# Dual-fuel HCCI Operation with DME/LPG/Gasoline/Hydrogen

BAE, Choongsik

Engine Laboratory

Department of Mechanical Engineering, KAIST

# Contents

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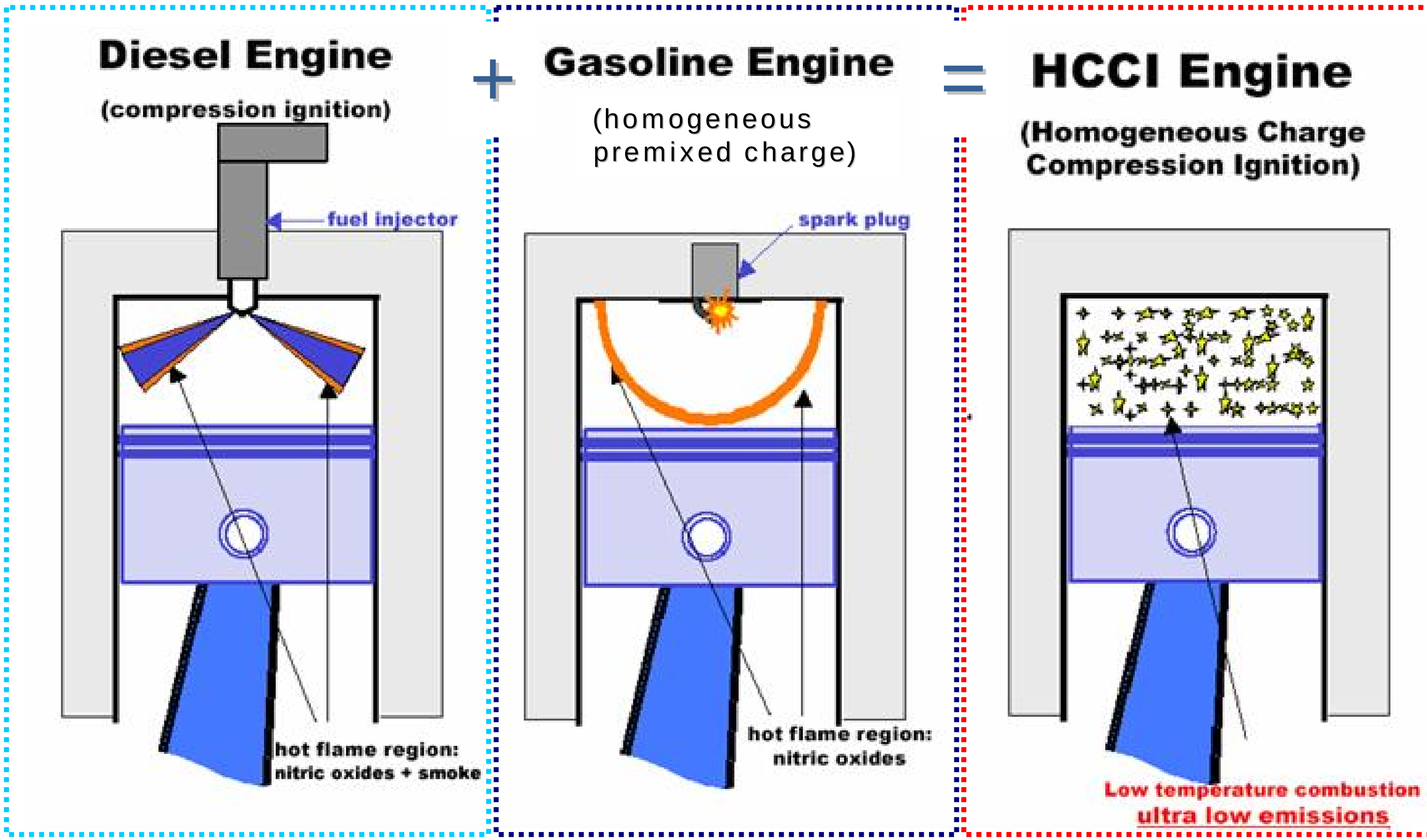
# Background - Homogeneous Charge Compression Ignition



# Background – Advantages & Disadvantages

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## ❑ Advantages and disadvantages of HCCI engine

**HCCI Engine Advantages**

- Usage of the different type of fuels
- Ultra low NOx & PM emissions
- Improved fuel economy

**HCCI Engine Disadvantages**

- Excessive combustion rate
- Engine noise
- HC and CO emissions

# Background & Objective

DME

HCCI

Short ignition delay
Short burn duration

Increase of Negative work

**Necessity of Combustion Phase Control**

# Background – Research Fields of HCCI Engine

## HCCI Engine research

### Combustion control

**Direct injection**

EGR and internal EGR

Compression ratio

Intake charge temperature

### Fuel characteristics

**DME +**

- **Gasoline**
- **LPG**
- **Hydrogen**
- Methanol and Ethanol

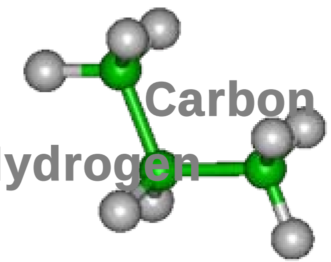
# Background & Objective

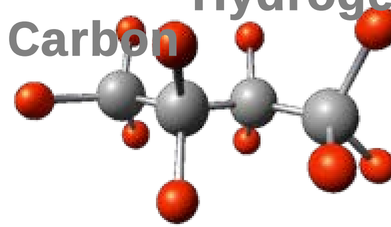


**DME HCCI** ← **Anti-knock property** / **Extend high load limit** — **LPG, Gasoline, Hydrogen**

**LPG**

**Propane**




**Butane**

| Propane | | Butane |
|---|---|---|
| -42.07 | **Boiling temperature (°C)** | -0.5 |
| 504 | **Ignition temperature (°C)** | 430 |
| [illegible] | **Net calorific value (kcal/Nm³)** | [illegible] |
| **114** | Octane number | **91** |

**Optimization of LPG composition**

# Dual-Fuel HCCI Combustion Based on SI Engine

- LPG Port  and DME Direct HCCI
- Comparing Propane and Butane

# Experimental apparatus

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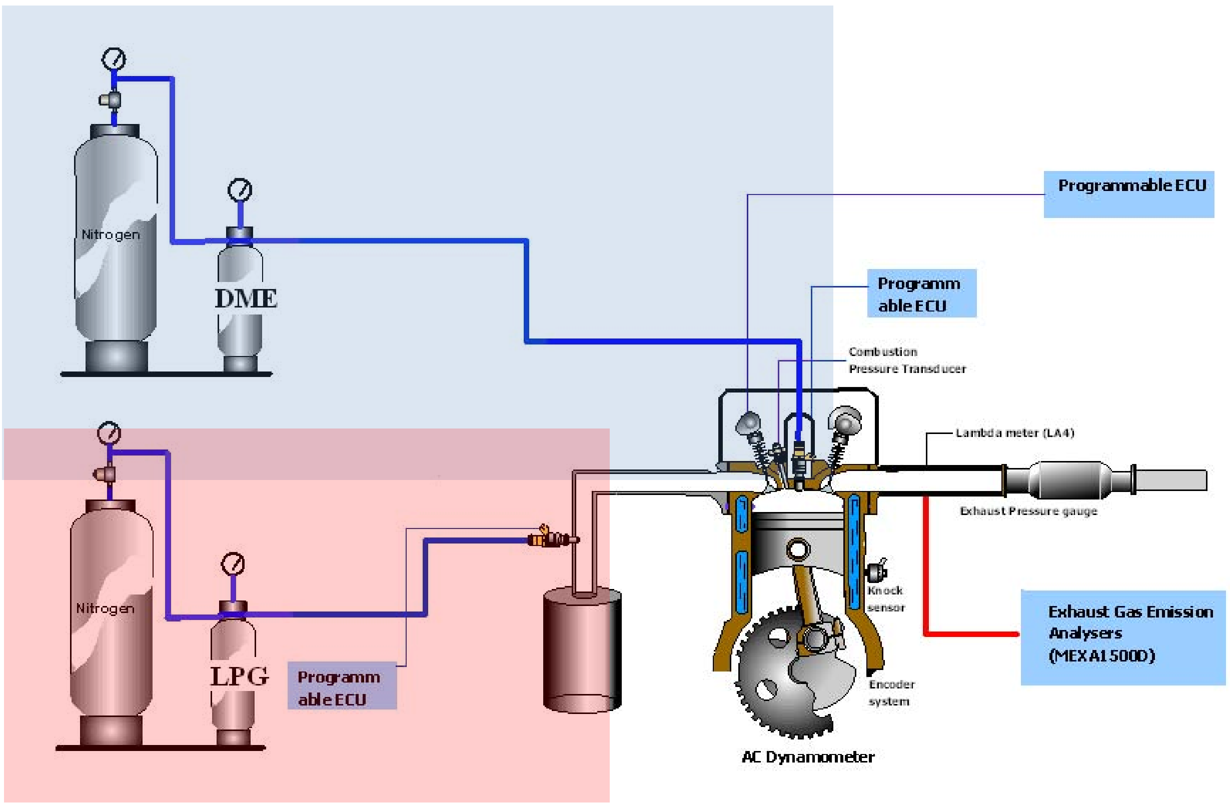
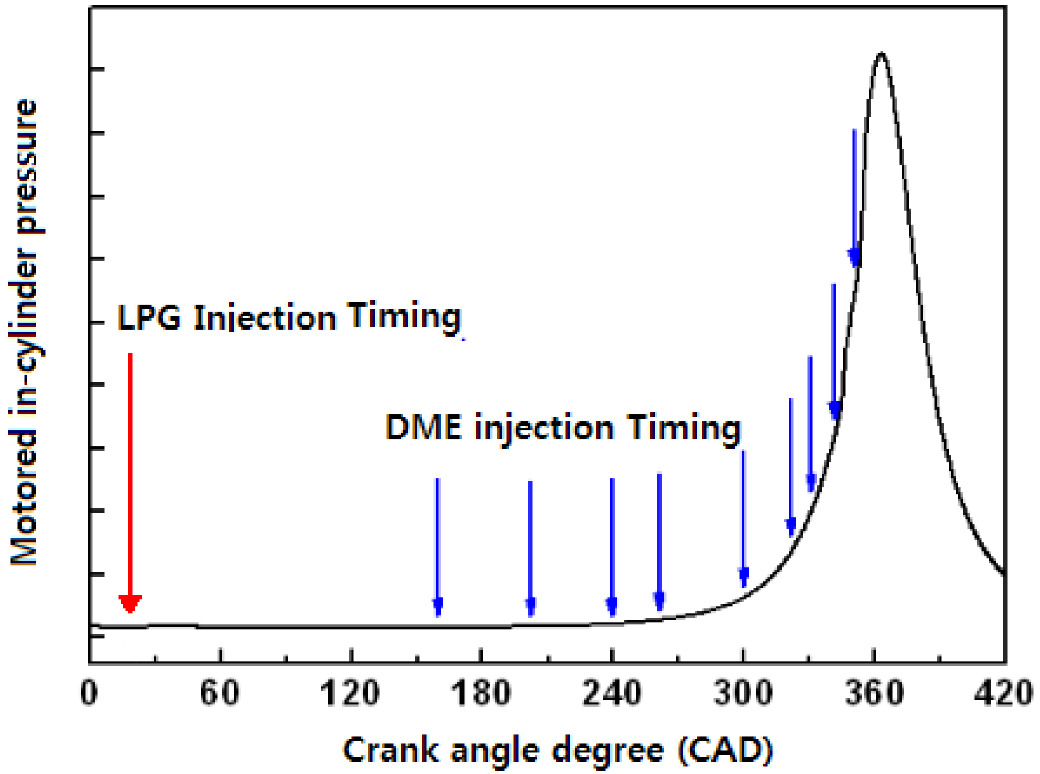



| Type | Description |
|---|---|
| Number of Cylinder | 1 |
| Bore (mm) | 82 |
| Stroke (mm) | 93.5 |
| Displacement volume (cc) | 493.7 |
| Compression ratio | 13.0 |
| RPM | 1000 |
| Intake Valve Open (CAD)* | 1 |

# Experimental Conditions






| Type | Description |
|---|---|
| Engine Speed (RPM) | 1000 |
| DME injection Quantity (J/stroke) | 413<br>677 |
| LPG injection Quantity (J/stroke) | 276<br>386<br>448 |
| LPG composition | Propane<br>Butane |

# Experimental Result and Discussion

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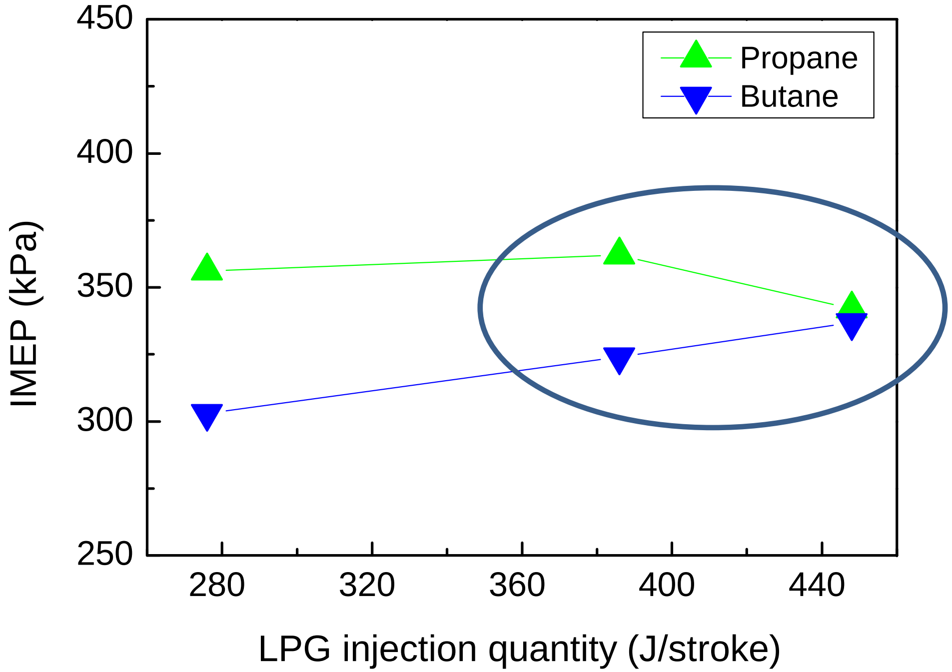
**Output Performance – Indicated Mean Effective Pressure (IMEP)**

DME combusted with Propane , Butane

**DME injection: 413 J/stroke, at Optimal timing (240 CAD)**




IMEP was decreased in spite of increased injection propane quantity

- The maximum IMEP was increased around 360 kPa
- Average IMEP was higher when propane was used

# Experimental Result and Discussion

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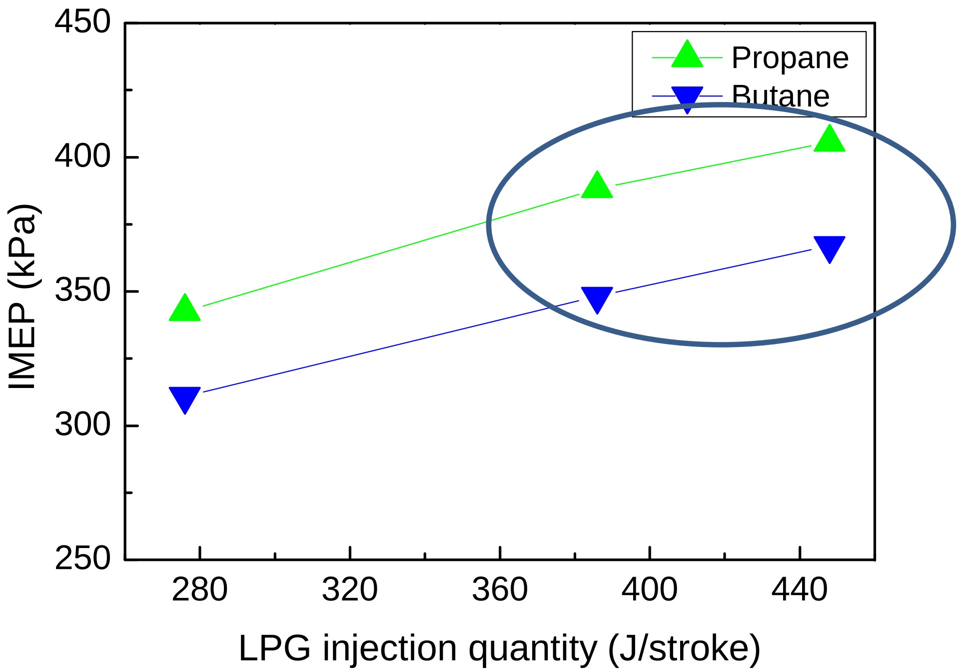
Output Performance – Indicated Mean Effective Pressure (IMEP)

**DME combusted with Propane , Butane**

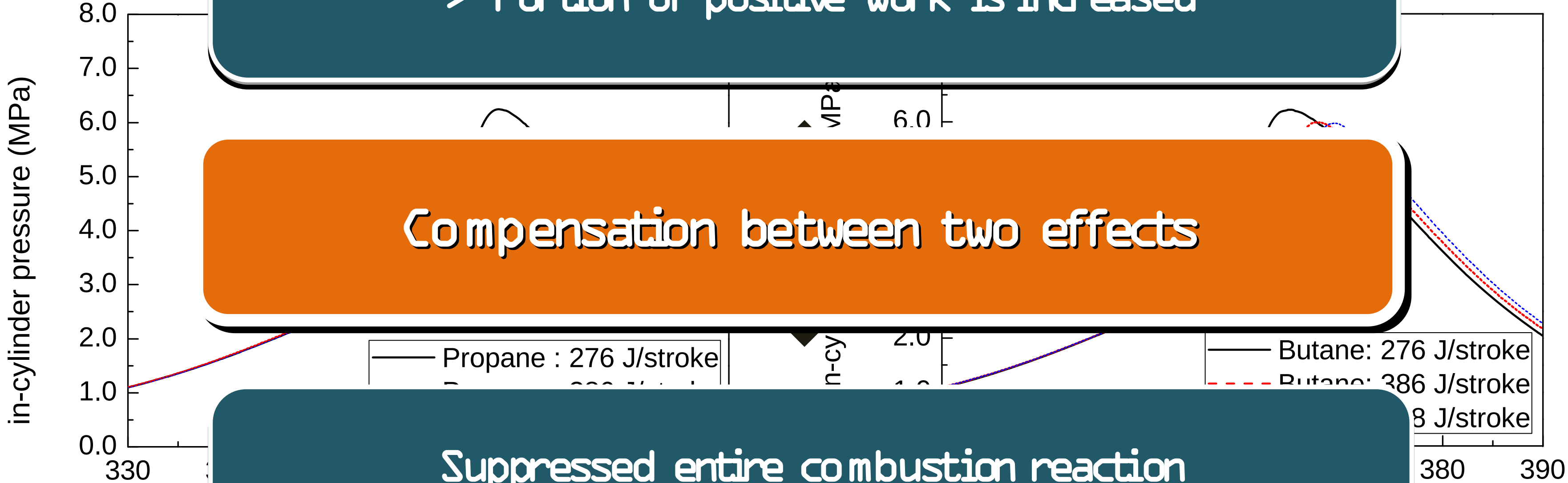
DME injection: 677 J/stroke, at Optimal timing (240 CAD)




IMEP was kept increasing as addition of LPG

- The maximum IMEP was increased around 400 kPa
- Average IMEP was higher when propane was used

Output Performance - Indicated Mean Effective Pressure (IMEP)




Increased ignition delay
-> Portion of positive work is increased

Compensation between two effects

Suppressed entire combustion reaction
-> Total amount of work is decreased

- Addition of EPG -> Increased ignition delay & decreased maximum pressure
- Better anti-knocking property of propane -> More suppression of combustion

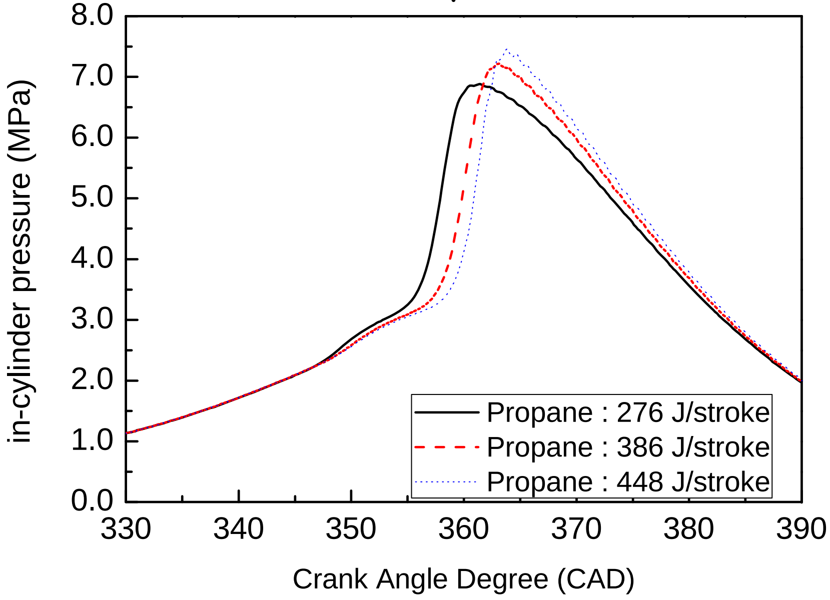
# Experimental Result and Discussion

KAIST ENGINE LAB.

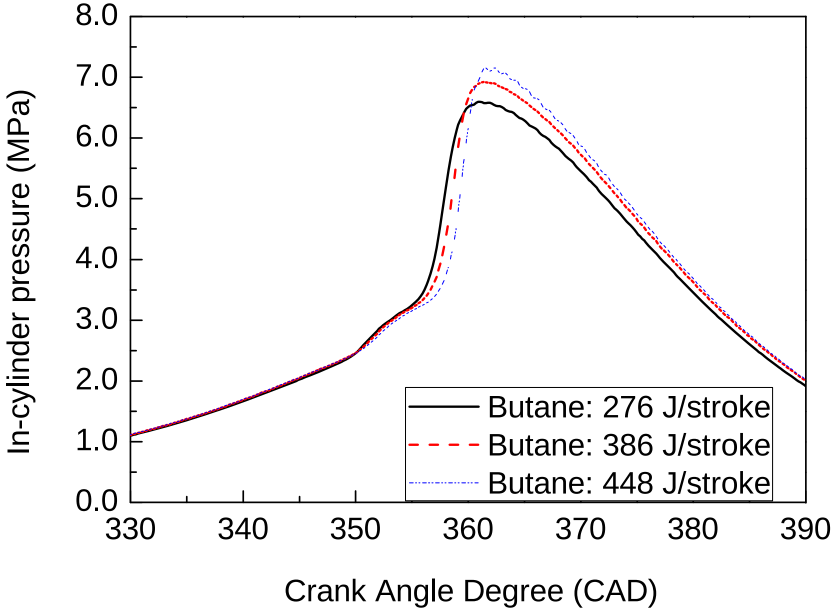
Output Performance - Induced Mean Effective Pressure (IMEP)

DME: 677 J/stroke, injected at Optimal timing (240 CAD)

Propane




Butane




- Enough amount of DME -> no suppression of entire reaction

  -> increased ignition delay & maximum pressure

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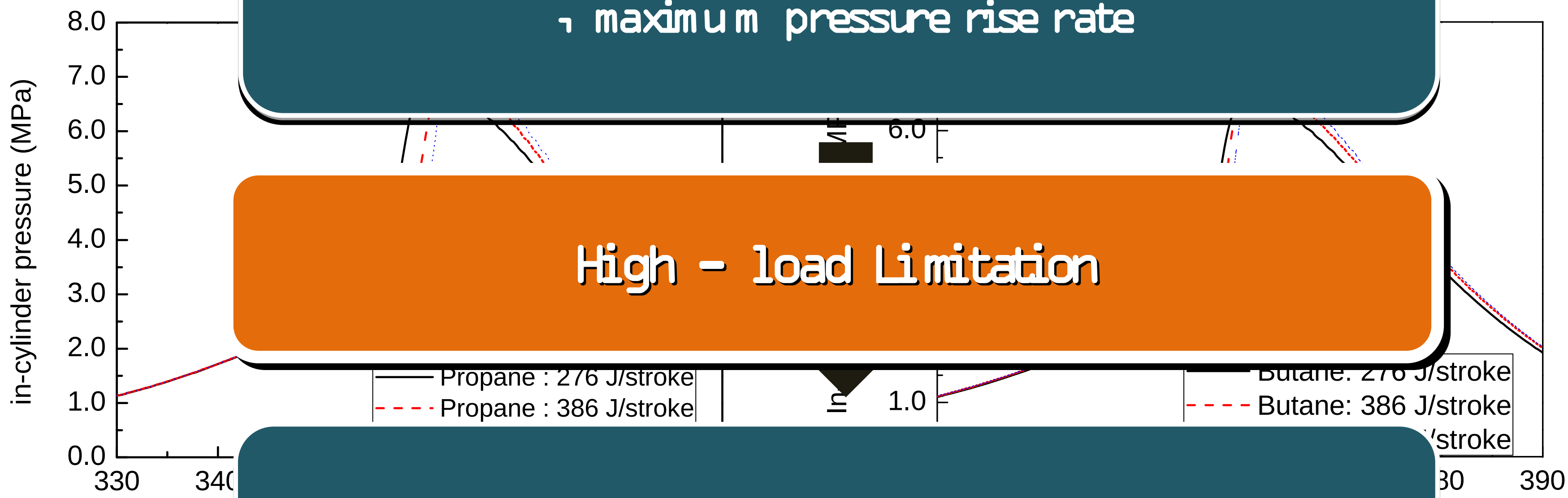
## Output Performance - Induced Mean Effective Pressure (IMEP)

Increased ignition delay, maximum pressure
, maximum pressure rise rate




High - load Limitation

Severe noise and knocking occurs

- Enough

-> increased ignition delay & maximum pressure

# Summary – DME HCCI combustion in Single Fuel Engine

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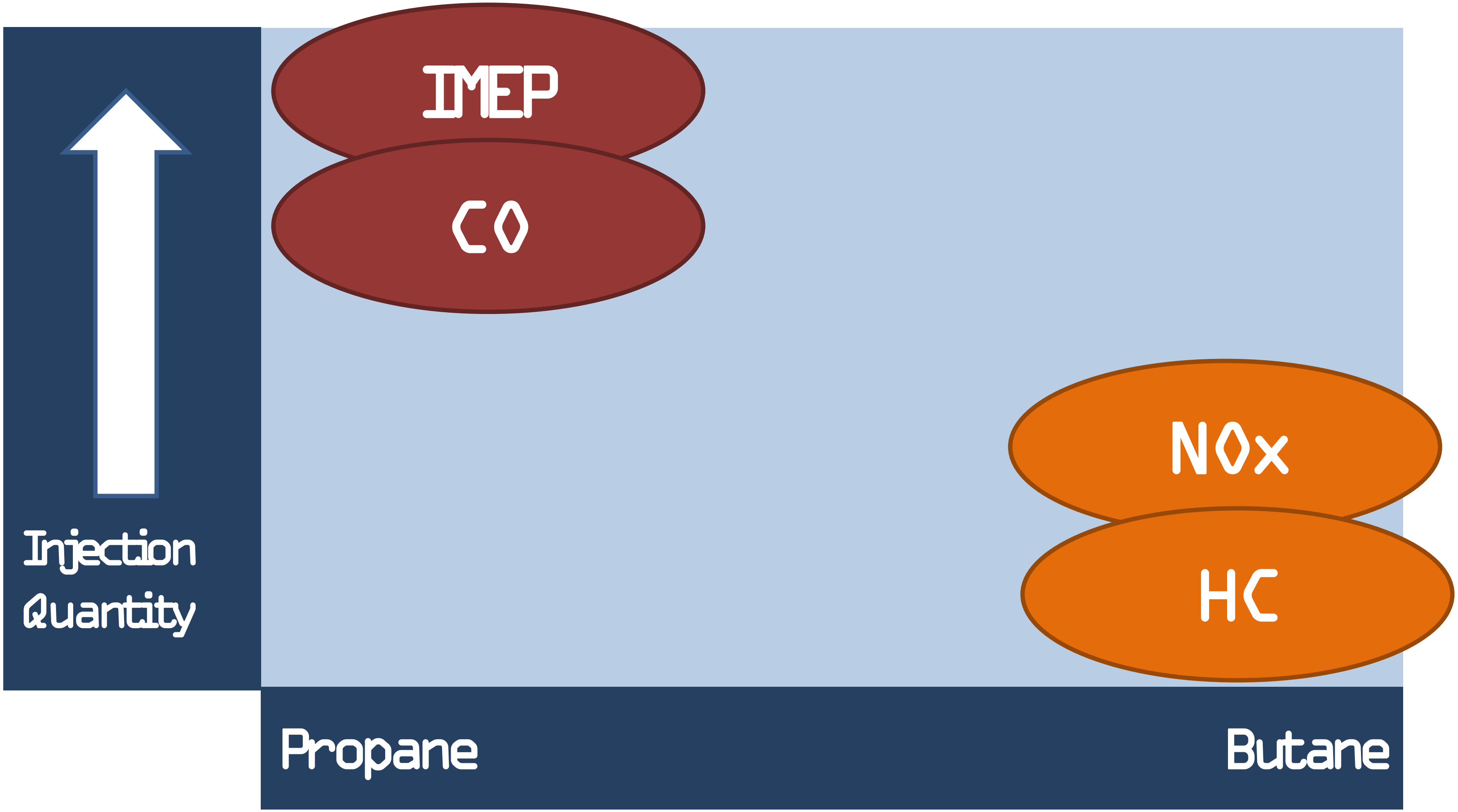
**The effect of LPG composition in a DME-LPG dual-fueled HCCI engine at various injection quantity and injection timing was observed**

1. In a DME HCCI engine, higher load limit was extended by using LPG as an ignition inhibitor

2. If injection quantity of LPG exceeds certain level compared to injected quantity of DME, IMEP was decreased

3. Propane was more effective way to increase IMEP in this study

# Summary – DME HCCI combustion in Single Fuel Engine

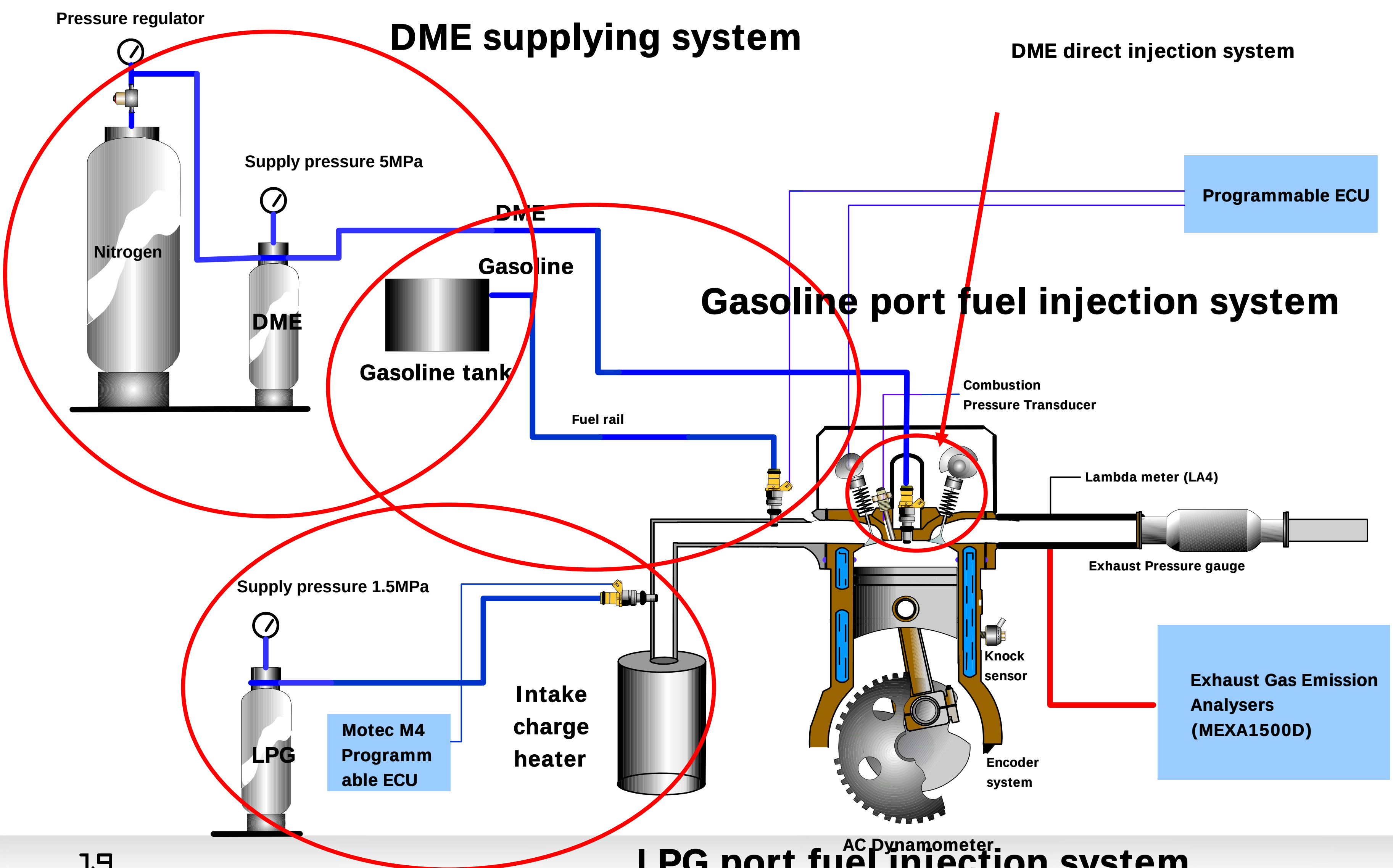


# Dual-Fuel HCCI Combustion Based on SI Engine

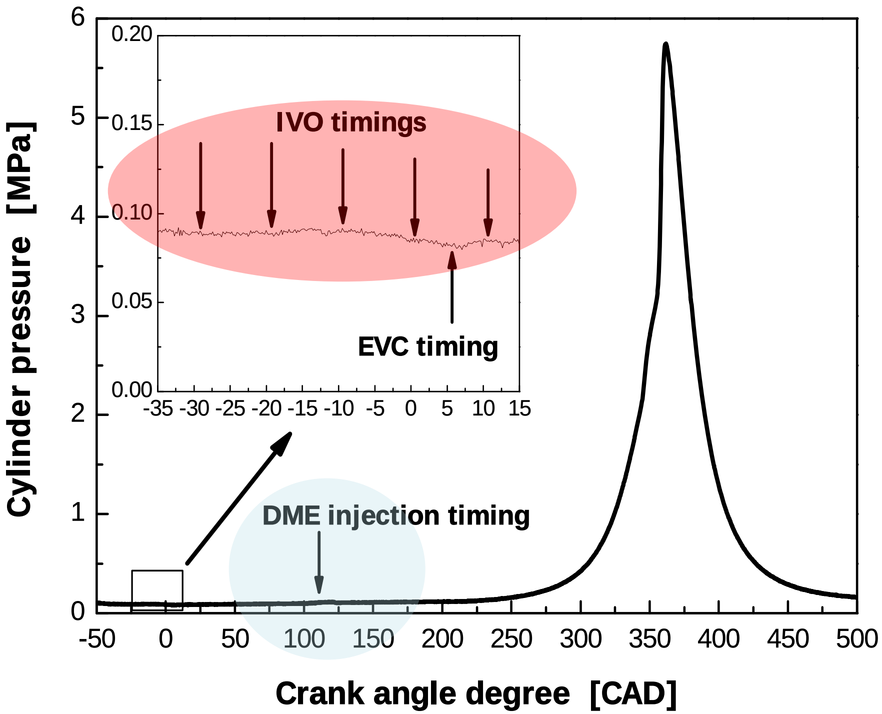
- Gasoline + DME HCCI
- LPG + DME HCCI

# Experimental apparatus





# Experimental conditions




## ❑ Experimental conditions

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

# IMEP of HCCI engine

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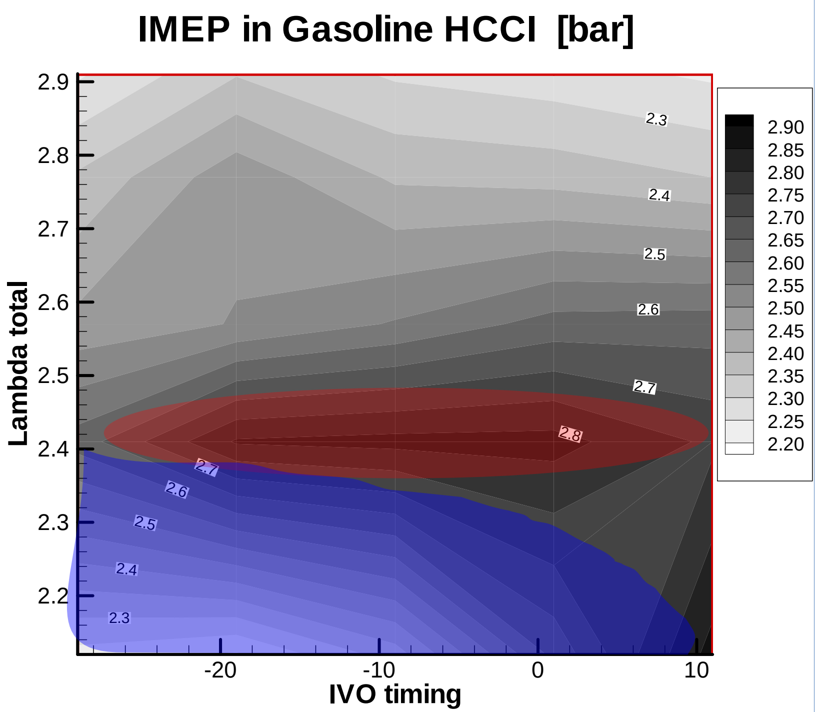
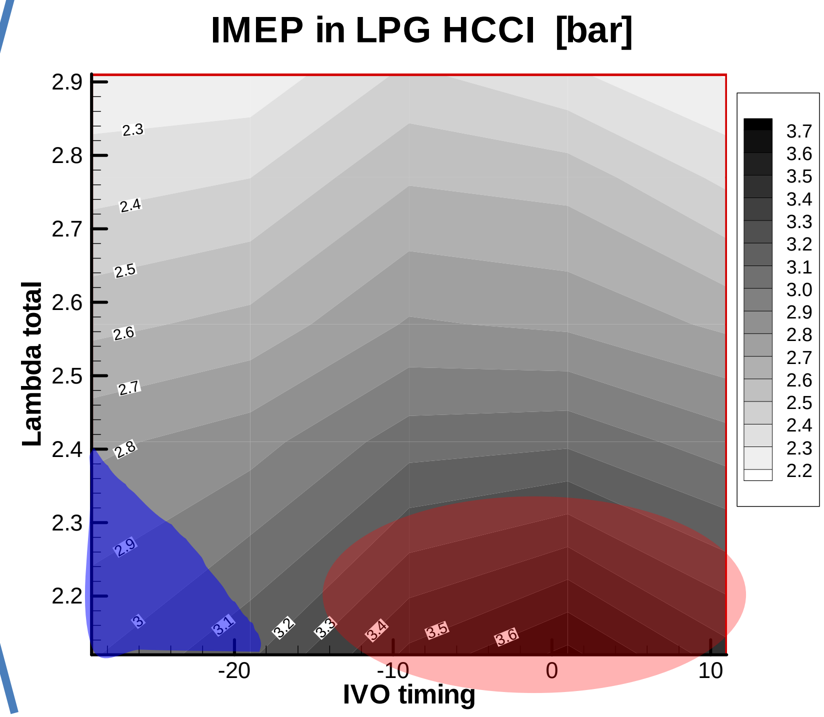



**Maximum IMEP region**

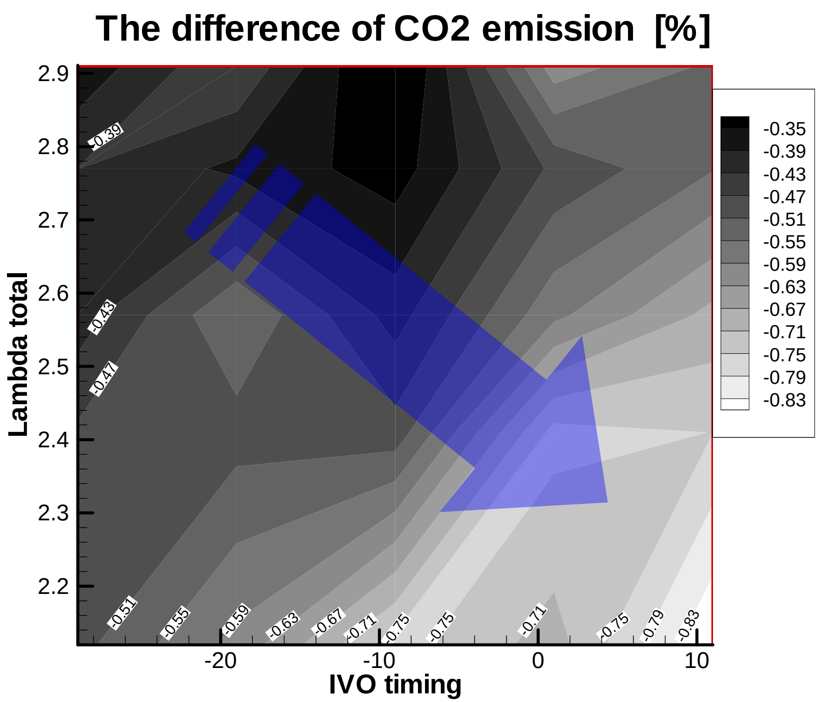
**Heavy knock region**

**IMEP was decreased due to <u>negative work</u>**

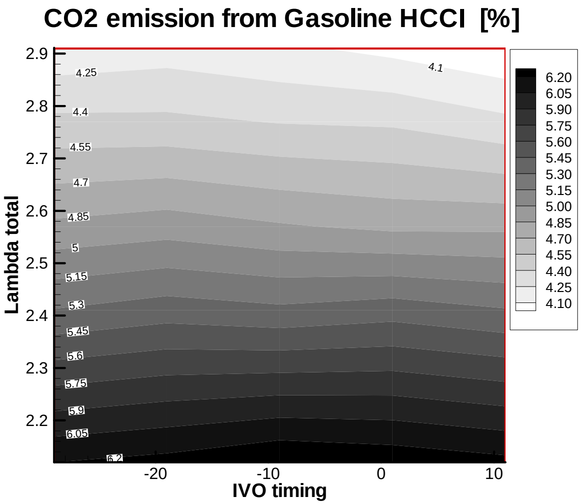
$$imep = \frac{W_{c,i}}{V_d}$$

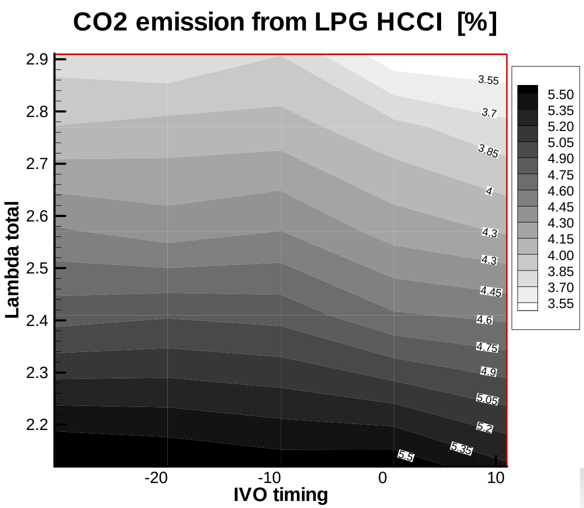
# $CO_2$ emissions of HCCI






The $CO_2$ emission difference was **increased** as the **IVO timing** was **retarded** and **$\lambda_{total}$** was **decreased**




The **$CO_2$** emission of **LPG** HCCI was **lower** than that of **gasoline** HCCI due to **low carbon contained** and **high octane number fuel**

Difference = LPG - gasoline

# Summary – HCCI combustion in Dual Fuel Engine

LPG-DME HCCI engine

Gasoline-DME HCCI engine

comparison

Combustion characteristics

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.

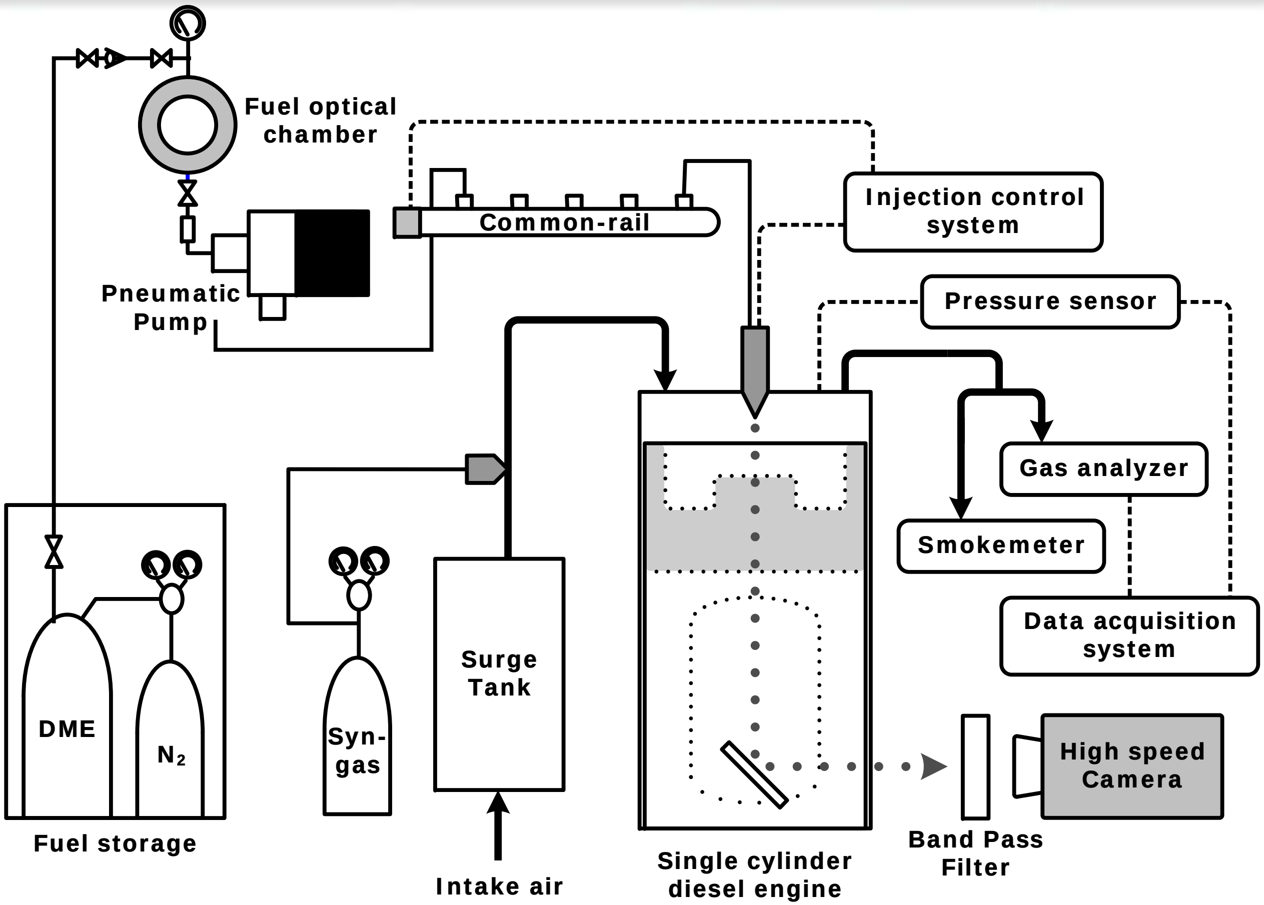
2. The $CO_2$ emission of LPG-DME HCCI engine was lower than that of gasoline-DME HCCI engine.

# Dual-Fuel HCCI Combustion Based on CI Engine

- Hydrogen Port and DME Direct HCCI

# Experimental setup





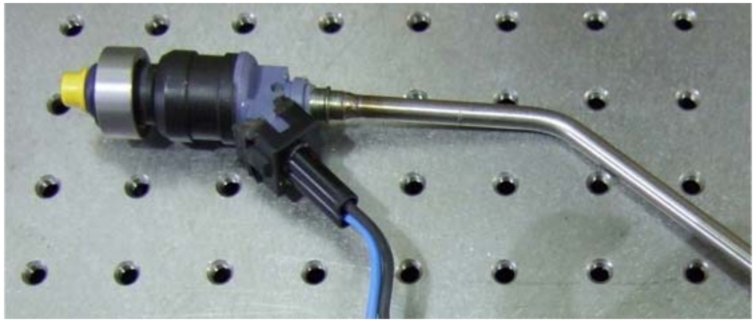

| | |
|---|---|
| Engine type | Single cylinder DICI |
| Displacement | 498 cc |
| Bore x Stroke | 83 x 92 mm |
| Compression ratio | 14.8 |

| | | |
|---|---|---|
| Fuel injection type | DME | **Common-rail injection system** (igniter) |
| | $H_2$ | **CNG injector** (port fuel injection) |

# Experimental setup – Hydrogen injector

## Hydrogen injection system

- Hydrogen injector : Bosch CNG injector



  - Peak and Hold (2A / 0.5A)
  - Supply voltage : 6 – 16V
  - Operating temperature : -20 – 70°C

- Hydrogen injector : 2 Ch CNG injector driver


  - Operate up to 2 injectors at once
  - Supply voltage : 220V

# Operating conditions – Effect of DME Injection Timing

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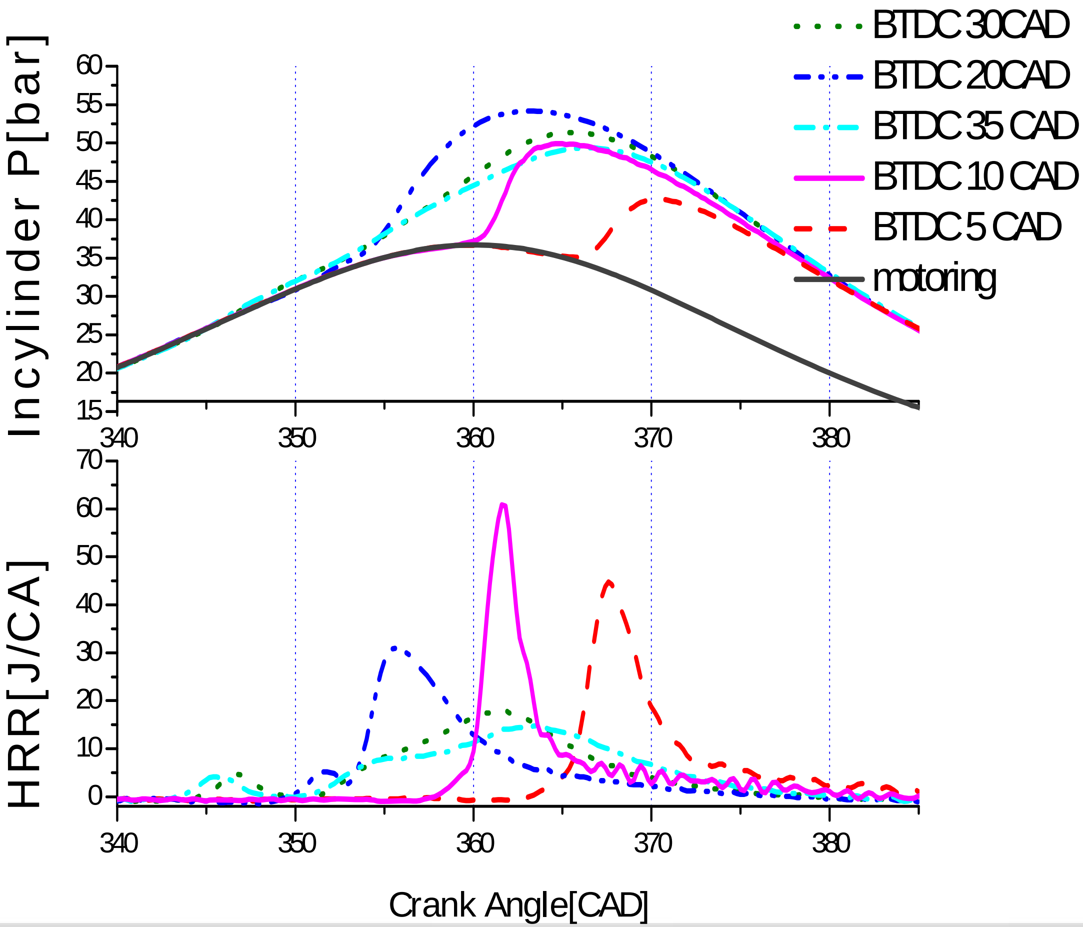
| | |
|---|---|
| **Fuel** | DME / $H_2$ |
| **Engine speed** | 1200 rpm |
| **Compression ratio** | 14.8 |
| **Load** | 0.2 MPa |
| **Injection timing of DME** | 40~2 CAD BTDC |
| **Injection timing of $H_2$** | 360 CAD BTDC |
| **Injection quantity of DME** | 5mg(fixed) |
| **Injection quantity of $H_2$** | varied(meet 0.2MPa IMEP) |
| **Coolant temperature** | 80°C |
| **Intake air temperature** | 30°C |

# Experimental results – In-cylinder pressure and HRR

| | |
|---|---|
| Engine speed: | 1200rpm |
| $T_{intake}$ : | 30°C |
| IMEP: | 0.2 MPa |




- **DME injection Before BTDC 10 CAD**

  - In-cylinder pressure and HRR were increased with retarding DME injection

  - LTR and HTR were observed

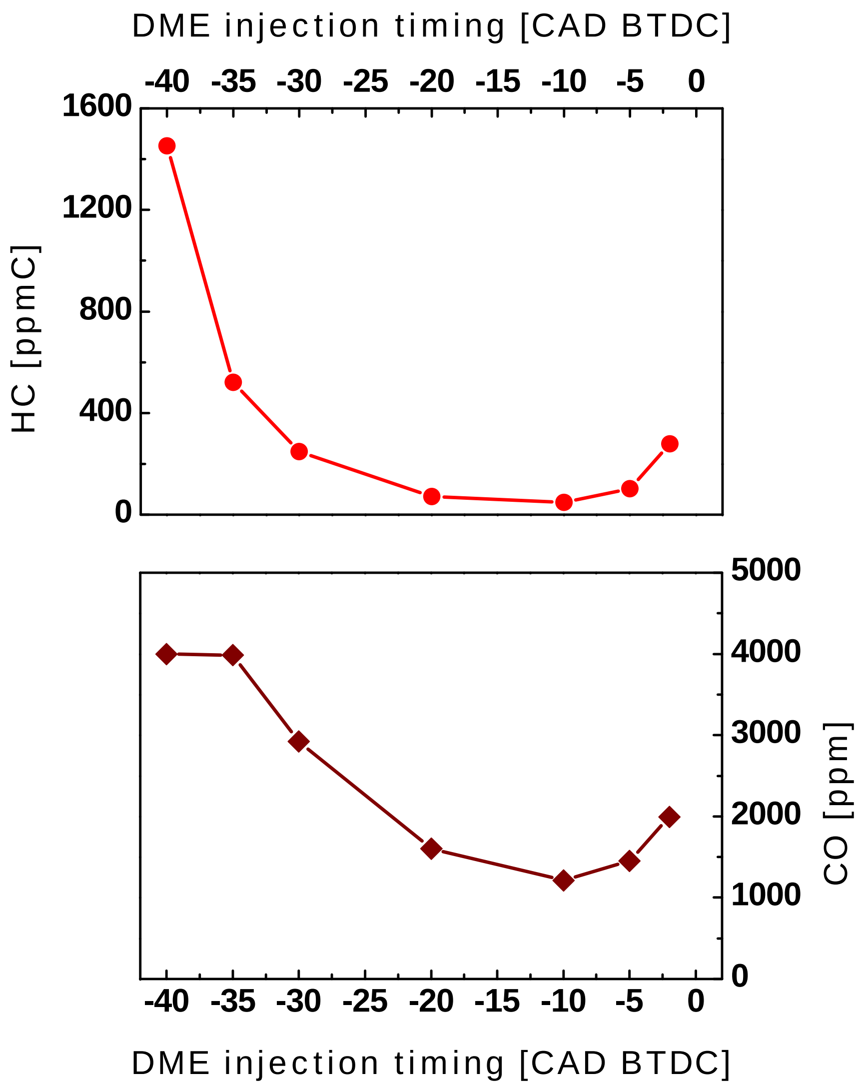
- **DME injection After BTDC 10 CAD**

  - In-cylinder pressure and HRR were increased with advancing DME injection

  - only HTR was observed

# Experimental results – HC and CO emission






- **CO and HC were not burned when DME was injected before BTDC 30 CAD due to low combustion temperature**
- **After BTDC 10 CAD DME injection CO and HC emissions started increase**

# Experimental results – NOx emission

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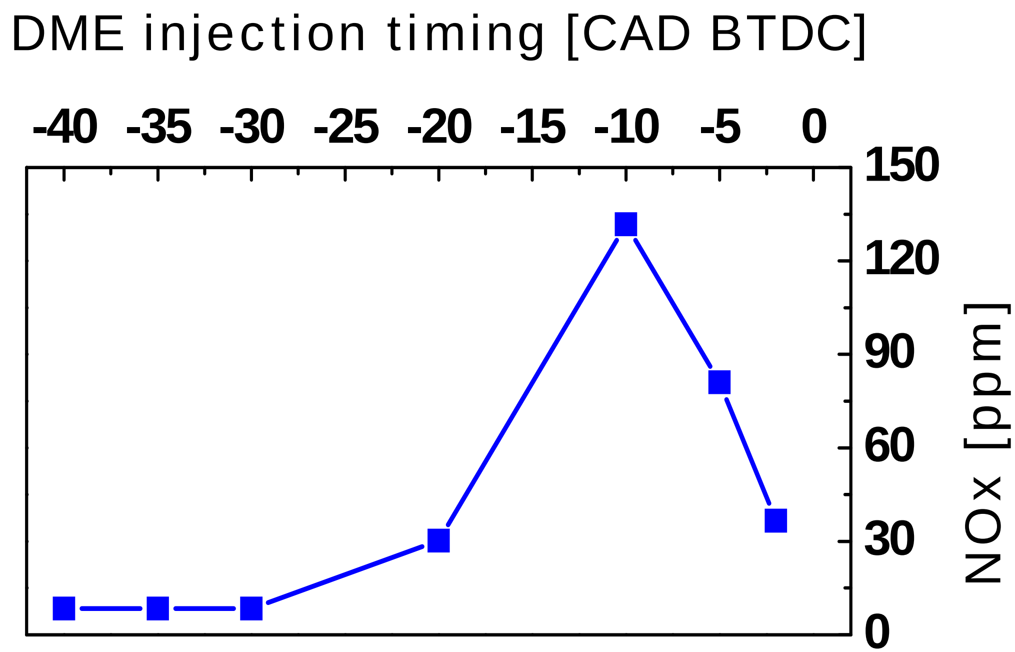


- NOx Emission was maximum when DME is injected at BTDC 10 CAD
- At BTDC 10 CAD DME injection, Heat release rate was Maximum

# Summary – Hydrogen + DME HCCI combustion

1. Combustion phase was retarded with higher portion of Hydrogen due to consumption of OH radial.
2. DME injection timing can control the ignition timing of Hydrogen-DME HCCI combustion.
3. With DME injection before BTDC 10 CAD, Low temperature reaction and high temperature reaction were observed.
4. With DME injection after BTDC 10 CAD, only high temperature reaction was observed
5. CO and HC were not burned when DME was injected before BTDC 30 CAD due to low combustion temperature
6. NOx Emission was maximum when the HRR was maximum.
7. The strategies to increase the combustion temperature such as fuel stratification are needed to improve the combustion efficiency and combustion stability.

# 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, Hydrogen)

↑

**Dual fuel**

BDC

TDC

Early ⟷ **Direct injection timing** ⟷ Late

HCCI

PCCI

Conventional CI

Local rich region and temperature drop

# Thank you!