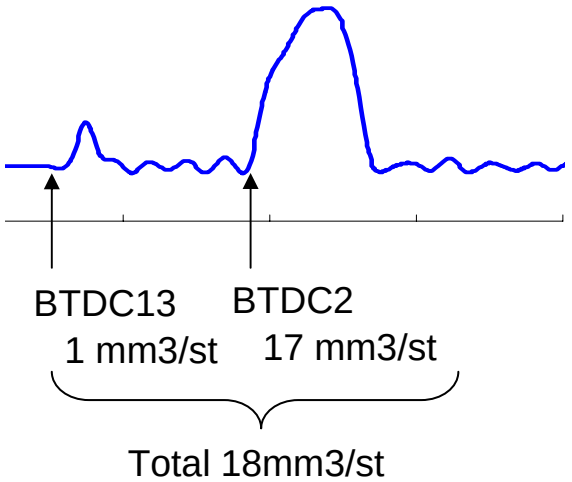


Contents

Test results ; Engine out emissions



Injection Timing & quantity



Nozzle A-G { Same spec. ϕ139[mm]×6 holes but…

⇨ **Differences of R.O.I. & spray form**

⇩

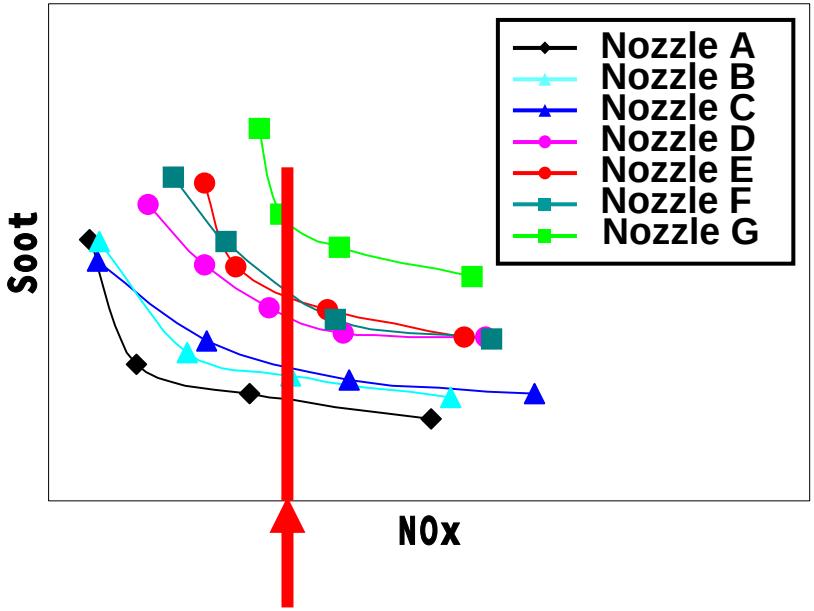
Make variance in emissions

Test conditions ; Spray form

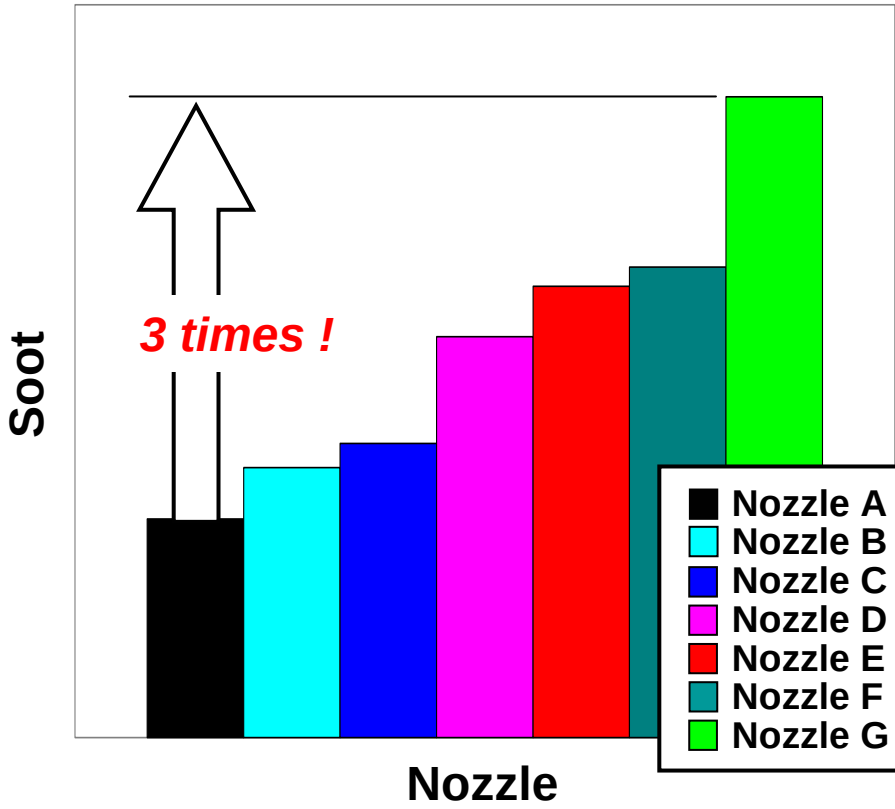
Fuel		Gas oil (E-2)
Fuel temperature	[K]	313
Rail pressure	[MPa]	71
Injection quantity	[mm^3/str]	18
Ambient gas		N2
Ambient gas pressure	[MPa]	1.4
Ambient gas density	[kg/m^3]	16.1
Ambient gas temperature	[K]	293

NOx & Soot trade-off curve

Ne=1500rpm, 25%Load



Setting point of multi-cylinder engine and vehicle



Items for evaluation

Engine out emissions

- Soot @ NOx=3 [mg/sec]

For evaluating relations between emission and spray characteristics

⇒ **Correlation coefficient**

1.Spray form

Hole-to-hole difference

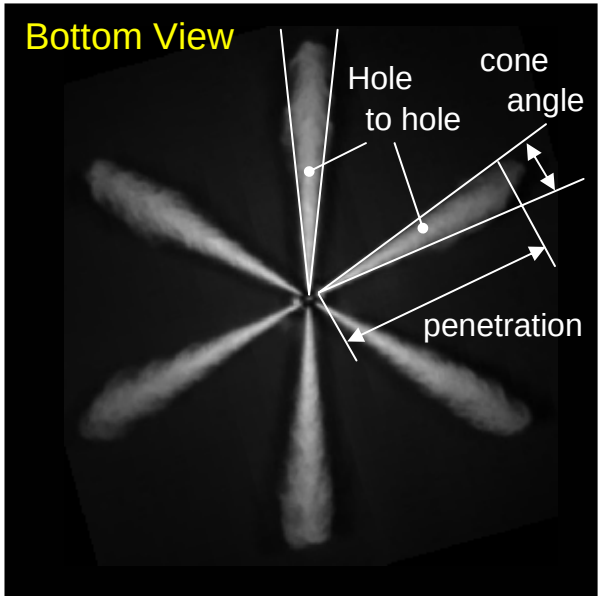
- Penetration
- Spray angle

Average of 6-holes

- Penetration
- Spray angle

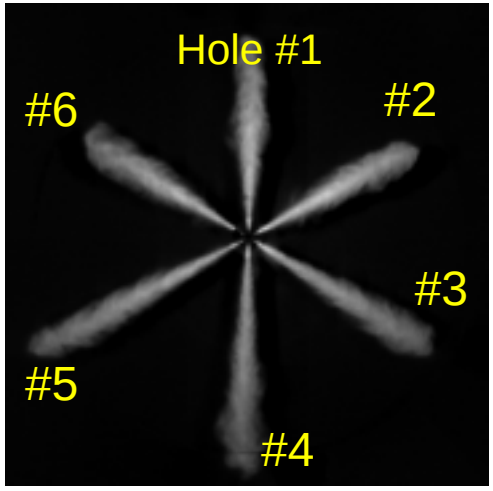
2.Rate of injection

- Averaged injection rate

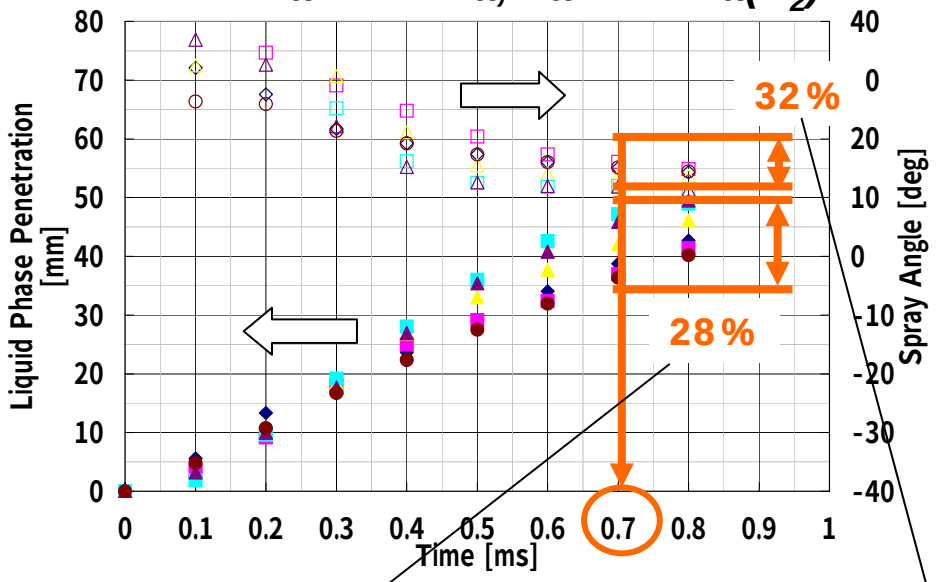


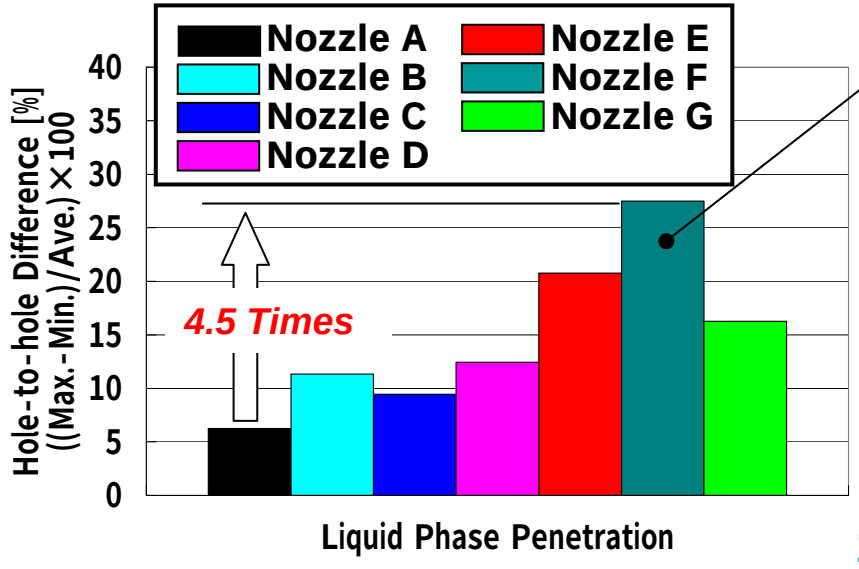
Hole-to-hole differences of spray form

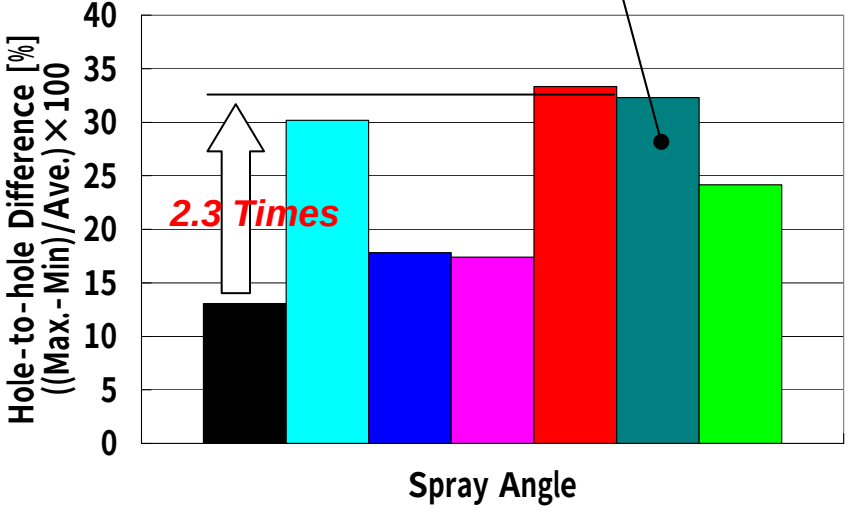
Ex.) Nozzle F



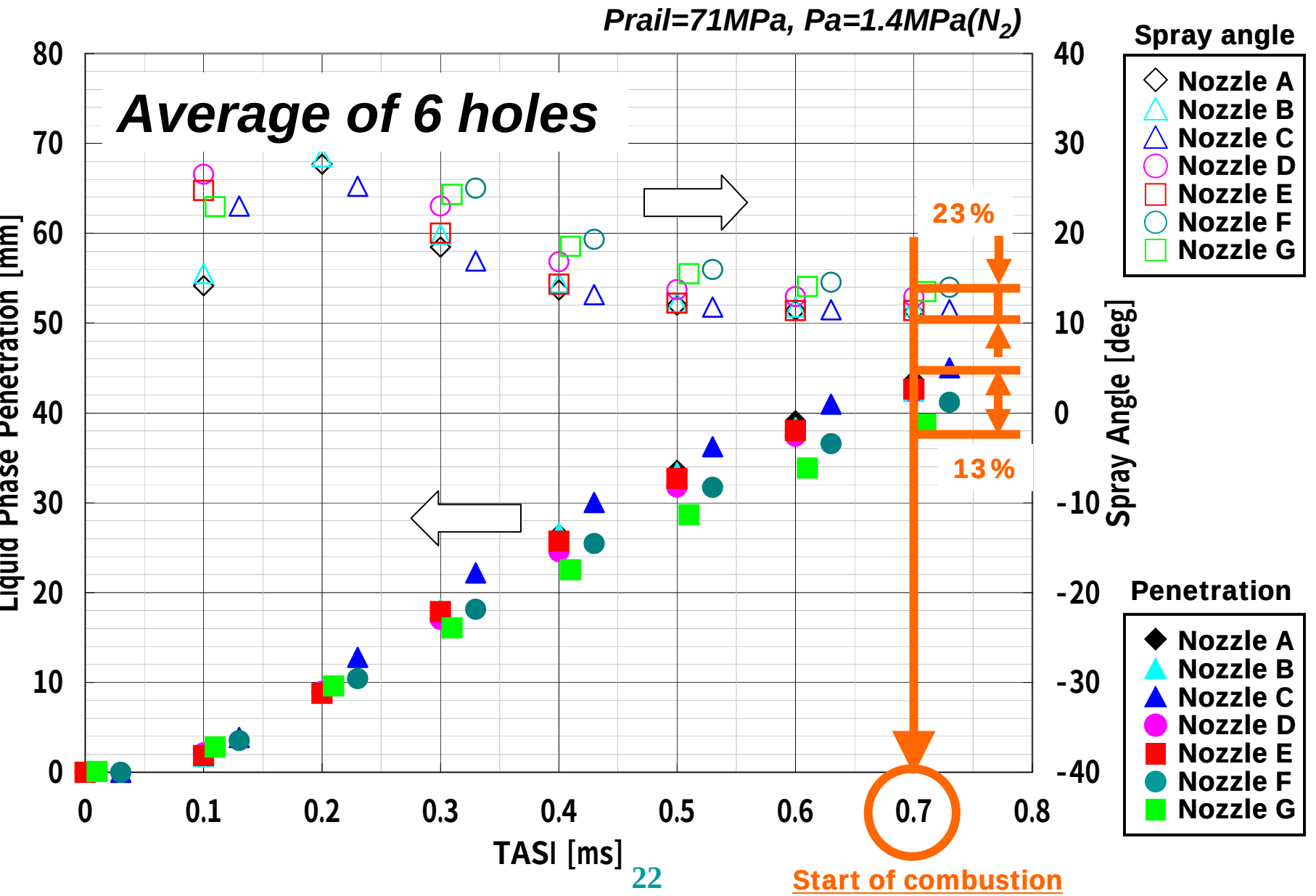
TASI 0.7 ms



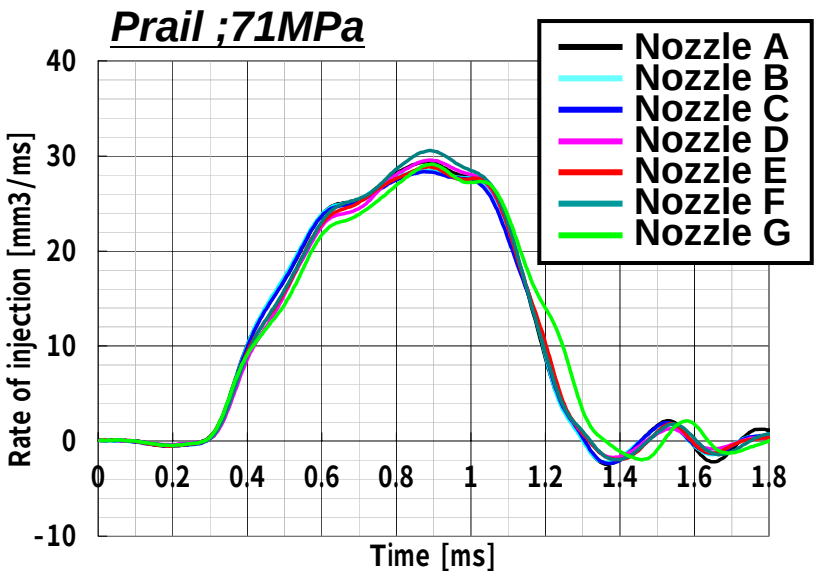


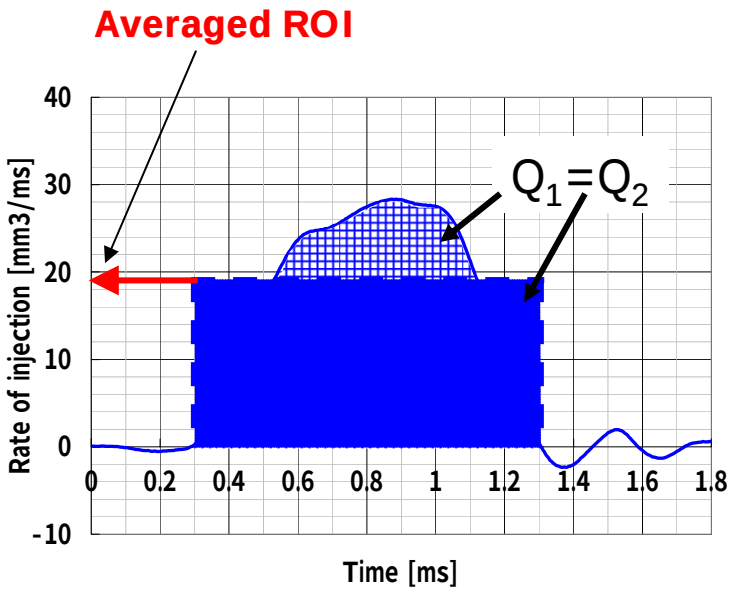


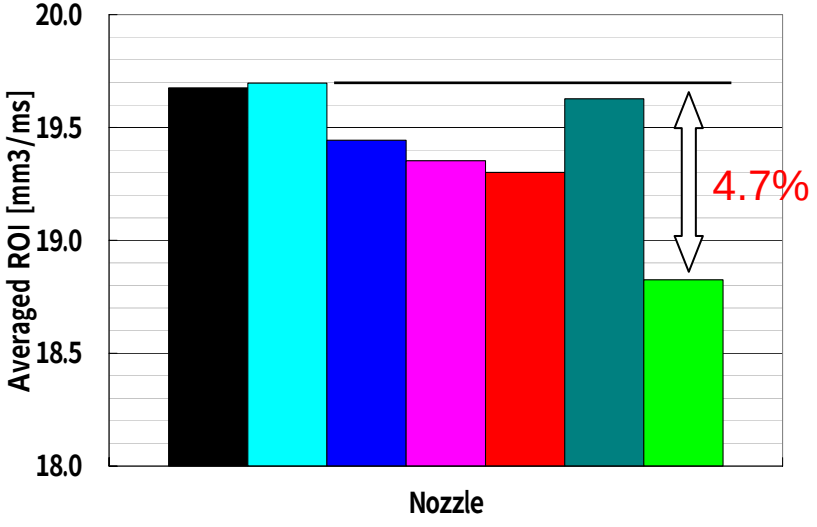
Averaged penetration & spray angle



Difference of rate of injection







Correlation coefficient

Correlation Coefficient ; R_{xy}

Sample ; $\{x_1, x_2, \cdots, x_n\}$

Sample ; $\{y_1, y_2, \cdots, y_n\}$

$$R_{xy} = \frac{\sum_{i=1}^{n} (x_i - \bar{x})(y_i - \bar{y})}{\left[\{\sum_{i=1}^{n} (x_i - \bar{x})^2\}\{\sum_{i=1}^{n} (y_i - \bar{y})^2\}\right]^{1/2}}$$

$1.0 \geqq \lvert R_{xy} \rvert \geqq 0.7$	Level 1
$0.7 > \lvert R_{xy} \rvert \geqq 0.4$	Level 2
$0.4 > \lvert R_{xy} \rvert \geqq 0.2$	Level 3
$0.2 > \lvert R_{xy} \rvert \geqq 0$	Level 4

Hi ⇧ Low

In this study…

Sample ; $\{x_1, x_2, \cdots, x_n\}$ ⇒ Soot at NOx=3[mg/sec] at each nozzle

Sample ; $\{y_1, y_2, \cdots, y_n\}$ ⇒ Spray form (6holes average, Hole-to-hole)
Rate of injection at each nozzle

Correlation of spray form & R.O.I. with emission

Item	Correlation coefficient
6 holes average penetration	-0.75
Averaged injection rate	-0.75
6 holes average spray angle	0.61
Hole-to-hole difference of spray angle	0.48
Hole-to-hole difference of penetration	0.46

Hi-penet. ↓ Low soot

Hi-rate ↓ Low soot

Findings

- Correlation of 6 holes average penetration and correlation of averaged injection rate are negative.
  - ⇒ Hi-penetration → Low soot
  - Hi-injection rate → Low soot
- "Correlations of 6 holes average data are higher than correlations of hole to hole difference data
  - ⇒ it is interesting !!

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Contents

Objective

To evaluate potential of these items

- **Hi-injection pressure**
- **Small diameter nozzle hole**
- **Hi-response actuator**

These are main items to meet upcoming more stringent emission regulation.

Contents

Test menu & experimental apparatus

1)Engine out emission

; Single cylinder engine

2) Rate of injection

; Injection test stand

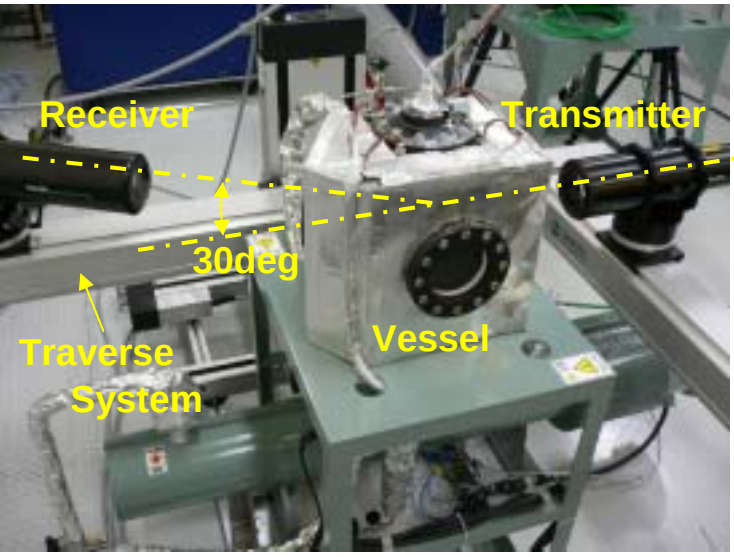
3) Spray form

; Hi-Speed image recording system

4) Fuel droplet size

; PDA

Phase Doppler Anemometry (PDA)



PDA

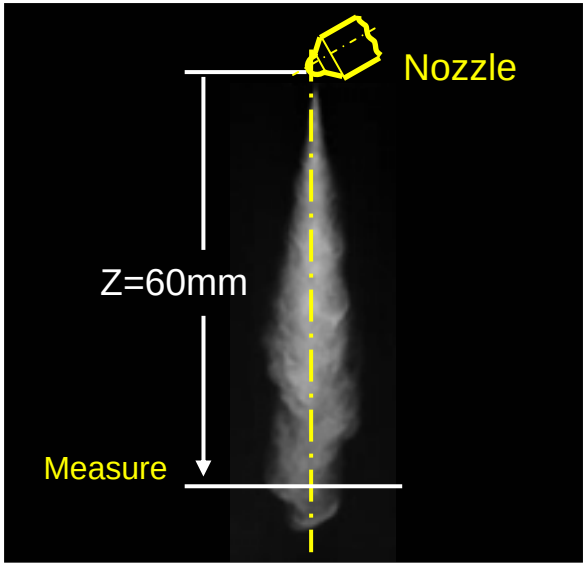
・Ar Laser ；1W (Max6W)

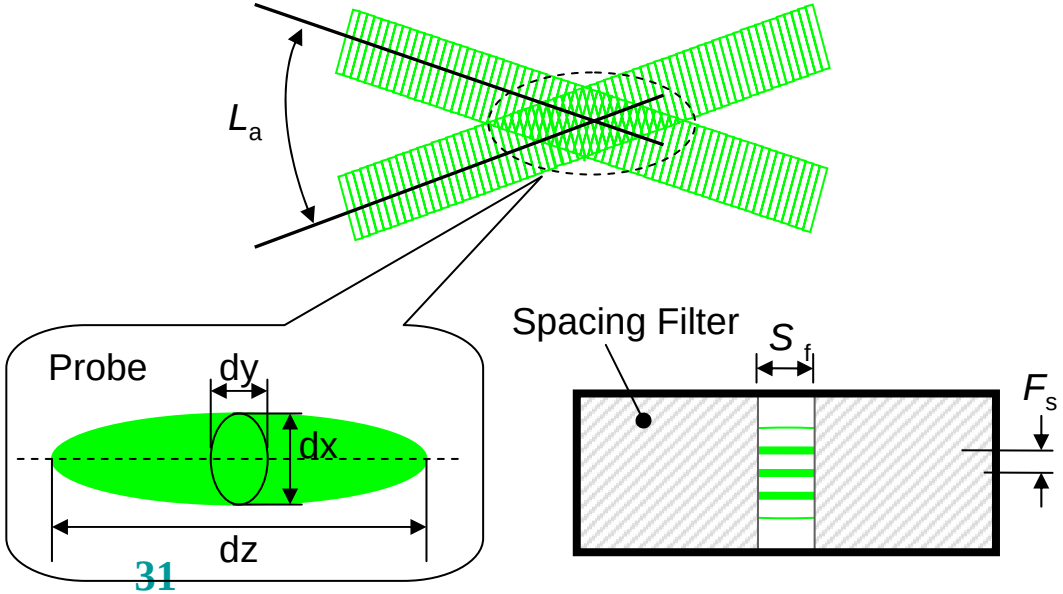
Vessel

・Window ; φ100mm ×3
・Pmax ; 2.0 MPa
・Ambient gas ; N 2
・Gas recirculation system

Traverse system

・Computer controlled
・ Resolution min ; 1mm





Specifications of Injector

Item	Mass-product	Proto-type
Actuator	Solenoid	Piezo
Hole Diameter (mm)	0.139	0.121
Number of Holes	6	8

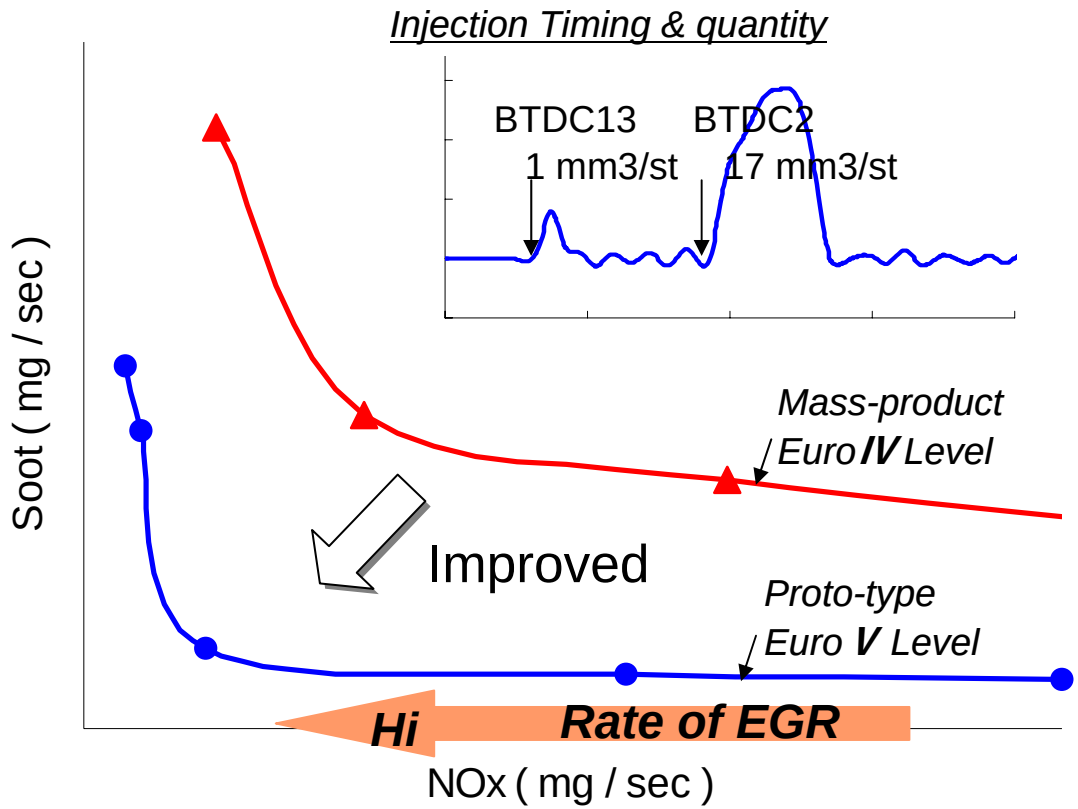
Test conditions ; spray

Fuel		Gas oil (E-2)
Fuel temperature	[K]	313
Rail pressure	[MPa]	71, 98
Injection quantity	[mm^3/str]	18
Ambient gas		N2
Ambient gas pressure	[MPa]	1.4
Ambient gas density	[kg/m^3]	16.1
Ambient gas temperature		293

Contents

Test results of a single cylinder engine

1500rpm 18mm3/st (25%Load)



	Φ(μm)	Pf (MPa)
Mass-product	139	71
Proto-type	121	98

Items

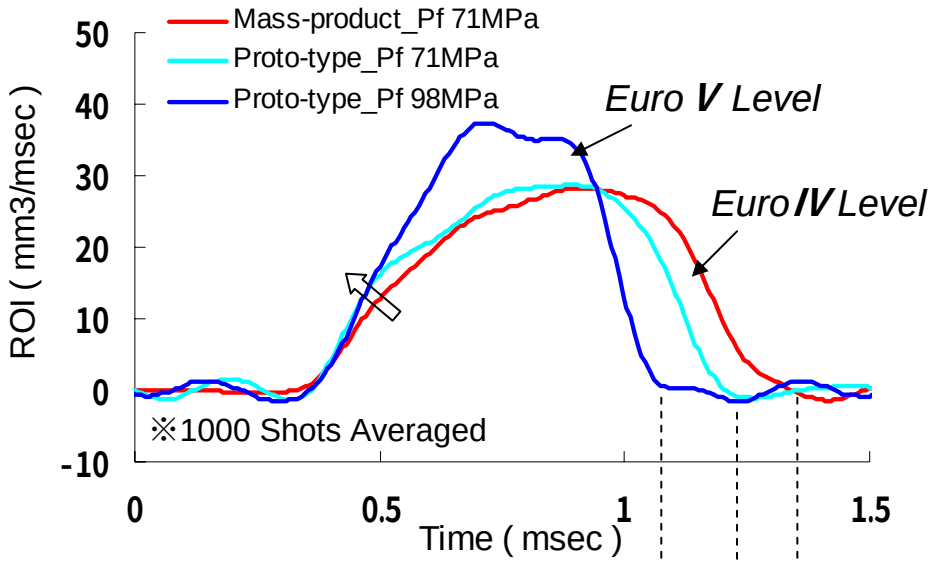
- Hole diameter
  Φ139μm → Φ121μm
- Fuel pressure
  71MPa → 98MPa
  ※Optimized
- Actuator
  Solenoid → Piezo
- Fuel leak
  → decreased

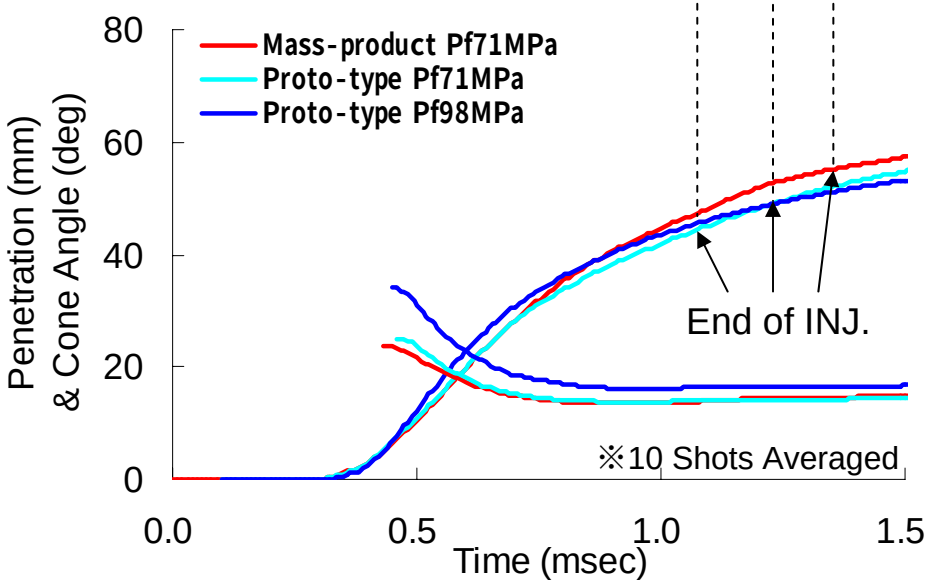
E / M is improved

without deteriorating fuel consumption

Test results ; Spray form and R.O.I.

Injection quantity ; 18mm3/st



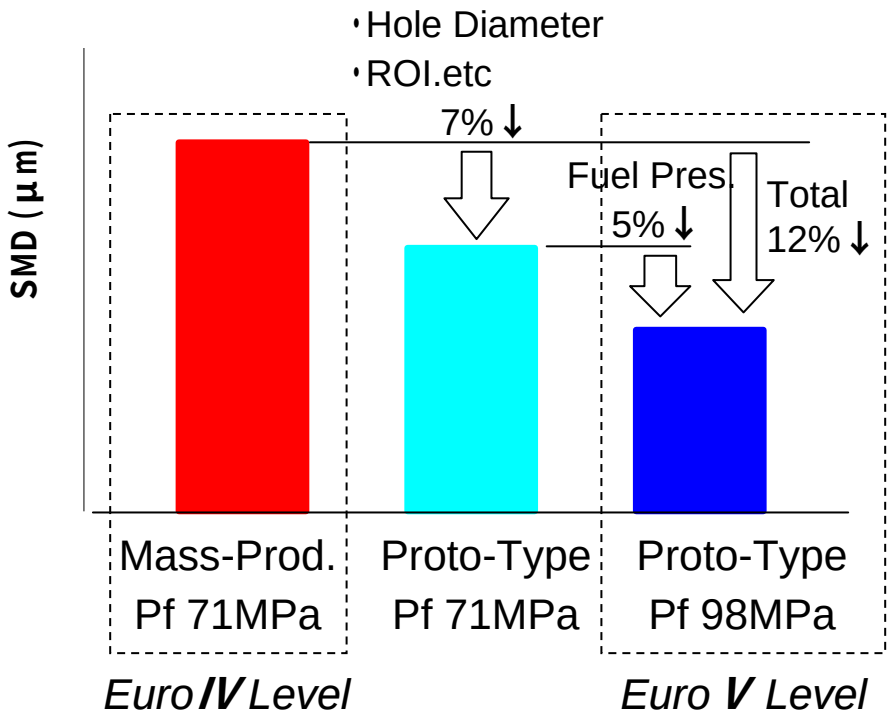


- Hi-response actuator and hi-fuel pressure improved rate of injection and penetration.
- Hi-penetration and hi-injection rate reduce emission

  same result as previous results.

Test results ; Fuel droplet size

Injection quantity ; 18mm3/st



- **Small hole diameter nozzle and hi-injection rate improved atomization by 7%**
- **Hi-fuel pressure improved atomization by 5%**

Table of Contents

Summary

1) Raking of items to evaluate relation between emission and spray characteristics as follows

High ↑

1) 6 holes average penetration
1) Averaged injection rate
3) 6 holes averaged spray angle
4) Hole-to-hole difference of spray angle
5) Hole-to-hole difference of penetration

2-1) Hi-injection pressure (71MPa→98MPa), small hole diameter (φ139→121μm) and hi-response actuator (solenoid → piezo) contribute to reduce NOx and soot significantly.

2-2) These items enhance atomization.
Effect of items evaluated by SMD as follows

Hi-injection pressure (71MPa→98MPa) 5% ↓
Small hole diameter (φ139→121μm)
Hi-response actuator (solenoid → piezo)
7% ↓
Total 12% ↓

Future Work

1. Hi-pressure vessel (room temp.)
   - Concentration

2. Optical Engine
   1) Spray
      2-1; Effect of hi-temperature
      2-2; Effect of swirl
   2) Combustion

Thank you so much for your kind attention

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The Power of Dreams