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The Effect of Mixture conditions on HCCI Engine Combustion Fuelled with Gasoline/LPG/DME

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Contents

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❑ Advantages and disadvantages of HCCI engine

Advantages	Disadvantages
• Usage of the different type of fuels	• Excessive combustion rate
• Ultra low NOx & PM emissions	• Engine noise
• Improved fuel economy	• HC and CO emissions

Active control method is needed

Background

❑ Research fields of HCCI engine

HCCI Engine research

- **Combustion control**
  - **EGR and internal EGR**
  - **Direct injection**
  - Compression ratio
  - Intake charge temperature
- **Fuel characteristics**
  - **Gasoline**
  - **LPG**
  - **DME**
  - Hydrogen
  - Methanol and Ethanol

Fuels for Engines

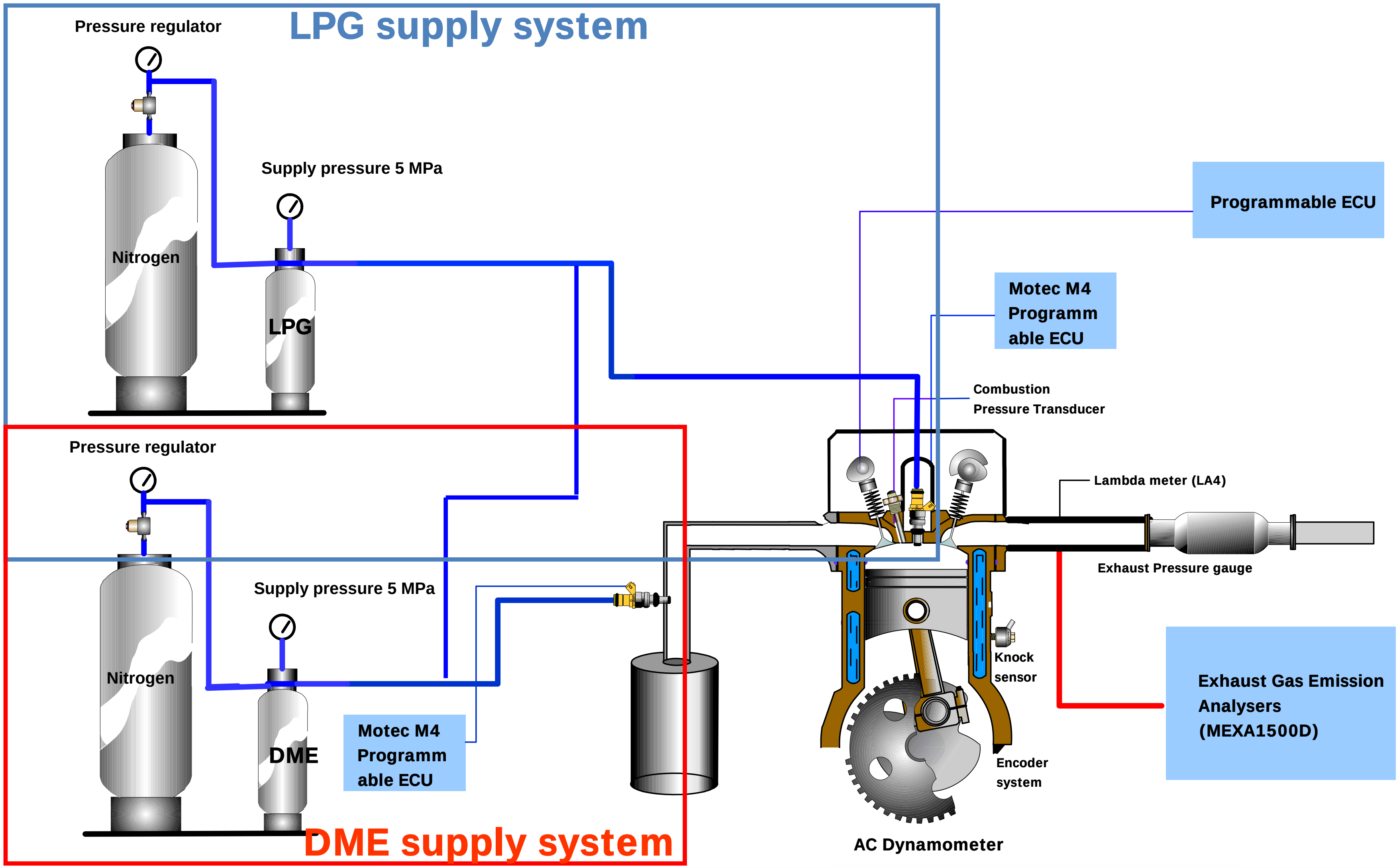
	Biodiesel (B20)	DME	Diesel	Ethanol (E85)	CNG	LPG	Methanol (M85)	Gasoline
Chemical Structure	Methyl esters of C_{16} to C_{18} fatty acids	CH_3OCH_3	$C_nH_{1.8n}$	CH_3CH_2OH	CH_4	C_3H_8	CH_3OH	$C_nH_{1.87}$
Cetane Number	46~60	55~60	40~50	N/A	N/A	N/A	N/A	N/A
Octane Number	~25	N/A	N/A	100	120+	104	100	80-90
Energy Ratio Compared to Gasoline	1.1 to 1 or 90% (relative to diesel)	1.47 to 1 or 68%	0.96	1.42 to 1 or 70%	3.94 to 1 or 25% @ 3000 psi 3.0 to 1 @ 3600 psi	1.36 to 1 or 74%	1.75 to 1 or 57%	1
Physical State	Liquid	Liquid	Liquid	Liquid	Compressed Gas	Liquid	Liquid	Liquid
Average Price* ($ per Gallon)	2.91	-	-	2.41	2.12 (per GGE)	2.56	-	-

*Clean Cities Alternative Fuel Price, September 2005
U.S Department of Energy
Energy Efficiency and Renewable Energy

DME HCCI Combustion in Dual Fuel Engine

- DME and LPG
- Injection location and Direct injection timing

Experimental apparatus



Experimental apparatus

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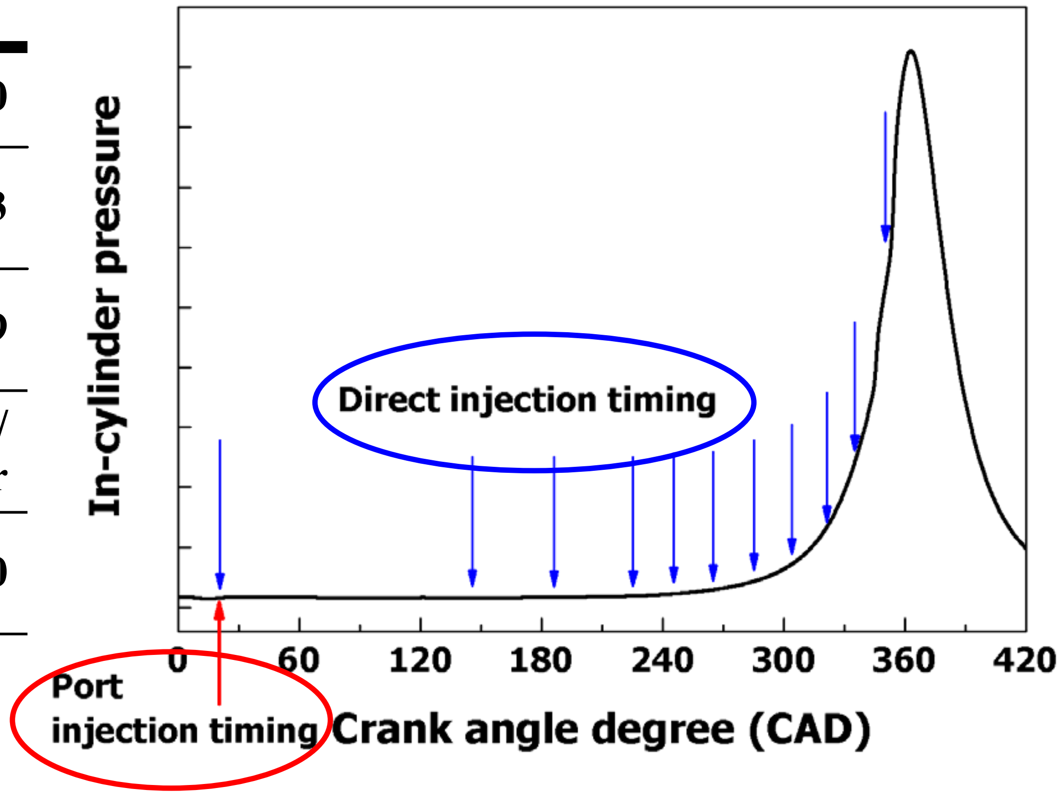
❑ Engine Specification

<table>
<tr><th colspan="2">Type</th><th colspan="2">Descriptions</th></tr>
<tr><td colspan="2">Number of Cylinder</td><td colspan="2">1</td></tr>
<tr><td colspan="2">Displacement, cc</td><td colspan="2">494</td></tr>
<tr><td colspan="2">Bore, mm</td><td colspan="2">82</td></tr>
<tr><td colspan="2">Stroke, mm</td><td colspan="2">93.5</td></tr>
<tr><td colspan="2">Compression ratio</td><td colspan="2">13</td></tr>
<tr><td colspan="2">Intake duration</td><td colspan="2">228</td></tr>
<tr><td colspan="2">Exhaust duration</td><td colspan="2">228</td></tr>
<tr><td rowspan="3">Valve Timing</td><td></td><td>Retard</td><td>Advance</td></tr>
<tr><td>IVO, ATDC</td><td>11</td><td>-29</td></tr>
<tr><td>IVC, ABDC</td><td>59</td><td>19</td></tr>
</table>

Experimental conditions

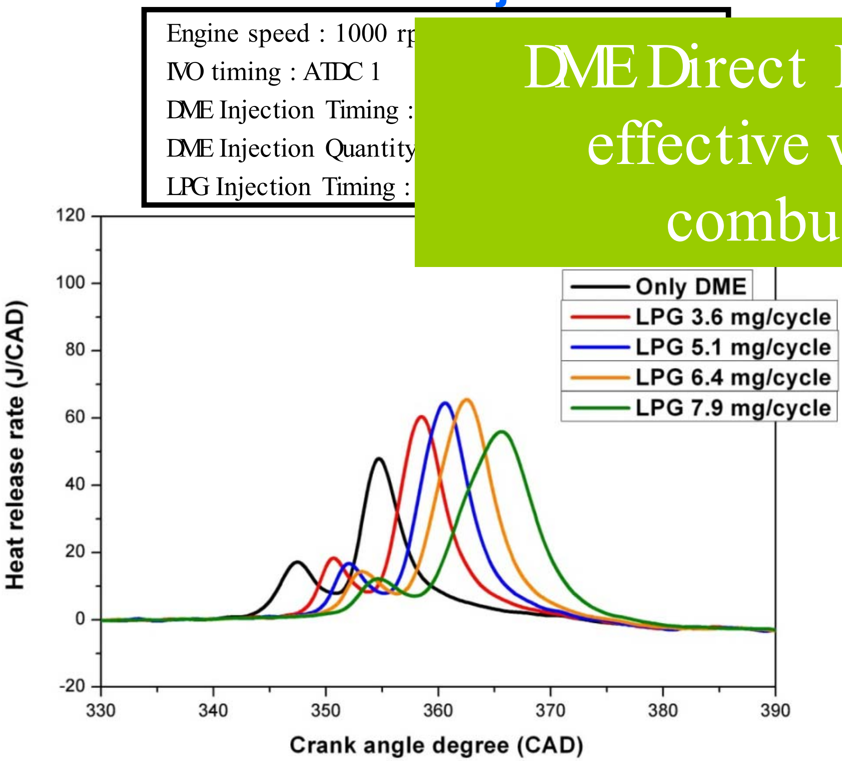
Engine speed (rpm)	1000
DME injection quantity (mg/stroke)	13
LPG injection quantity (mg/stroke)	1.08 ~ 7.9
Injection location	Port/ In-cylinder
Direct Injection timing (CAD)	160 ~ 350



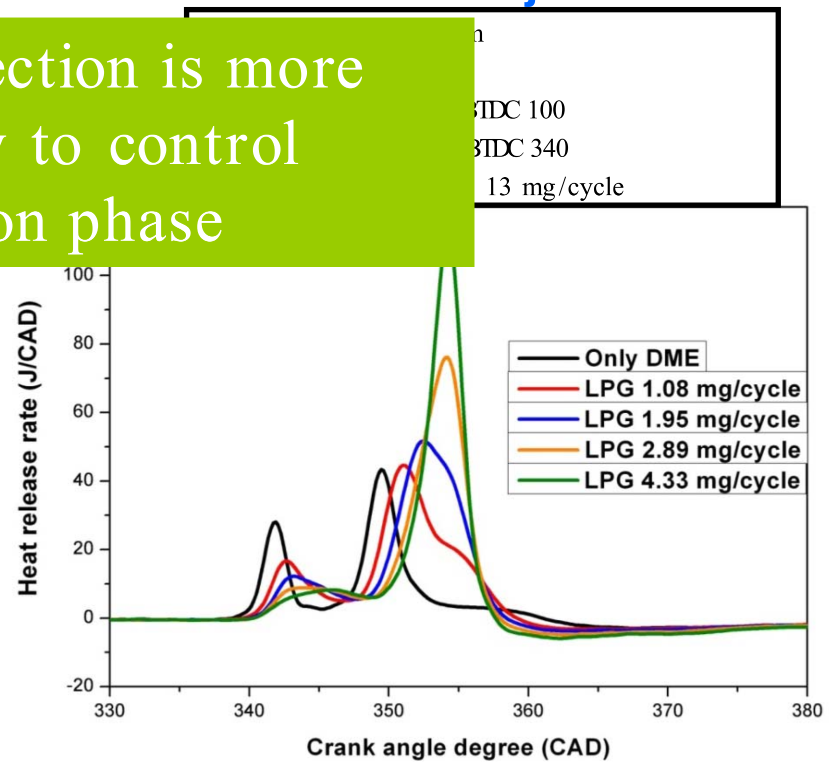
Heat release rate
; Injection location & DI timing

- DME direct injection : LPG quantity↑ ➔ late and long combustion↑
- LPG direct injection : LPG quantity↑ ➔ LTHR↓, late HTHR & HTHR↓

DME Direct Injection



LPG Direct Injection



DME Direct Injection is more effective way to control combustion phase

□ LTHR : low temperature heat release rate, HTHR : high temperature heat release

IMEP; Injection location & DI timing

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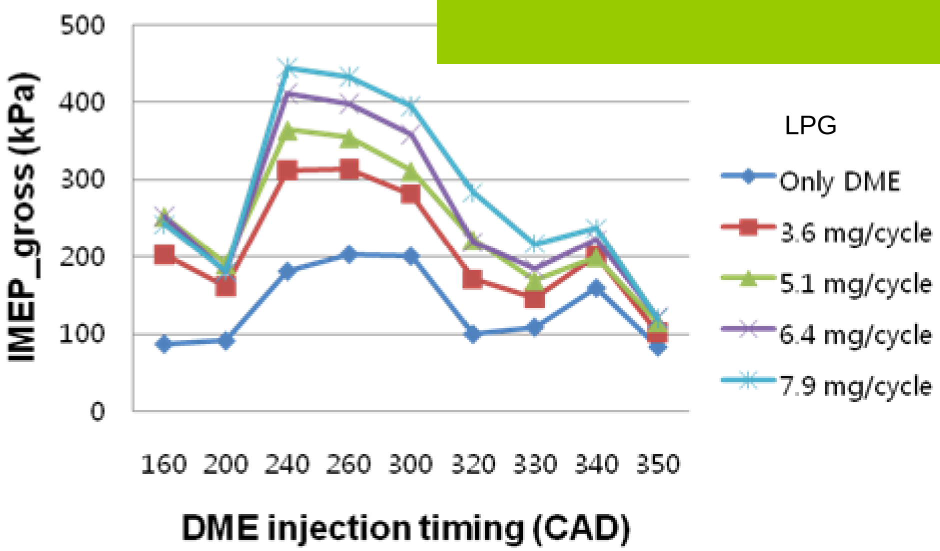
- DME direct injection : LPG quantity↑➔ IMEP↑, Optimal DME DI timing
- LPG direct injection : LPG quantity ↑➔ IMEP↑

DME Direct Injection

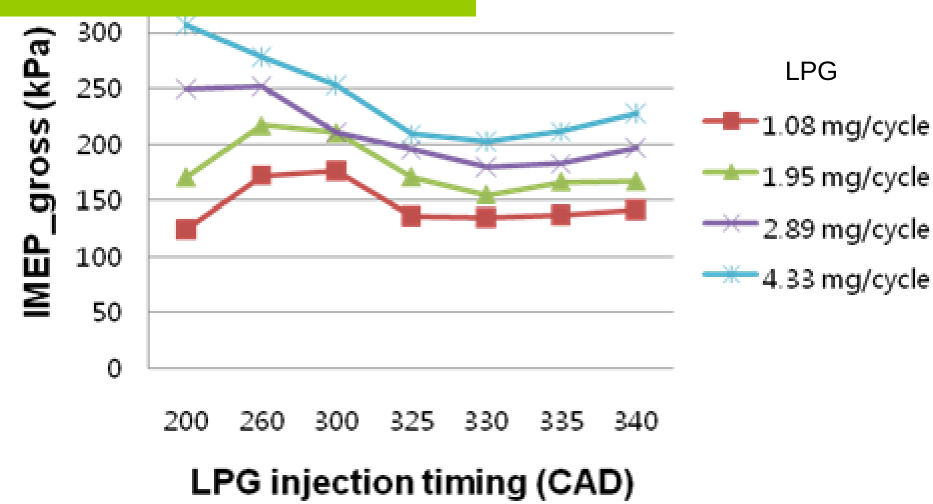
Engine speed : 1000 r
IVO timing : ATDC 1
DME Injection Quantit
LPG Injection Timing :

DME Direct Injection is more effective way to improve IMEP



LPG Direct Injection

mg/cycle
340



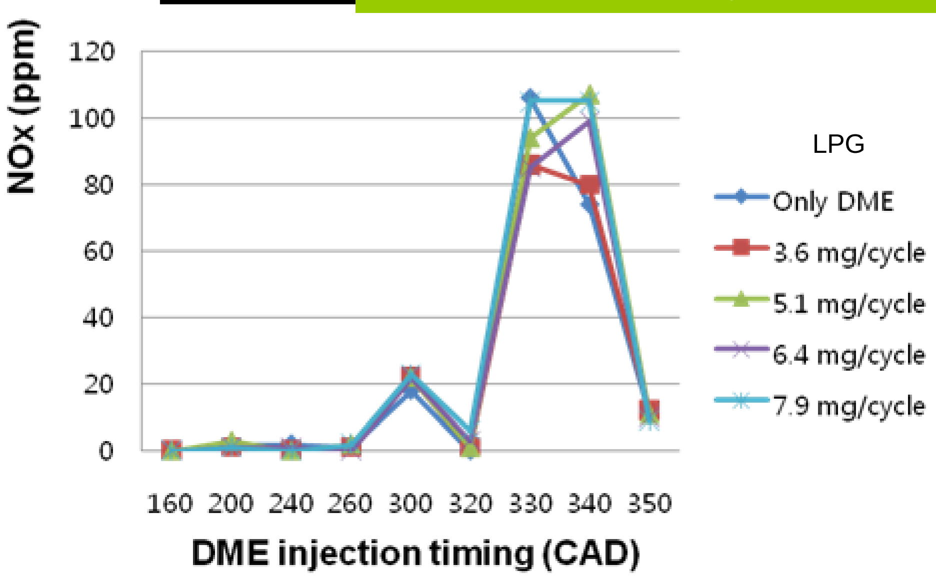
NOx ; Injection location & DI timing

- DME direct injection : DME DI timing after 260 CAD → NOx↑
- LPG direct injection : late LPG DI timing & quantity → NOx↑

DME Direct Injection

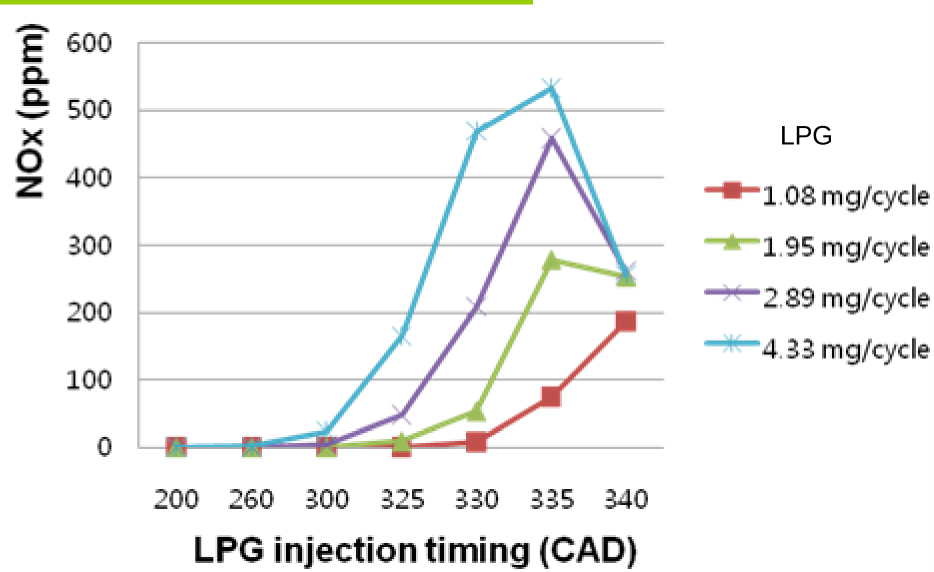
Engine speed : 1
IVO timing : ATD
DME Injection Qu
LPG Injection Ti

DME Direct Injection is more effective way to reduce NOx



LPG Direct Injection

ycle



THC ; Injection location & DI timing

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- DME direct injection : early and late DME DI & LPG quantity↑➔ HC↑
- LPG direct injection : late LPG DI timing ➔ HC↓

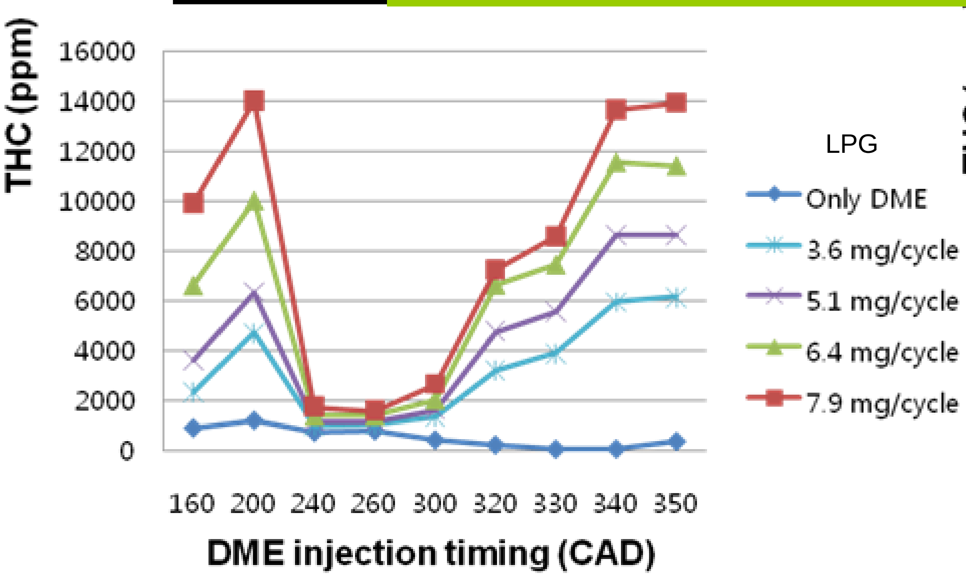
DME Direct Injection

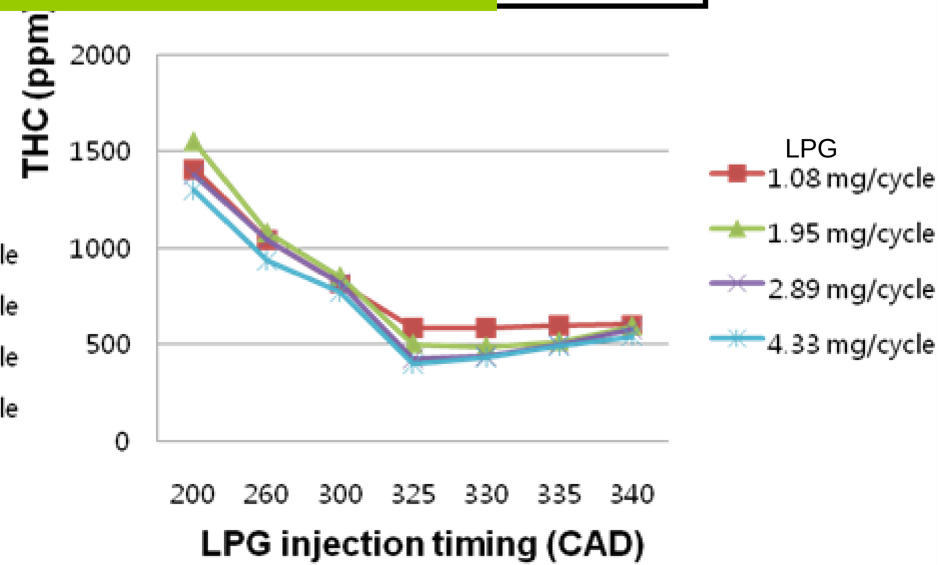
Engine speed : 10
IVO timing : ATDC
DME Injection Qua
LPG Injection Tim

LPG Direct Injection

g/cycle
40

LPG Direct Injection is more effective way to reduce NOx





Summary
– DME HCCI combustion in Dual Fuel Engine

1. DME direct injection is effective way to improve

   Combustion phase

   IMEP

   NOx emission

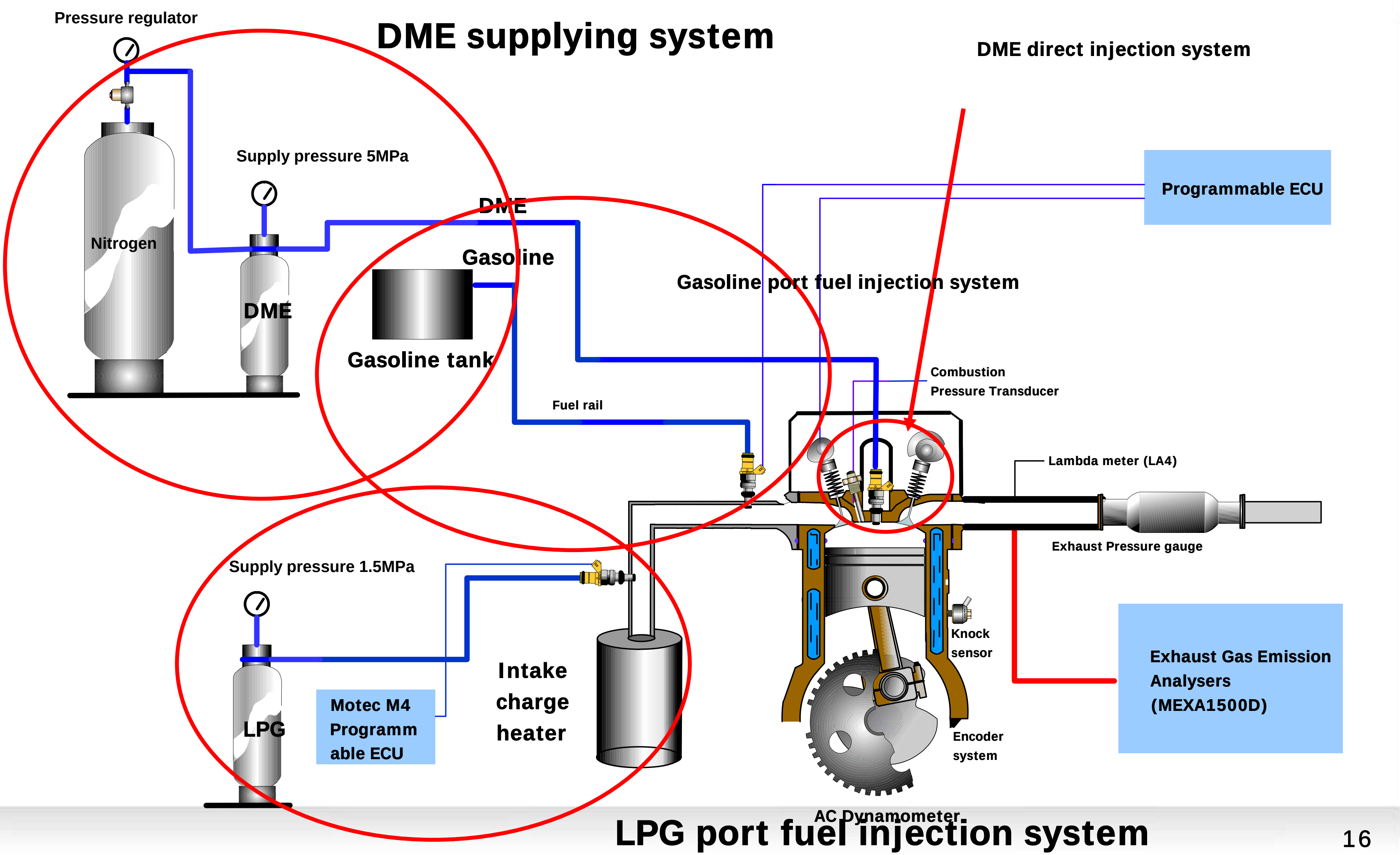
2. LPG direct injection is effective way to improve

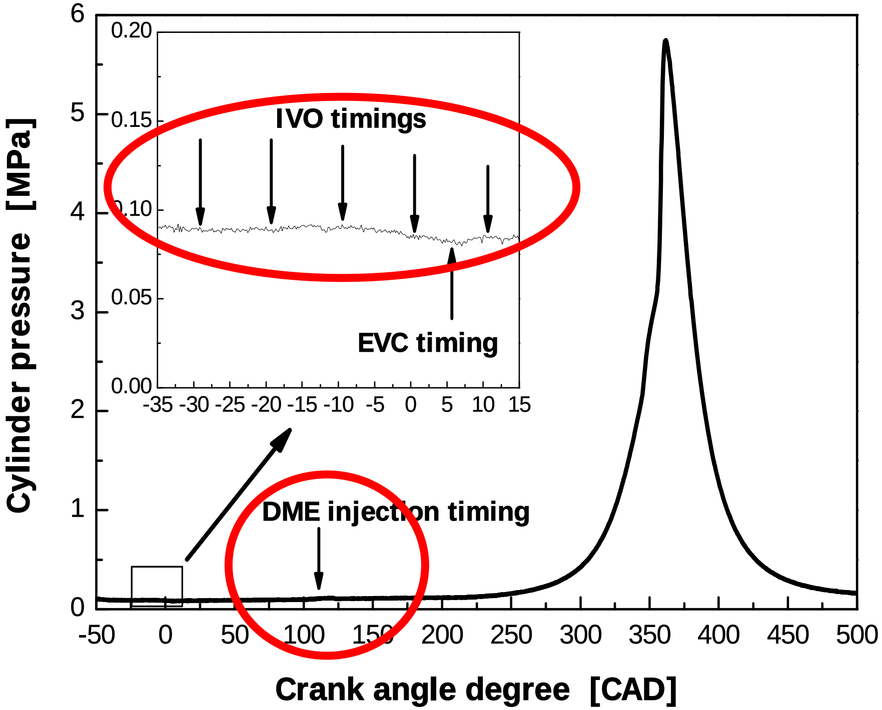
   HC emission

HCCI Combustion in Dual Fuel Engine

- Gasoline + DME HCCI
- LPG + DME HCCI

Experimental apparatus

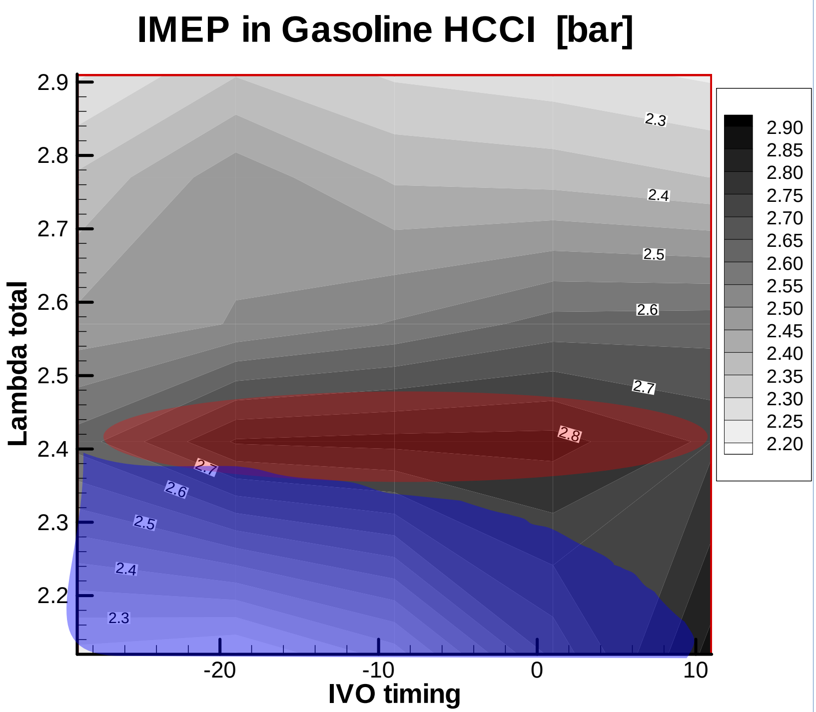


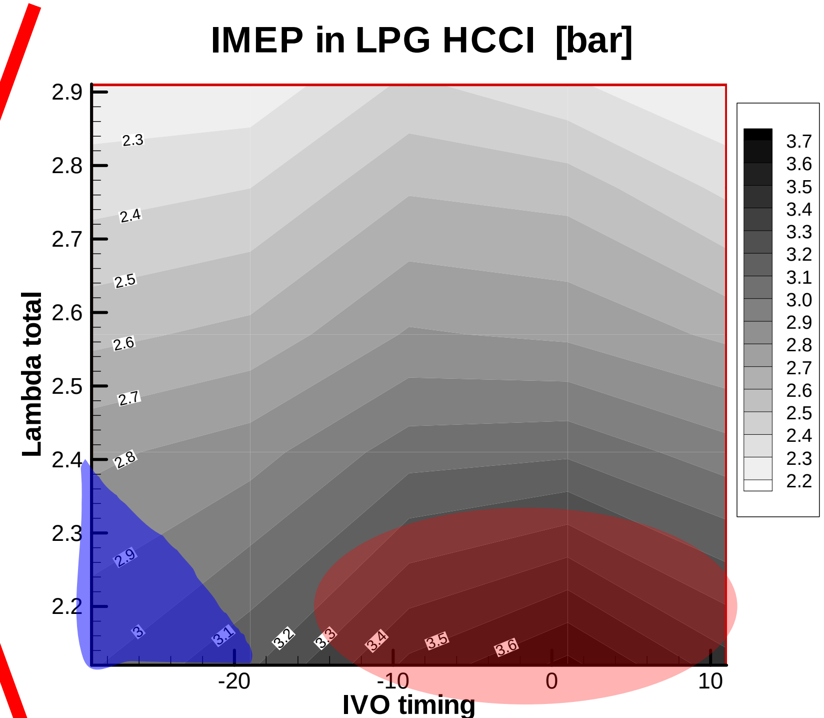


❑ Experimental conditions

Engine speed, rpm	1000
IVO [ATDC]	-29, -19, -9, 1, 11
DME injection timing [ATDC]	110
λ_{TOTAL}	2.12, 2.41, 2.57, 2.77, 2.91
λ_{DME}	3.7
Intake air temperature, ºC	30
Coolant / Oil temperature, ºC	80 / 80

IMEP of HCCI engine





$IMEP_{Gasoline} < IMEP_{LPG}$ ➔ latent heat and octane number

IMEP was decreased due to negative work

Maximum IMEP region | **Heavy knock region**

$$imep = \frac{W_{c,i}}{V_d}$$

Knocking Characteristics ; Ringing intensity

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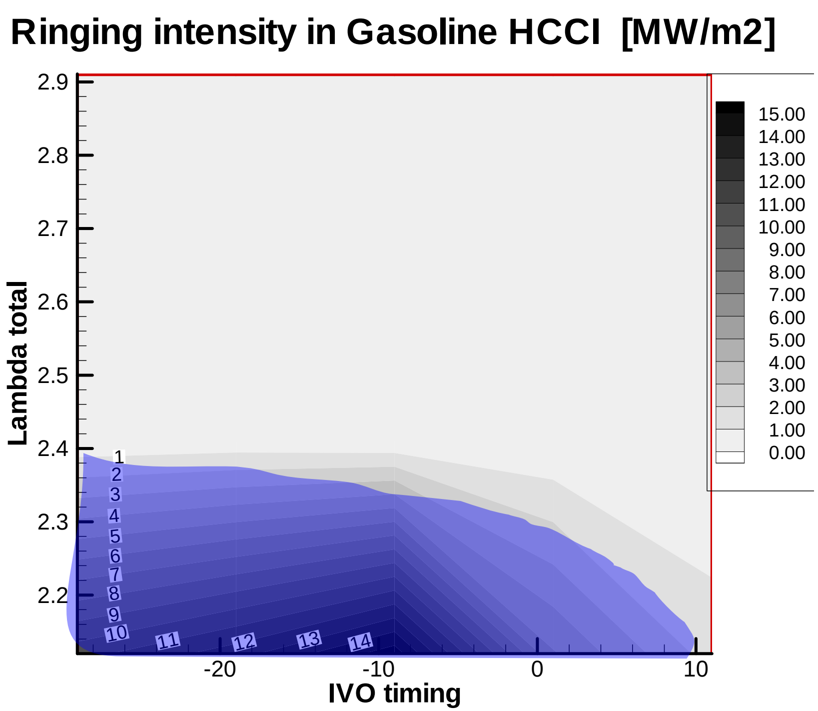
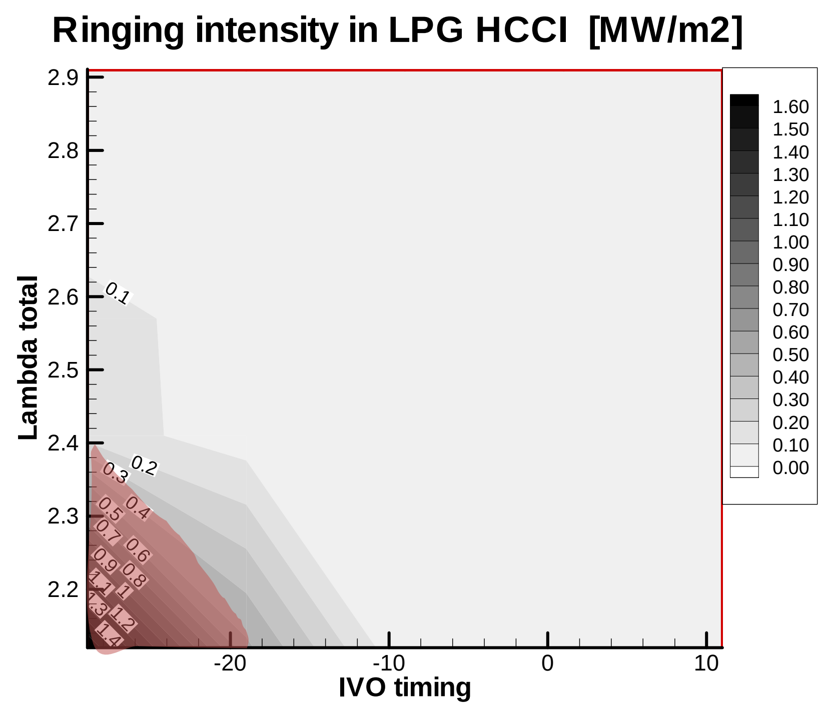




Ringing intensity represents knocking characteristics

The relationship between the IMEP and the RI showed that **IMEP** was **dropped** at the **RI** was **over 0.5MW/m²**

Ringing intensity From Eng. (2002)

$$RI = \frac{1}{2\cdot\gamma}\cdot\frac{\sqrt{\gamma RT}}{P}\cdot\frac{1}{N}\cdot\sum_{1}^{N}(0.05\cdot(\frac{\partial p}{\partial t})_{max})^2$$

Summary – HCCI combustion in Dual Fuel Engine

LPG-DME HCCI engine		Gasoline-DME HCCI engine
Combustion characteristics	comparison	Combustion characteristics

Operating range extension and phase control

1. The operating range of LPG-DME HCCI engine was wider than that of gasoline-DME HCCI engine due to higher latent heat of vaporization and octane number.

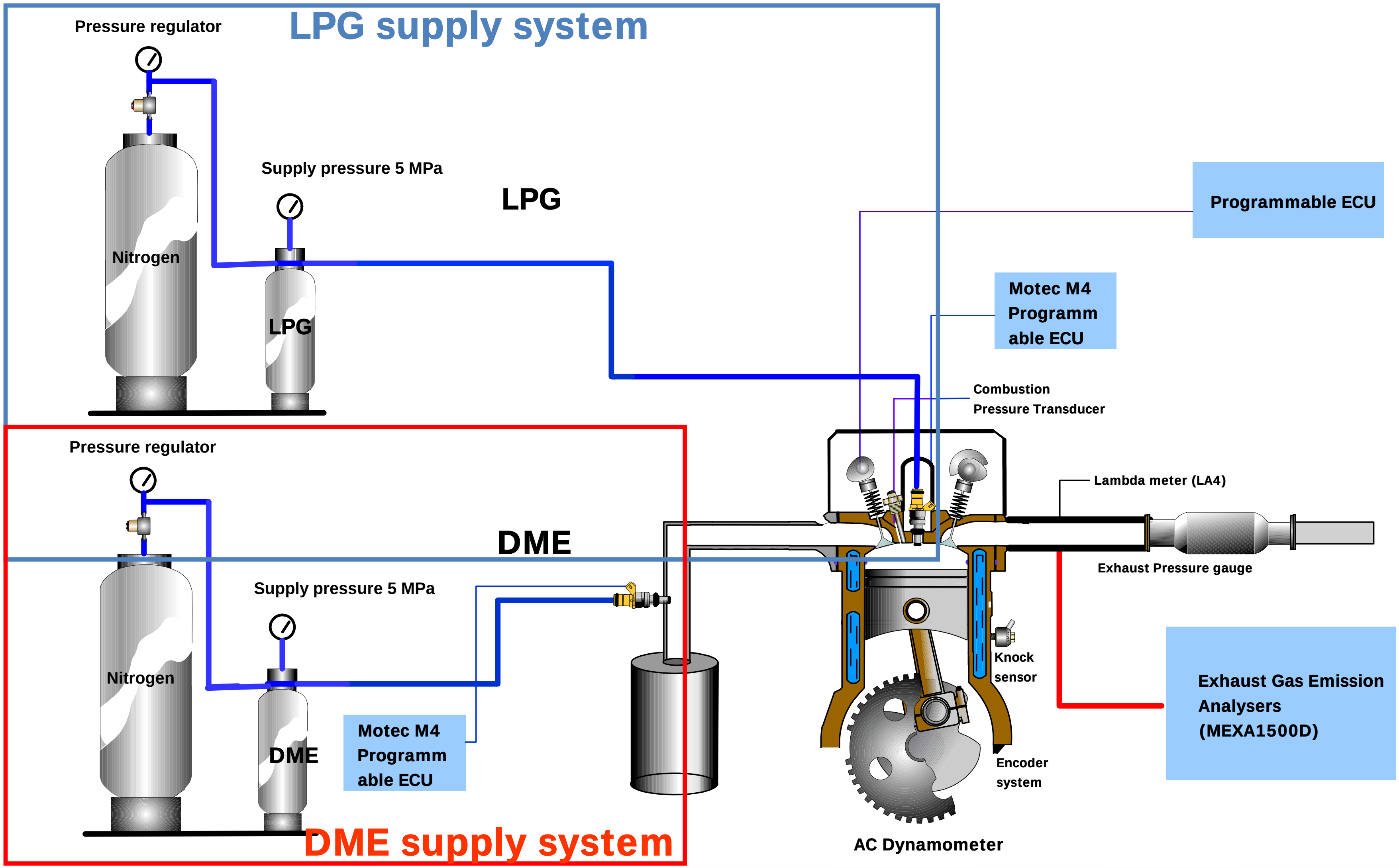
2. Ringing intensity represents knocking characteristics

3. On the basis of IMEP drop, the high load operating range of the test engine was limited to under 0.5 MW/m2.

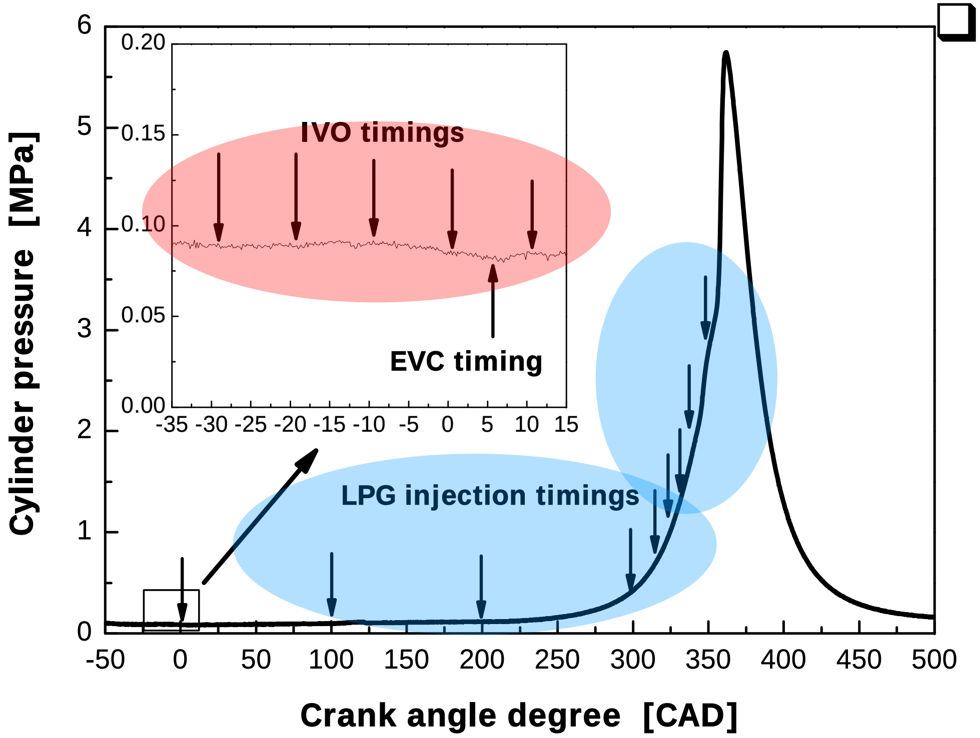
LPG HCCI + SCCI Combustion in Dual Fuel Engine

- LPG direct injection + DME port injection

Experimental Setup



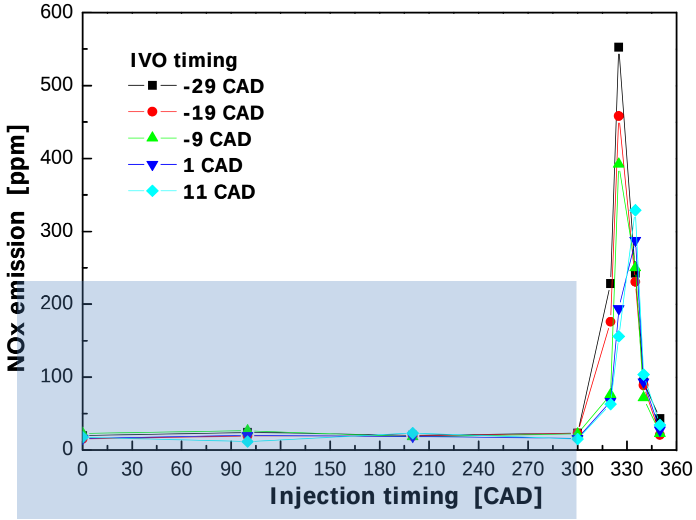
Experimental conditions

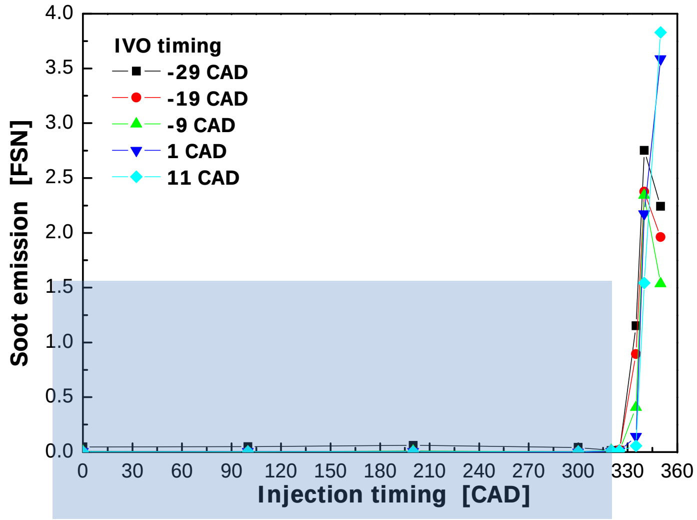


❑ Experimental conditions

Engine speed (rpm)	1000
Intake Valve Open timing (CAD)	-29, -19, -9, 1, 11
LPG injection timing (CAD)	0, 100, 200, 300, 320, 325, 335, 340, 350
λ_{TOTAL}	1.667
λ_{DME}	3.7
Intake charge temperature (^{O}C)	30
Coolant / Oil temperature (^{O}C)	80 / 80

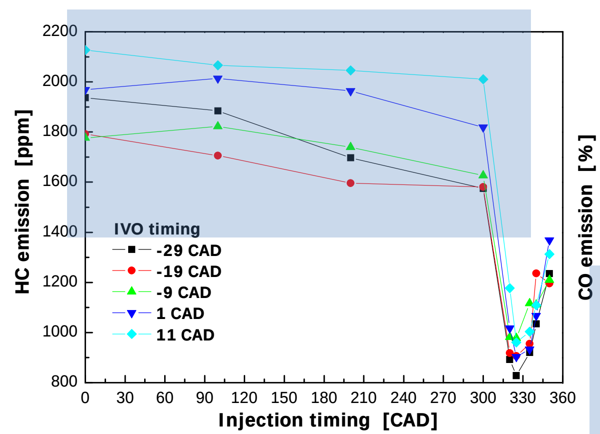
Homogeneous Charge CI region ; Exhaust gas

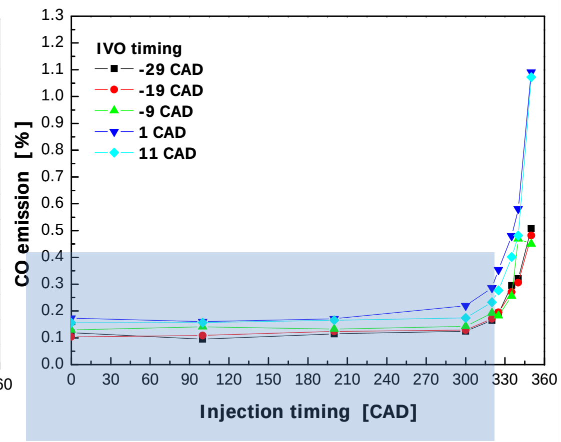




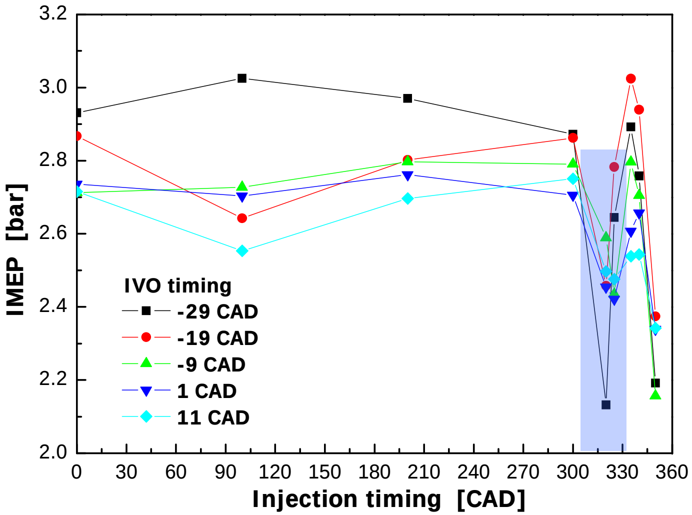
HCCI region

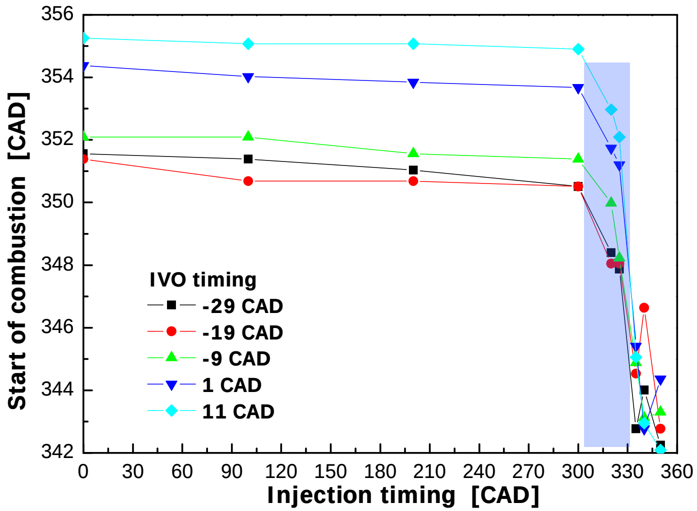
- No soot and NOx emissions
  - 0 ~ 300 CAD of SOI





Stratified Charge CI region
; Exhaust gas

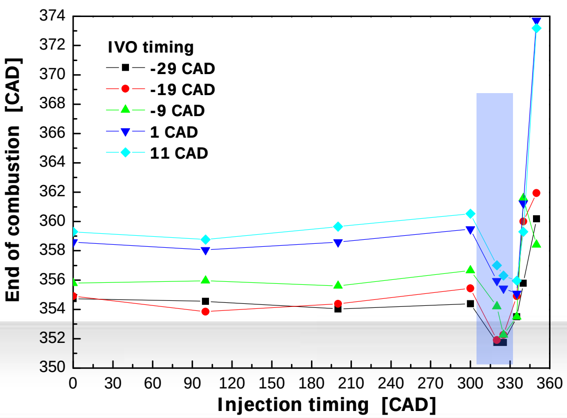


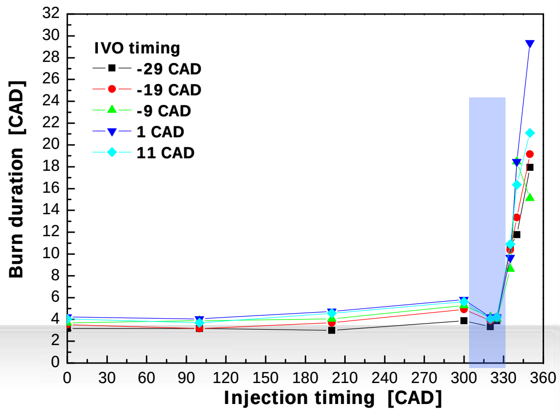


Decreased IMEP

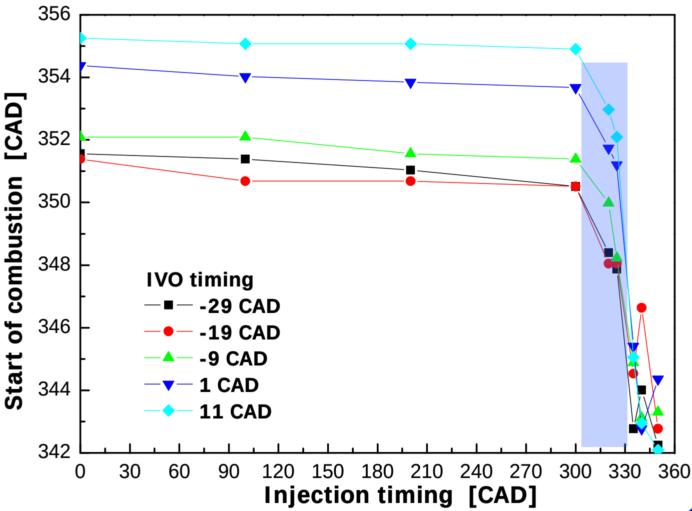
Early start and
end of combustion

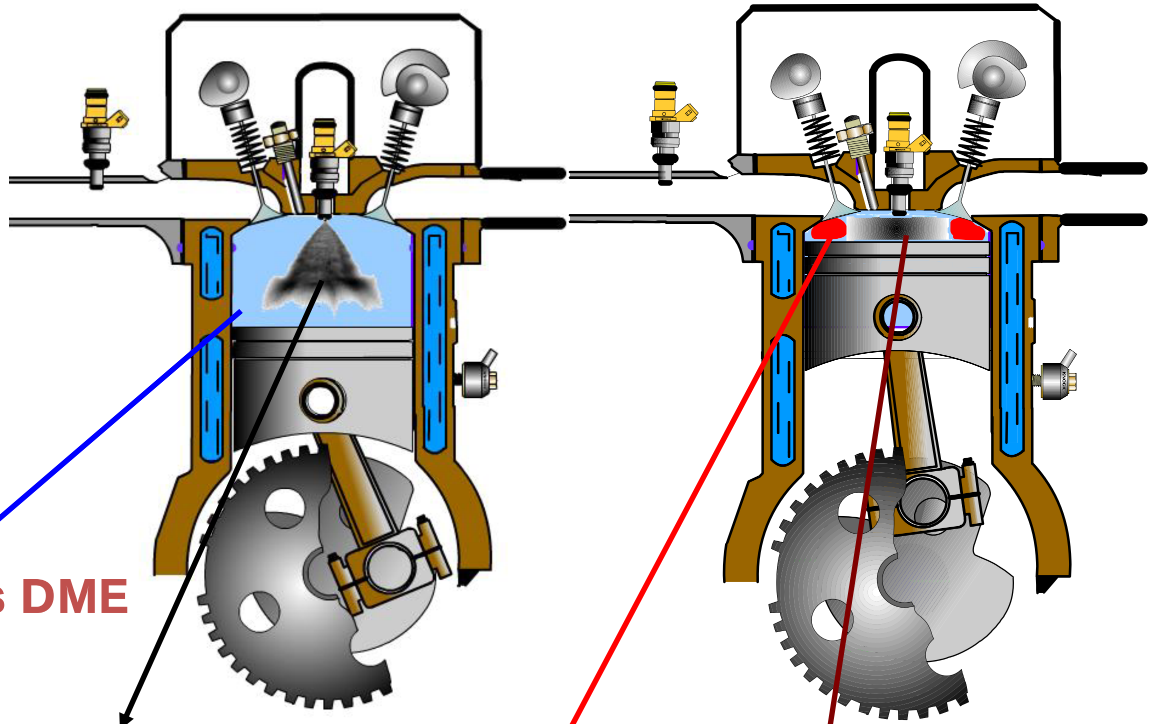
Increased negative work





Stratified Charge CI region
; Ignition timing





Homogeneous DME

LPG spray

First: DME auto-ignition at LPG lean region

Second: LPG auto-ignition at LPG rich region by the heat and pressure of DME auto-ignition

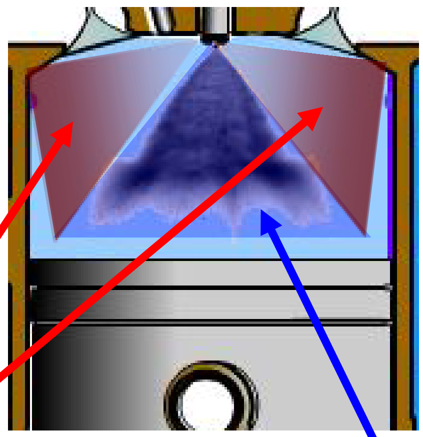
Stratified Charge CI region
; Effect of LPG on ignition delay

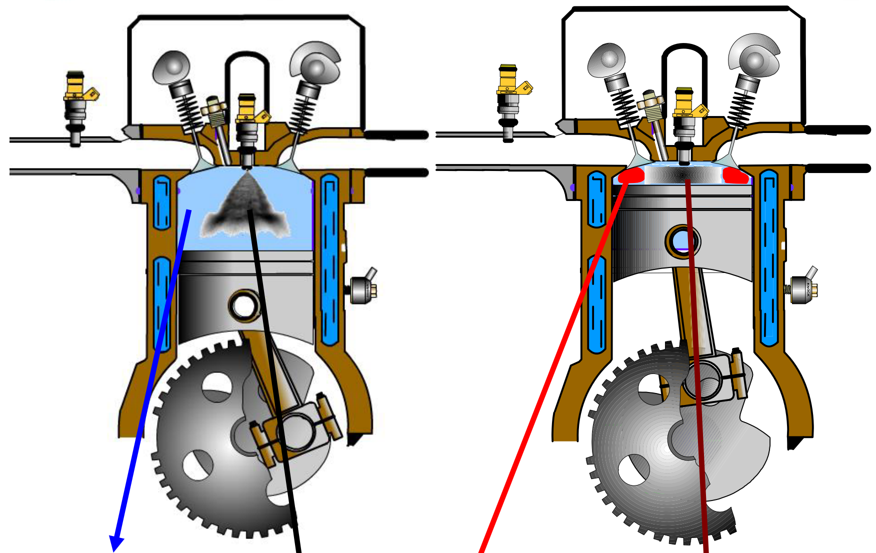
DME auto-ignition

DME low temperature oxidation

$CH_3OCH_3 + OH \rightarrow CH_3OCH_2 + H_2O$

by heat and pressure





Homogeneous DME

LPG spray

First: DME auto-ignition at LPG lean region

Second: LPG auto-ignition at LPG rich region by the heat and pressure of DME auto-ignition

High temperature region

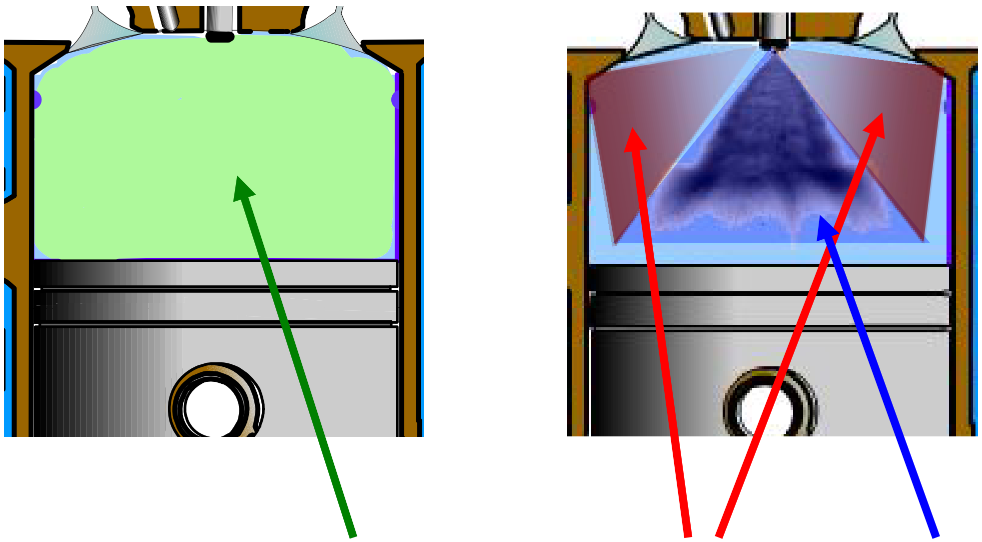
Low temperature region due to vaporization of LPG

Stratified Charge CI region
; Effect of LPG on ignition delay

Temperature of mixture just before auto-ignition

LPG + DME premixed
(0 CAD injection of LPG)

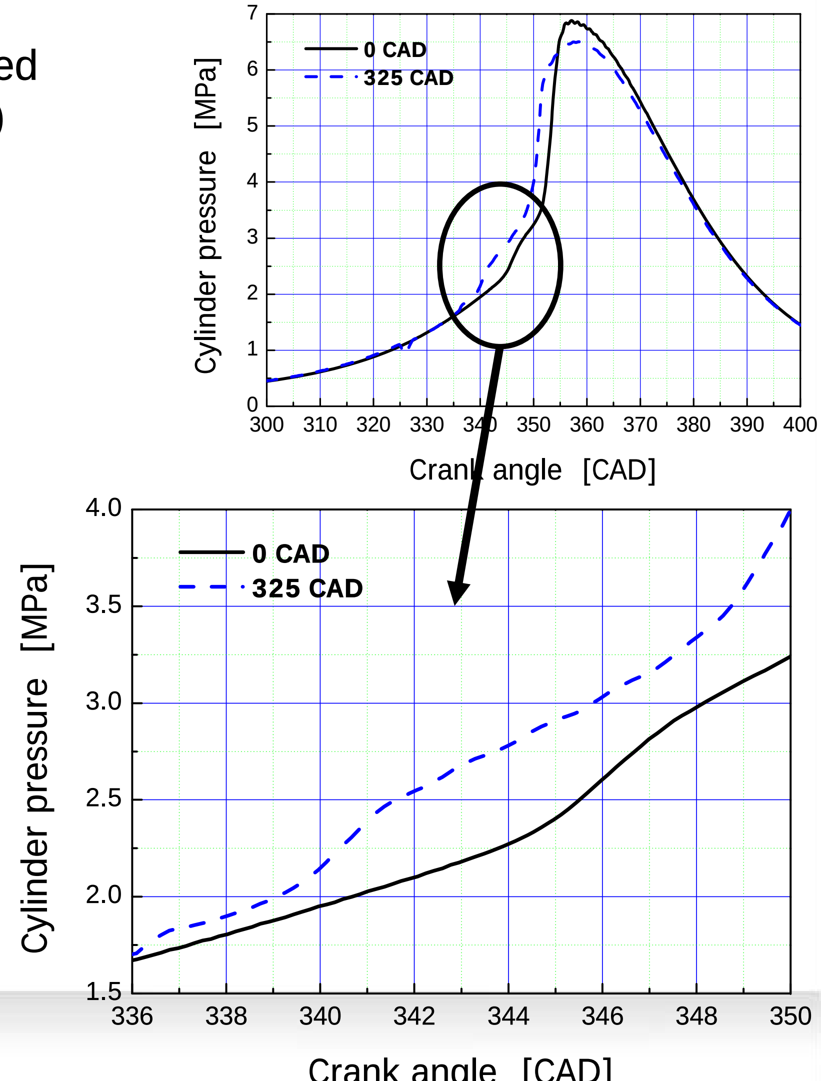
LPG stratified+ DME premixed
(325 CAD injection of LPG)



676K @ 344 CAD

731K @ 339 CAD

656K



Isentropic compression

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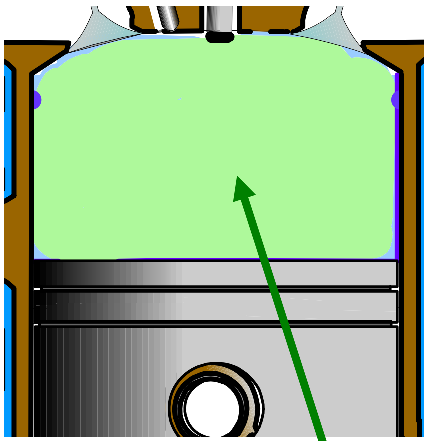
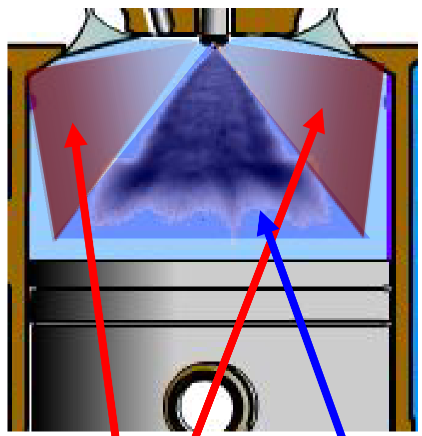
Cetane number of mixture just before auto-ignition

LPG + DME premixed
(0 CAD injection of LPG)



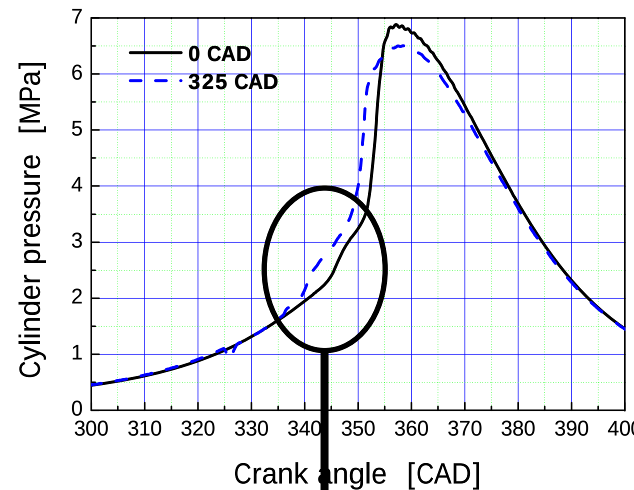
Moderate cetane number region

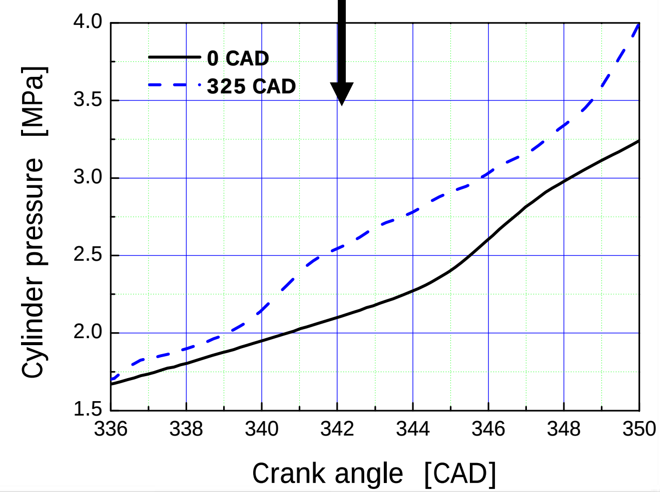
LPG stratified+ DME premixed
(325 CAD injection of LPG)



High cetane number region

Low cetane number region





Summary
– LPG HCCI + SCCI combustion in Dual Fuel Engine

The exhaust combustion characteristics of LPG HCCI and SCCI combustion with VVT and DME were investigated. Following conclusions were drawn from experiments.

1. The combustion and exhaust emission characteristics were significantly different according to the injection timing of LPG.

2. The HC emission was reduced by LPG stratified charge combustion. However, the CO emission was increased at local rich region.

3. The NOx and soot emissions were increased at local rich region when the LPG was stratified.

Summary

Single fuel HCCI → High cetane Fuel (DME)

IMEP increase ← **→ Late burn** **Exhaust gas recirculation**

(Dilution, Heat capacity)

Ignition timing → **Combustion phase control**

→ **Increased IMEP**

↑

Limited by knocking

High Octane
Fuel (LPG, Gasoline)

↑

Dual fuel

BDC TDC

Early **Direct injection timing** Late

HCCI PCCI Conventional CI

Local rich region and temperature drop

Summary

The effect of mixture conditions on HCCI engine combustion fuelled with gasoline, LPG and DME was investigated.

1. The HCCI engine with high octane numbered fuel like a LPG and gasoline was needed to promote the auto-ignition.

   ➔ DME

2. Because of simultaneous effect of the ignition suppressor with high octane numbered fuel and ignition enhancer with high cetane numbered fuel, operating range of HCCI engine could be increased.

   ➔ IMEP was limited by knocking resulting from higher increase rate of in-cylinder pressure owing to the multi-point ignition.

3. Direct injection timing changed the combustion feature from HCCI to conventional CI.

   ➔ in-cylinder local rich region and temperature drop