Effect of Hydrogen in DME HCCI Combustion

IEA IMPLEMENTING AGREEMENT
ON ENERGY CONSERVATION AND EMISSIONS REDUCTION IN COMBUSTION
30TH TASK LEADERS MEETING

SEP 2008, CAPRI

Choongsik Bae

Department of Mechanical Engineering
KAIST

KAIST Korea Advanced Institute of Science and Technology

CERC

Effect of Hydrogen in DME HCCI Combustion

Introduction

DME HCCI

Objective

Experimental Setup / Operating Conditions

Results

Conclusions

Introduction

Limited fossil fuel energy.

Air quality deterioration by pollutant matters.

Global warming by green house gases.

Petroleum alternatives

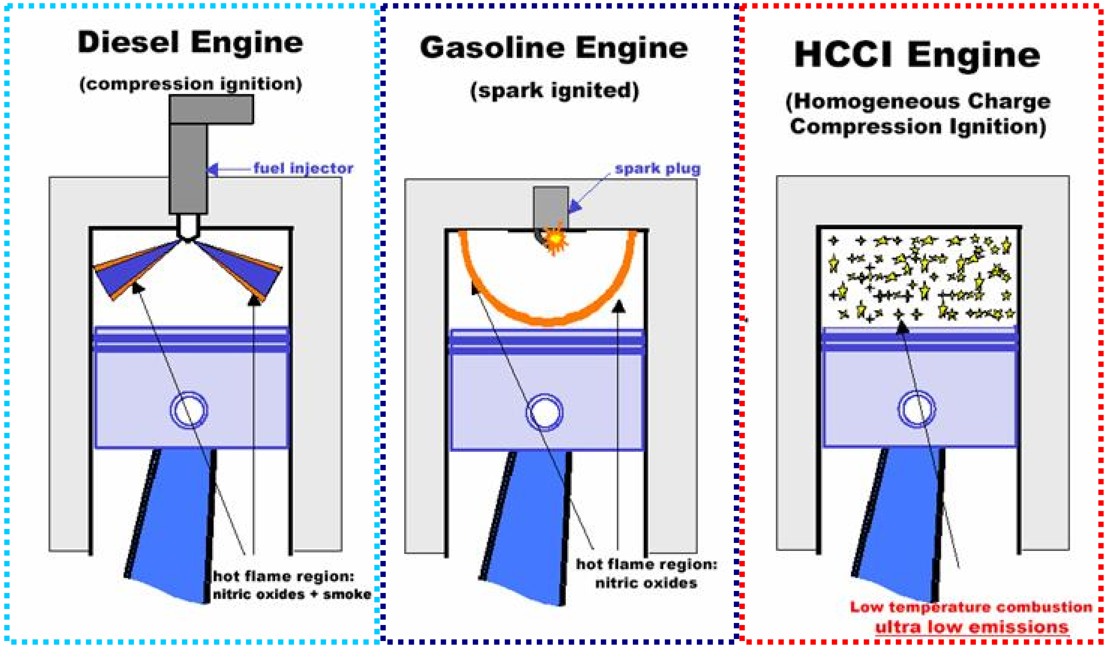
Sustainable energy

Clean energy

Higher efficiency Alternative fuels

Introduction

HCCI + **Low Carbon Alternative Fuel**



Advantages

- Fuel
- Low fuel consumption
- Low NOx emission
- Low soot emission

Disavantages

- High in-cylinder peak pressure
- Narrow operating range
- High HC and CO emission

Introduction

High Energy Efficiency + **Low Carbon Alternative Fuel**

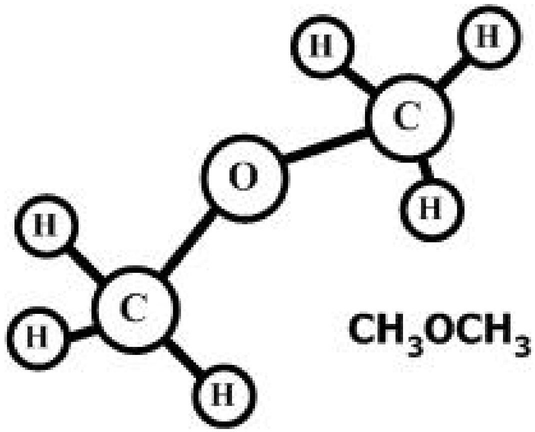
CNG
DME
Hydrogen
Ethanol / Methanol
Bio-fuel
etc.

Prospects of Alternative Fuels for CI Engines

- The proportion of Gasoline & Diesel will decrease
- Commercialization of Gaseous Fuels : LPLi, CNG, DME
- Diversification of alternative fuels
- Rise of Hydrogen ICE in the future to supplement or to compete Fuel Cell

Dimethyl-Ether, DME

KAIST ENGINE LAB.



CH_3OCH_3

- Liquefied gas similar to LPG
- Simple oxygenate compound
- "Synthetic Fuel" derived by chemical conversion of NG or coal.

Physical Properties of DME and Diesel

	DME	Diesel	Note
Chemical structure	CH_3OCH_3	$C_nH_{1.8n}$	Oxygenated fuel
Bulk modulus ($\times 10^8$ N/m^2) @20	6.37	14.9	Compressibility
Stoichiometric A/F ratio	9.0	14.6	
Low calorific value (MJ/Kg)	28.4	42.5	
Density (g/ml)	0.668	0.84	
Cetane number	>> 55	40~50	Compression ignition
Auto ignition Temp. @1atm ()	235	250	
Boiling point ()	-25	180~370	Pressurized fuel line

Hydrogen-rich Synthetic gas

- A feedstock is converted into SYN GAS composed of CO and Hydrogen

Steam Reforming

- $CH_4+H_2O \rightarrow CO + 3H_2$

Partial Oxidation

- $2CH_4+O_2 \dashrightarrow 2CO + 4H_2$

SYNGAS

Typical composition of SYNGAS

H_2 35~75%

CO 15~45%

CO_2 2~10%

- ideal H_2 / CO ratio for Fischer-Tropsch process : 2

→ Partial oxidation is more often employed

DME HCCI

- HCCI – diesel like thermal efficiency with NOx emission and PM
- Problems : high unburned hydrocarbon and CO emissions, difficulty in controlling
- DME/air mixture: heat release value in the LTR(at 650K) is larger than that of petroleum(at 850K)

High cetane number

More than 55, from the viewpoint of its thermo-chemical characteristics

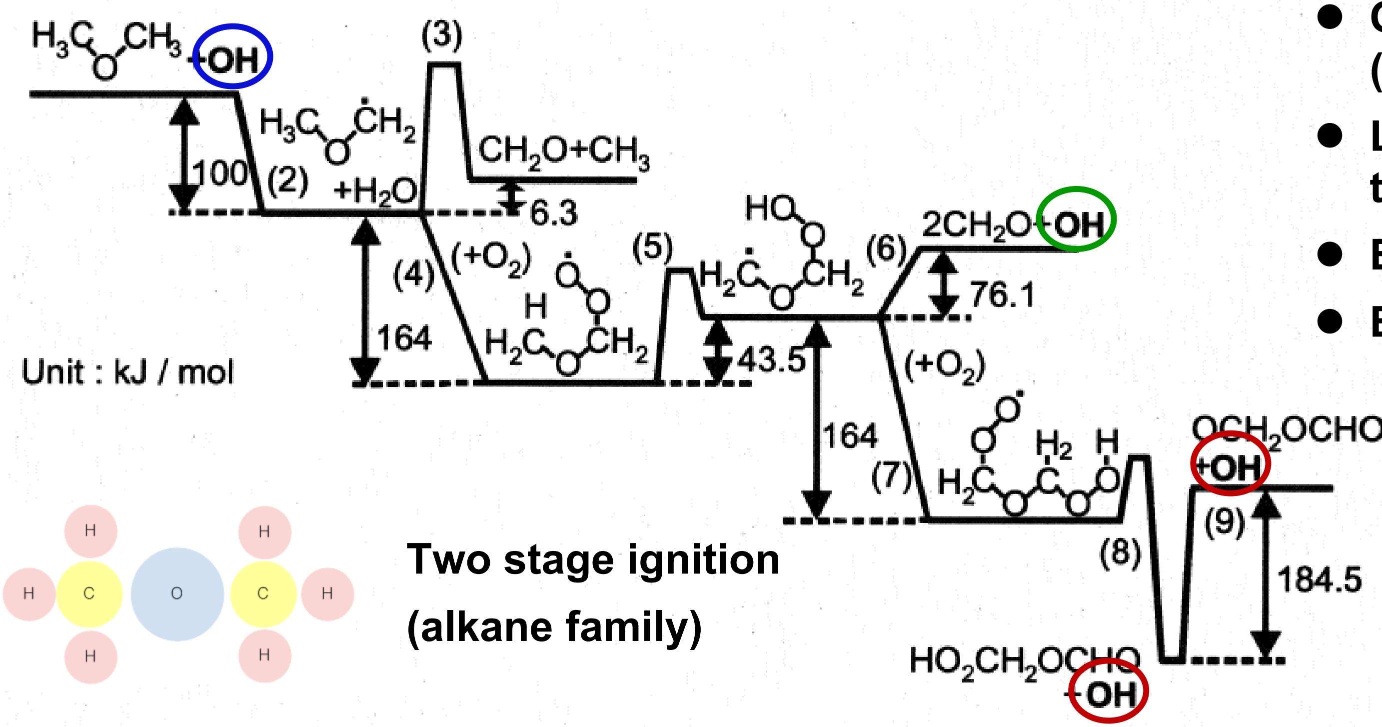
- Good ignition quality
  - Intake heating is unnecessary
- Too early ignition
  - High in-cylinder pressure and combustion noise
  - Low work conversion efficiency

→ **Ignition timing control**

- Exhaust gas recirculation (EGR)
- Additives ; High octane number fuel (H_2, methane, methanol ...)

DME HCCI

Low temperature oxidation of DME



Two stage ignition

(alkane family)

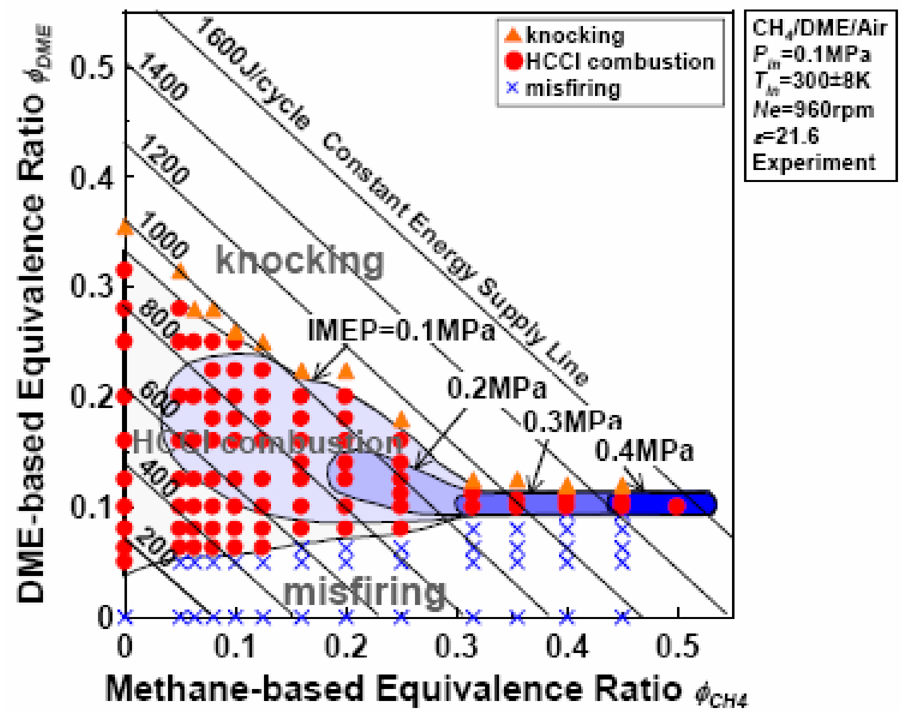
- Occurs 650K
  (cf. petroleum : 850K)
- Larger heat release than that of petroleum
- Begins with the C-H
- Bond blockage

H. Yamada, et al., 2003

DME HCCI

- **Heat release during LTO and fuel properties influence directly to HTO.**

Combustion phasing by high octane number fuel addition	
Changing the auto-ignition temperature	**Reduce the OH radical (prominent chain carrier) concentration**



S. Sato, et al. (2005)

- **The start of HTO can be altered over a wide range of values by fuel mixing ratio of poor ignition high octane fuel and good ignition DME.**

Objective

KAIST ENGINE LAB.

High efficiency combustion

HCCI

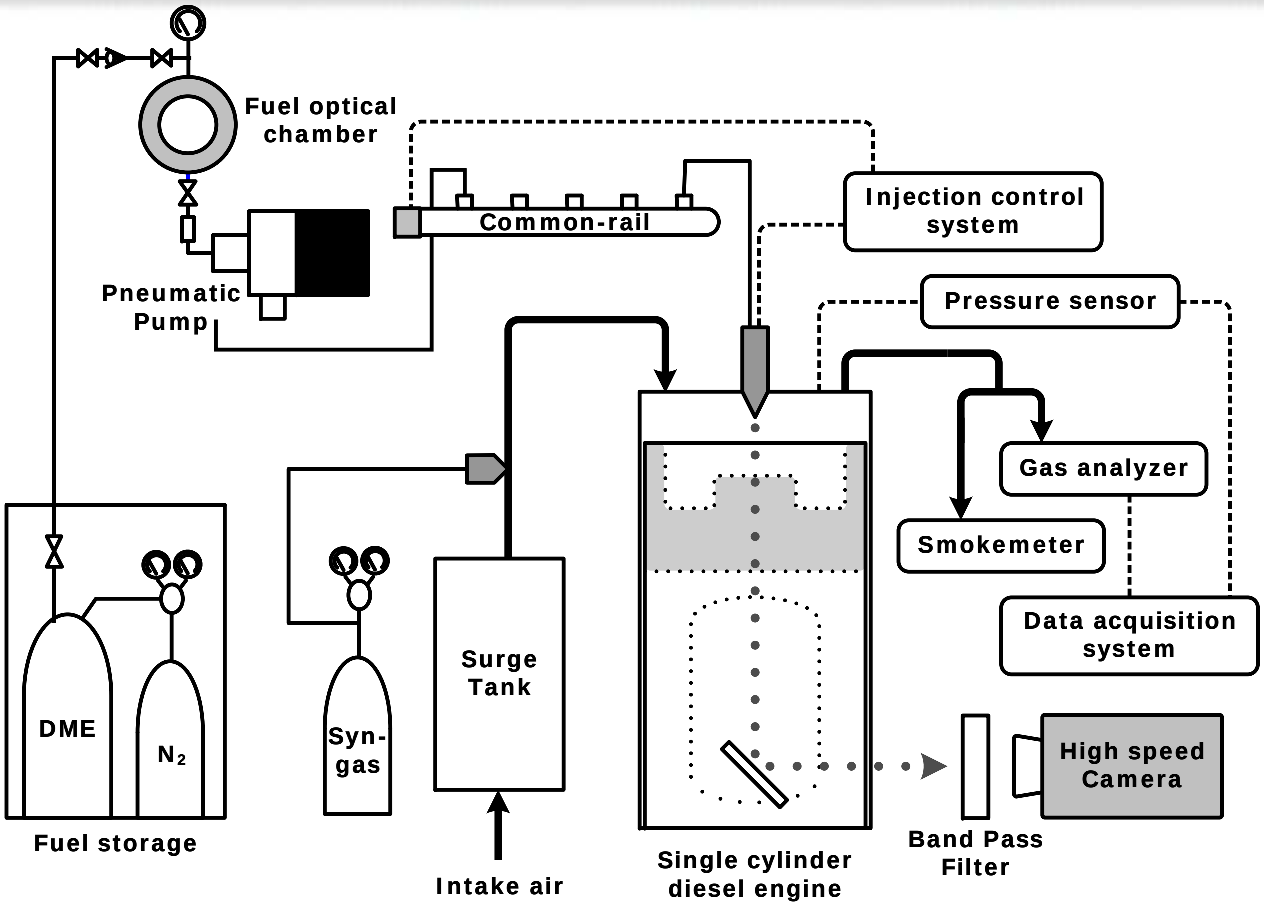
Clean alternative fuels

DME + H_2 rich gas

Increase the efficiency by combustion phasing

& Emission reduction by using clean fuel

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 (Early injection)
	Syn-gas	CNG injector (port fuel injection)

Operating conditions

Experimental conditions

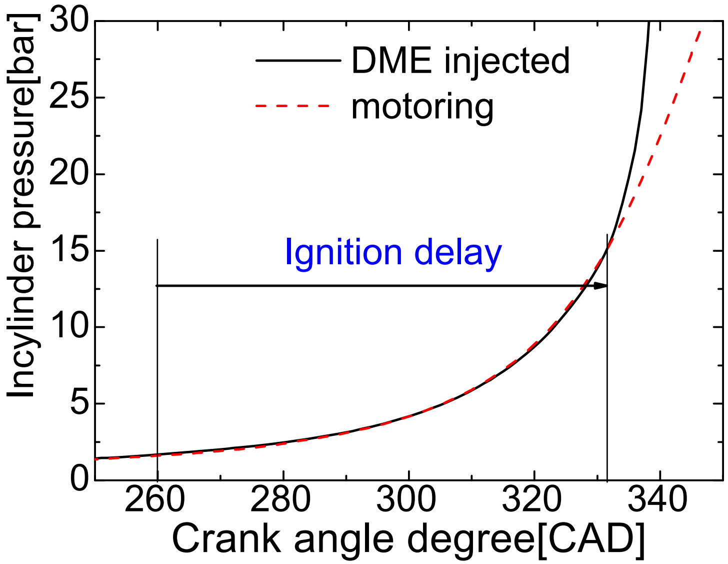
Fuel	DME / H_2 / CO
Engine speed	800 rpm / 1200 rpm
Compression ratio	14.8
Total low heating value	406 J
Start of injection of DME	100 CAD BTDC
Start of injection of H_2	360 CAD BTDC
Intake air temperature	30°C

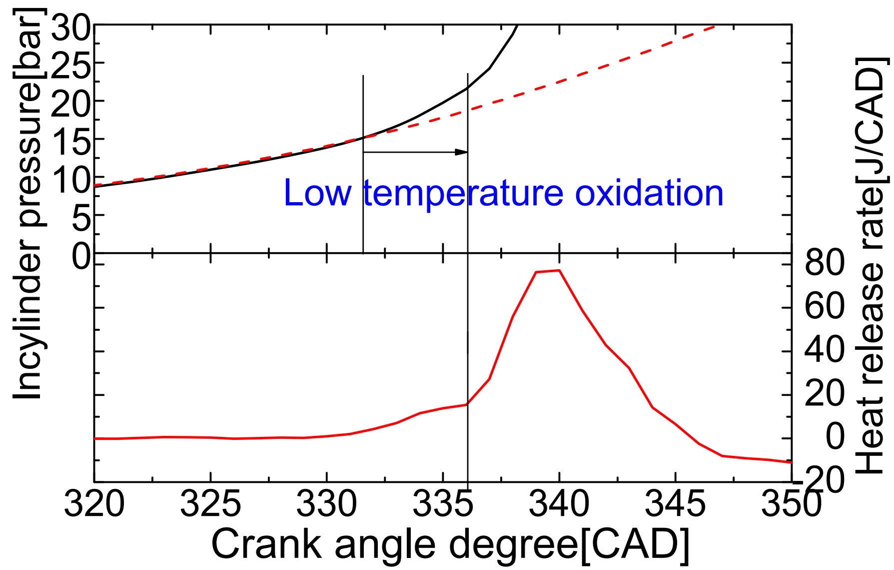
Fraction rates of additive fuel

$$R_{H_2} = \frac{Q_{H_2 \text{ or } CO}}{Q_{Total}} \times 100\ (\%)$$

$$Q_{fuel} = Q_{LHV} \times m_f$$

Definition of Ignition Delay and Duration of LTO





Ignition delay

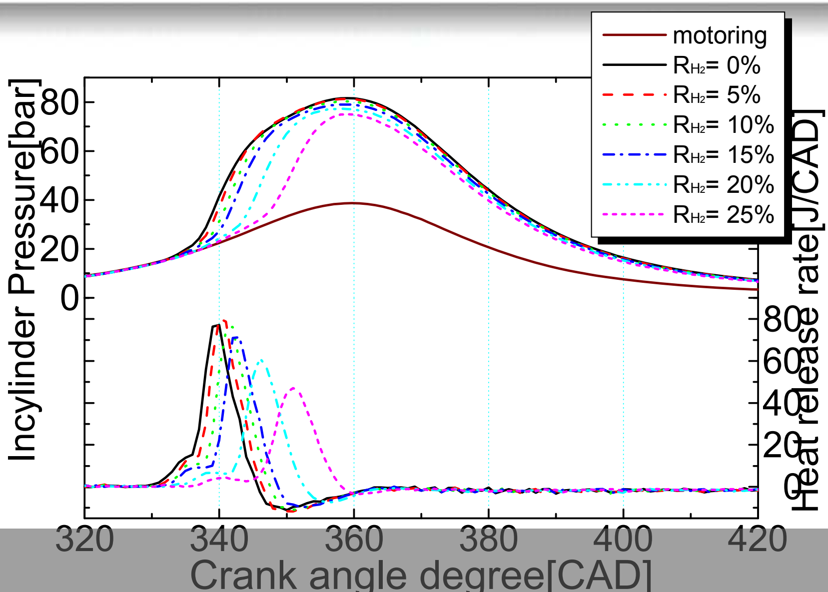
: From SOI to the moment overcoming the motoring pressure

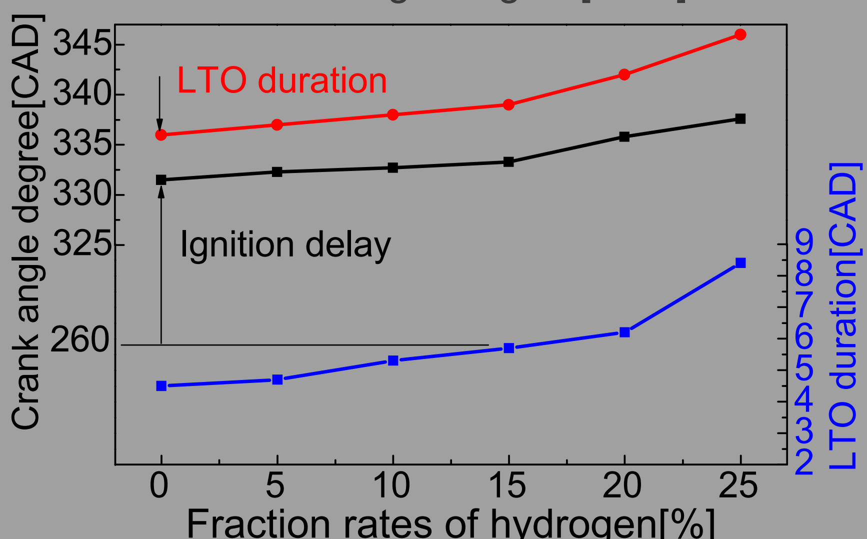
Duration of LTO

: From the end of ignition delay to the moment that heat release rate is suddenly increased

DME HCCI with Hydrogen

KAIST ENGINE LAB.





Engine speed:	**800rpm**
T_{intake} :	**30°C**
Total low heating value :	**406 J / cycle**

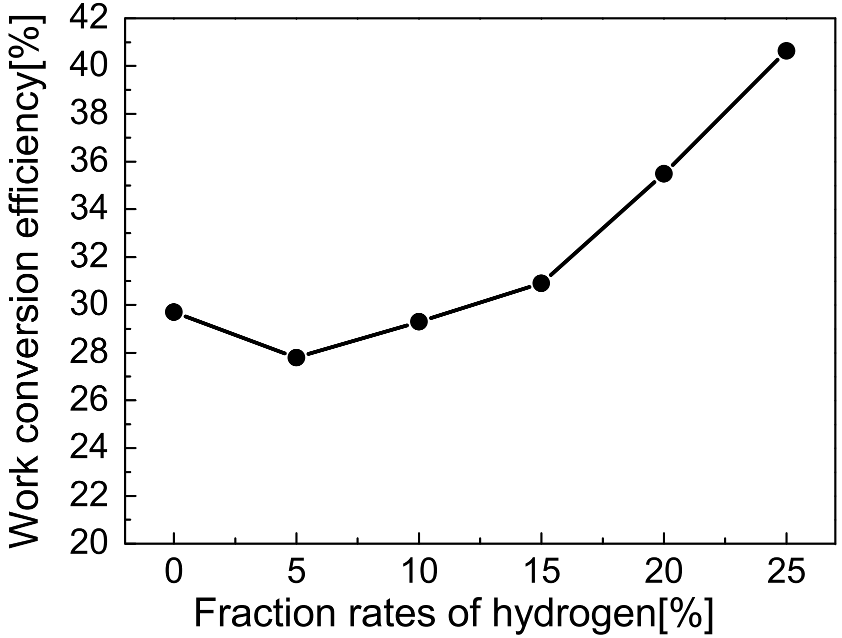
Low temperature oxidation of H_2

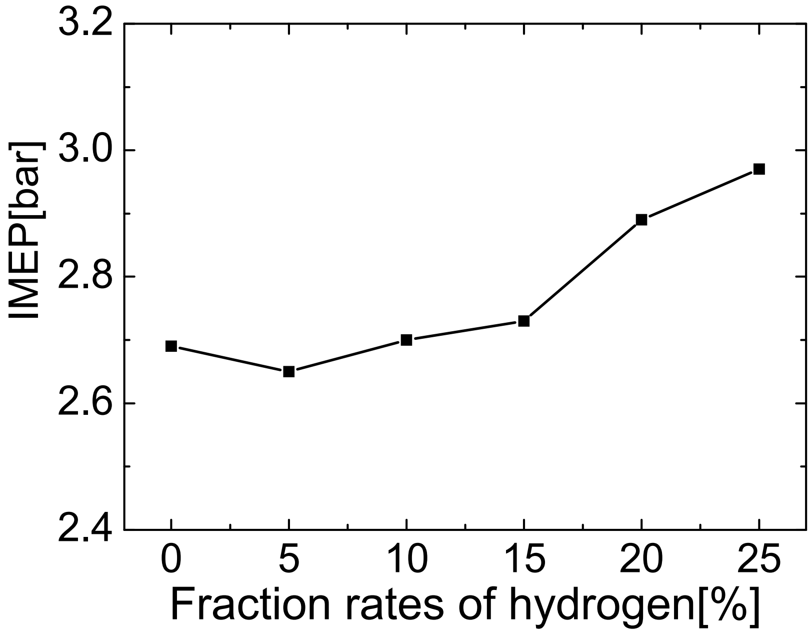
$$H + O_2 \rightarrow O + OH$$
$$O + H_2 \rightarrow H + OH$$

$$H_2 + OH \rightarrow H_2O + H$$
$$CH_3OCH_3 + OH \rightarrow CH_3OCH_2 + H_2O$$

Ignition timing control by *Hydrogen*

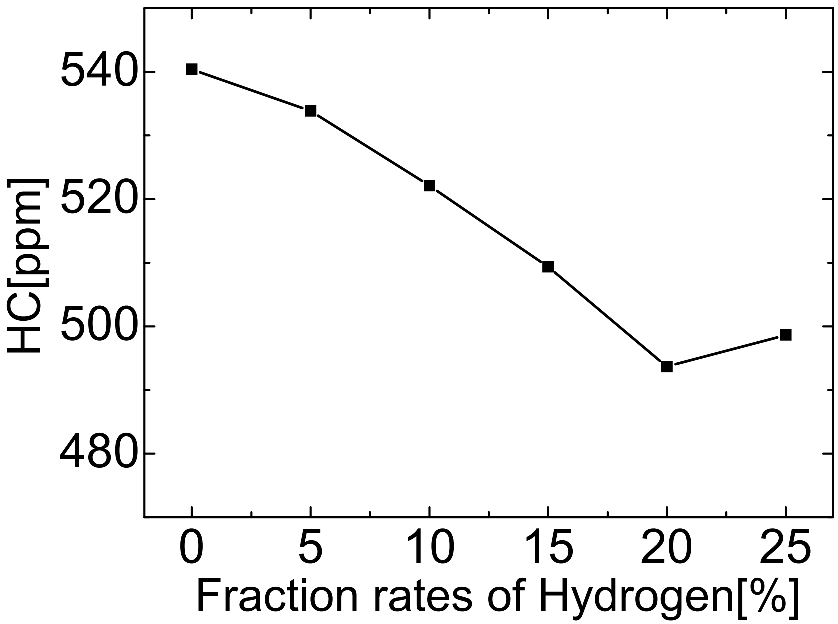
DME HCCI with Hydrogen

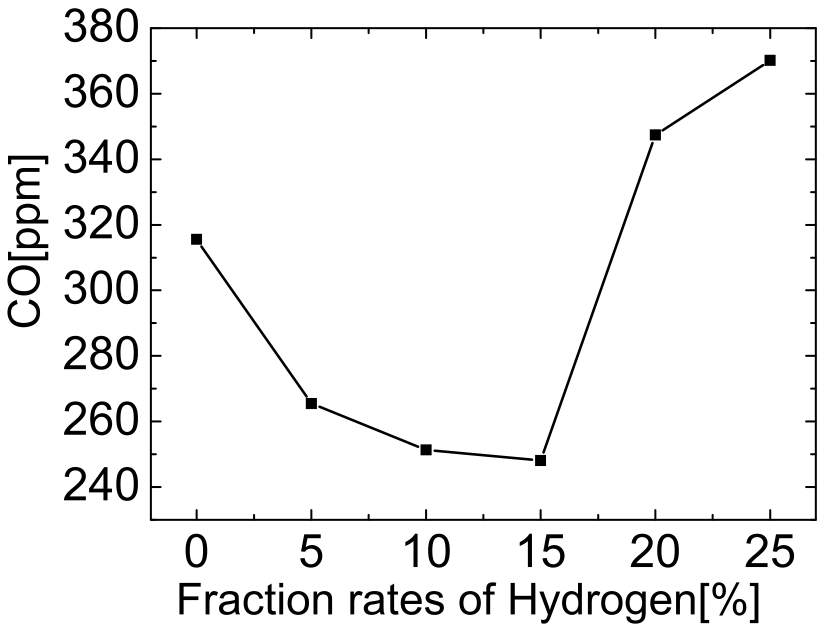




- **Combustion phase is retarded with increasing H_2 energy fraction.**
- **Retarded combustion phasing results in work conversion efficiency increase.**

DME HCCI with Hydrogen

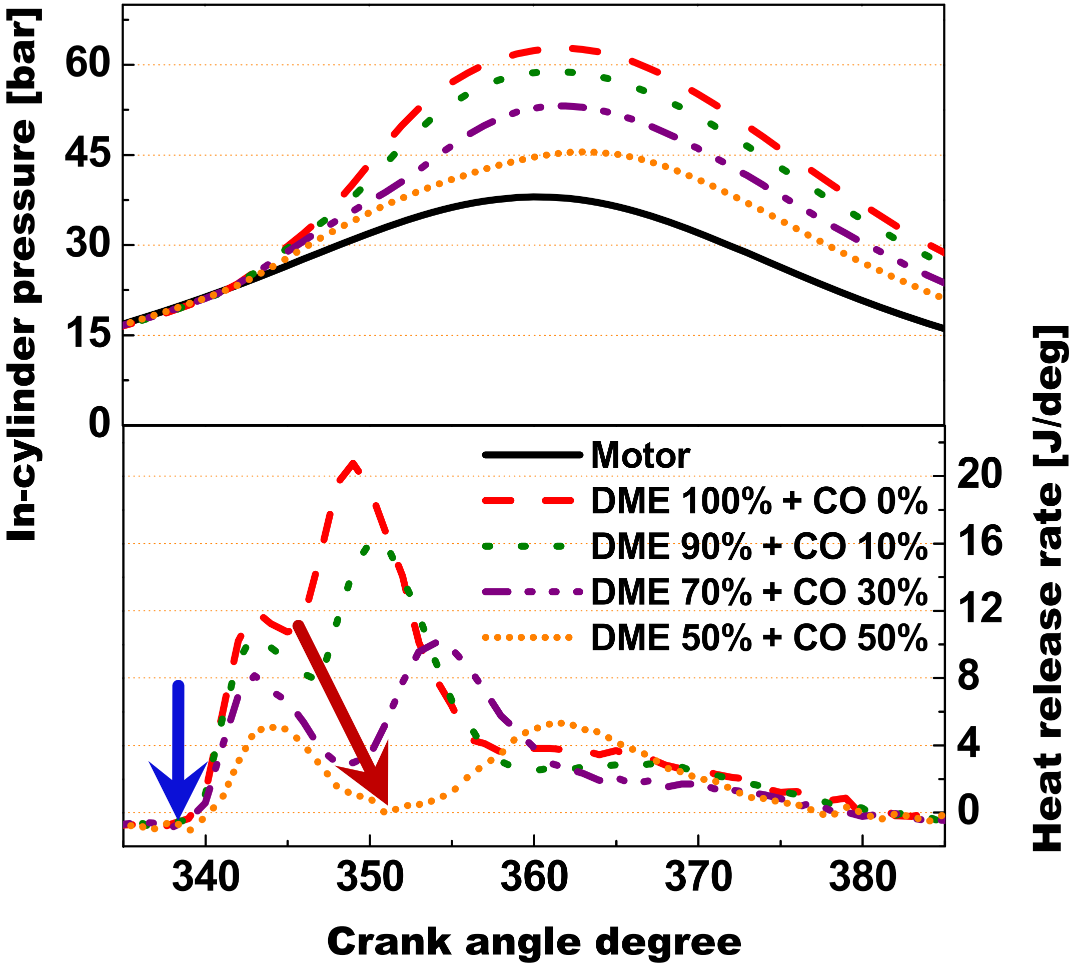




- **HC and CO emissions decreased with increasing H_2 energy fraction due to the reduction of C atoms in fuel/air mixture.**
- **However, the HC and CO increased with H_2 fraction rate over 15%, due to the low combustion temperature to oxides the HC and CO.**

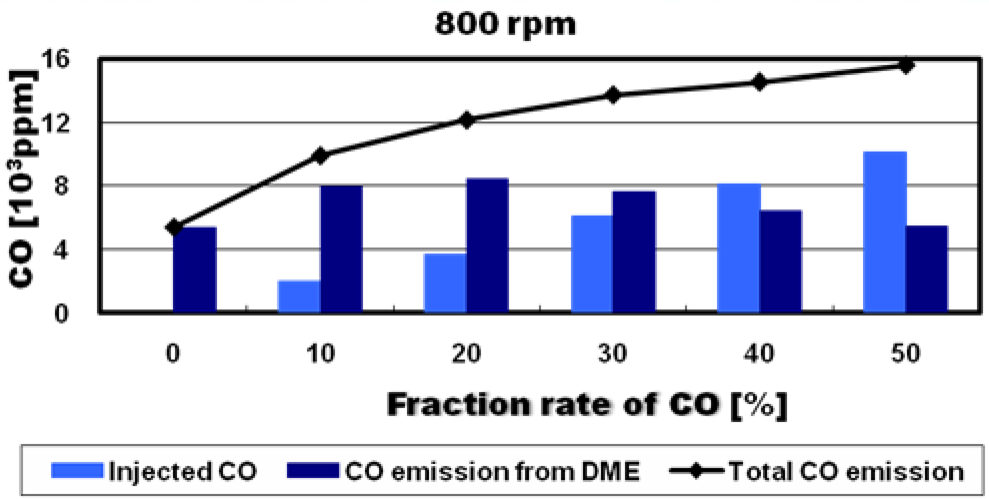
DME HCCI with Carbon Monoxide

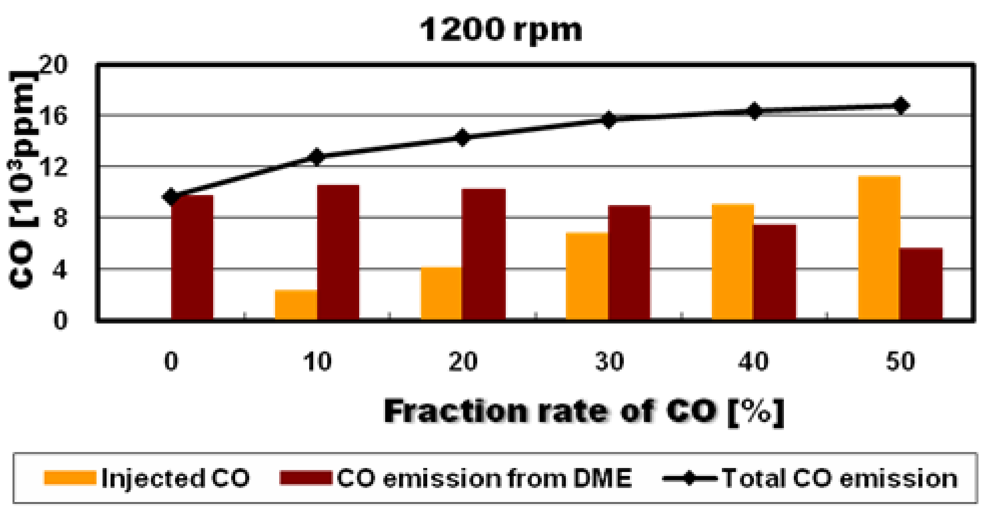
Engine speed:	800rpm
T_{intake} :	25°C
Total low heating value :	406 J / cycle



- Combustion is unstable as the fraction rate of CO increases over 50% (COV_{imep} > 5%).
- HTO is retarded with increasing CO energy fraction with the unchanged start of LTO.
- Heat release decreases as the fraction rate of CO increase, and lower heat release during the low temperature oxidation retards the start of HTR.

DME HCCI with Carbon Monoxide





with CO in DME HCCI

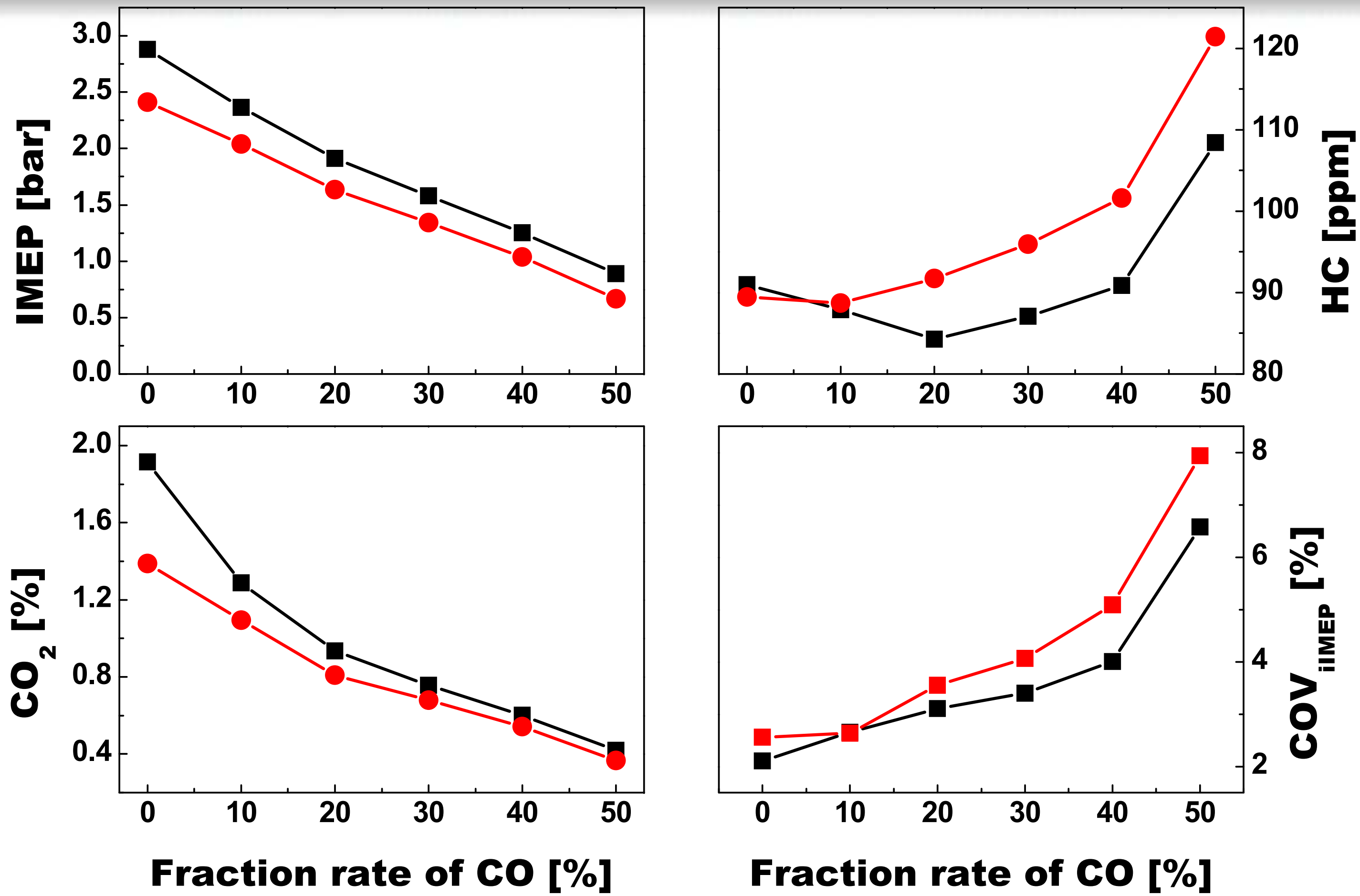
CO oxidation above 1500 K

+

Low $T_{combustion}$ in DME HCCI

Added CO does not burn in DME HCCI combustion

DME HCCI with Carbon Monoxide



- Low combustion efficiency, and high CO emissions with CO addition.
- Increase of $T_{combustion}$ is need to improve the CO oxidation; fuel stratification, so on.

Conclusion

- In DME HCCI combustion, the NOx emission is less than 10 ppm.
- H_2 / CO addition in DME HCCI is the effective way to control the combustion phase, can increase the work conversion efficiency.
- With H_2 addition, HC and CO emissions reduced by the decrease of the carbon atoms in fuel/air mixture.
- CO did not burned in DME HCCI due to the low combustion temperature.
- The strategies to increase the combustion temperature such as intake heating, fuel stratification are needed to improve the combustion efficiency and combustion stability.

Thank you for your attention.

Choongsik Bae

csbae@kaist.ac.kr

+82 42 350 3044