The Effects of Two-Stage Fuel Injection on DME HCCI Engine Combustion

IEA Combustion

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Backgrounds

New Combustion Method - HCCI

Homogeneous charge	+	Compression ignition
gasoline engine		diesel engine

Advantages

High efficiency
Low NOx and soot emissions

Disadvantages

Difficult to control the combustion phase
High HC and CO emissions
Narrow operating range

- **Ignition controlled by chemical kinetics**
  - High cyclic variation
  - Difficult to control the combustion phase
- **Low combustion temperature**
  - High HC/CO emissions (Low combustion efficiency)
- **Simultaneous ignition in-cylinder**
  - High pressure rise rate
  - Narrow operating range

Backgrounds

HCCI engine combustion control

- **Addition of ignition suppressor; OH radical concentration control**
  - **Methanol, Formaldehyde, H_2, CO**
- **Internal EGR or External EGR; Dilution / Heat capacity effects**
  - **Dilution / Heat capacity effects**
  - **Rebreathing / NVO**
- **Inhomogeneity of mixture and temperature distribution in combustion chamber**
- **Fuel design**
  - **NTL series fuel (n-heptane and toluene blended fuel)**
  - **Dieseline (diesel and gasoline blended fuel)**
- **Ignition control by multiple injection**
  - **MULDIC / UNIBUS / 2 stage injection**

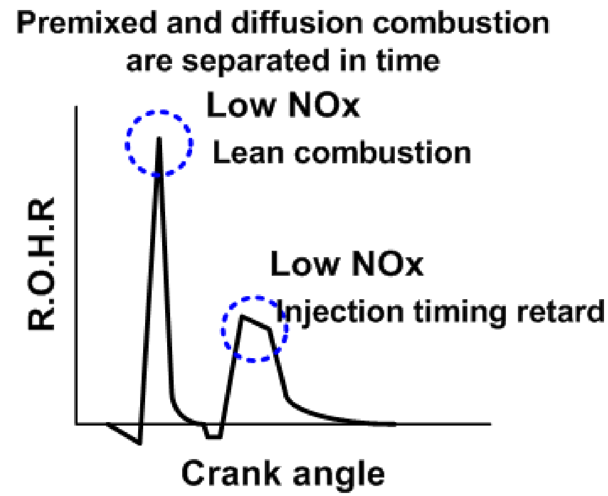
Backgrounds

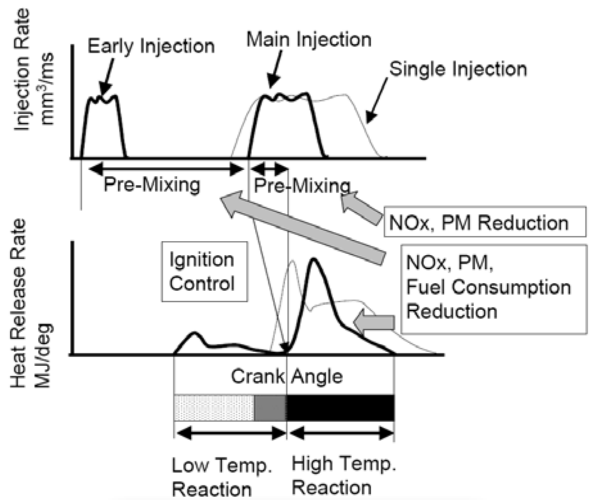
Multiple injection

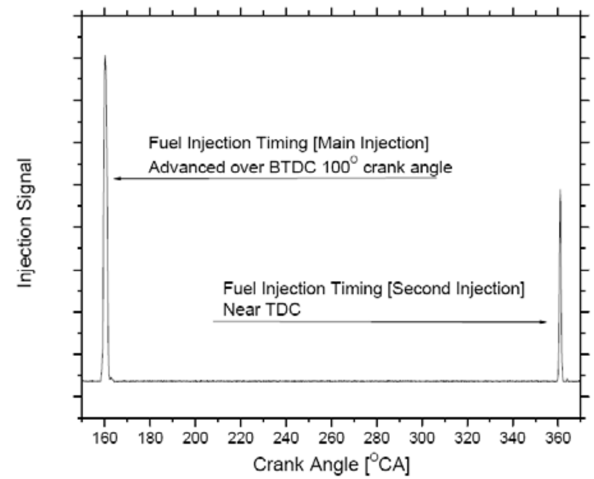
- **Very attractive way to improve the performance of diesel engine**
  ; significant improvements in emission reduction without significant increase in cost
- **Strong sensitivity of engine performance to the injection parameters**

Good knowledge of some basic phenomena
& D/B of the experimental results are needed
for engine optimization

Backgrounds







MULDIC (New ACE, 1998)

UNIBUS (Toyota, 2000)

2 stage Inj. (C. Bae, 2004)

- **Extremely early 1st injection to create premixed charge**
- **Retarded 2nd injection to form charge stratification for combustion phase control and performance improvement**

➔ Reduced smoke as well as NOx **with** improved fuel consumption **to level of the conventional diesel.**

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Objective

HCCI engine combustion

Dimethyl-ether

Low carbon alternative fuel for Diesel

2-stage injection

Fuel injection strategy to improve efficiency and reduce exhaust emissions

To improve the performance of HCCI combustion and reduce the HC and CO emissions with 2-stage injection strategy

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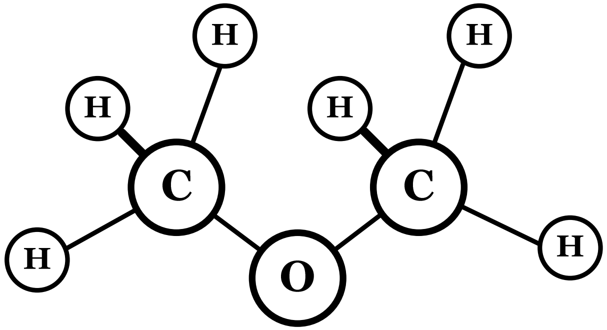
Fuel: Dimethyl-ether, DME



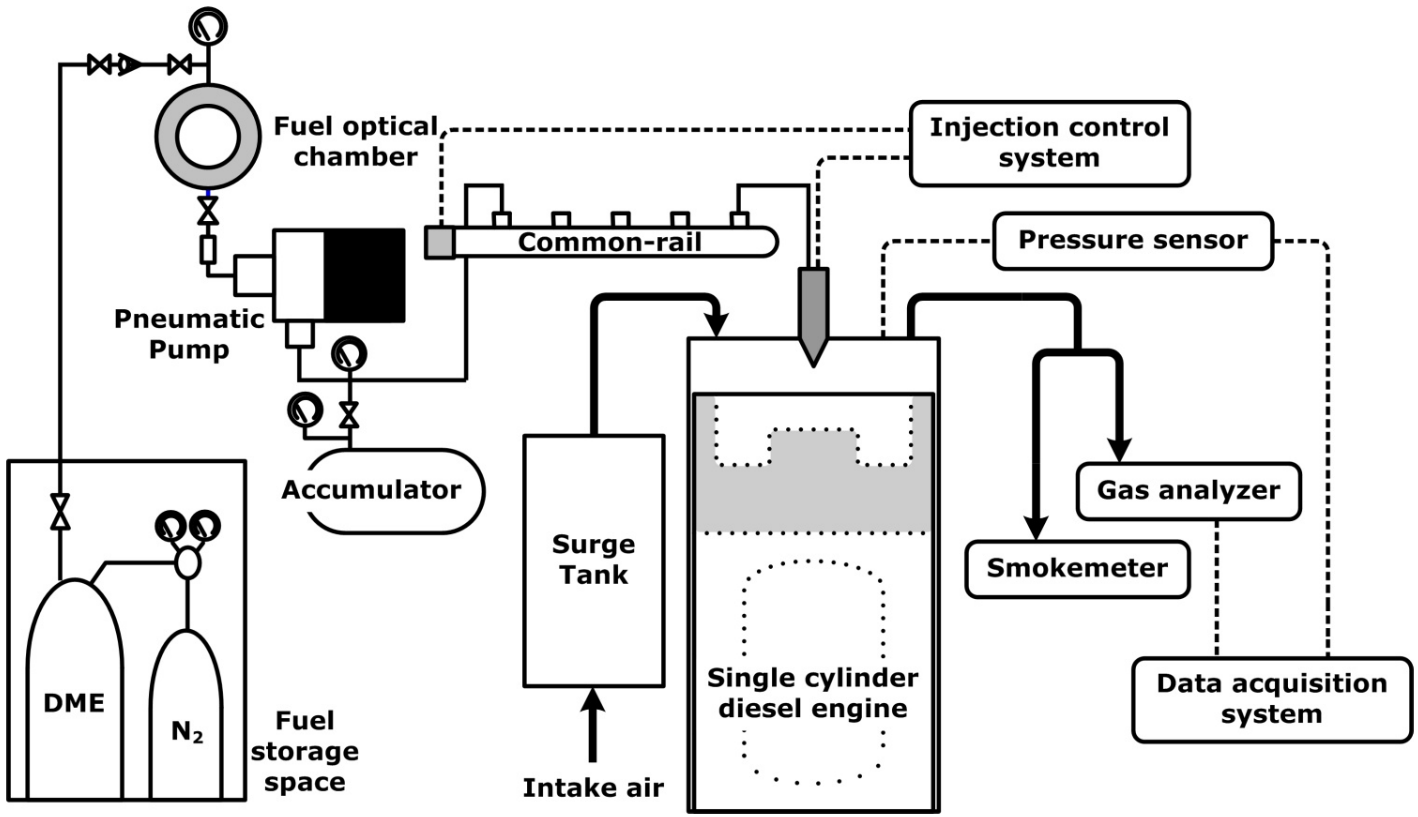
DME, CH_3OCH_3

- 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 ($\times10^8$ 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

Test Engine



Engine type	Single cylinder direct injection
Displacement	498 cc
Bore x Stroke	83 x 92 mm
Compression ratio	14.8
Fuel injection type	Common-rail injection system

Operating Conditions

	Engine operating conditions
Fuel	DME (with lubricity additive, 500 ppm)
Engine speed	1200 rpm
Injection pressure	30 MPa
Load	0.2 MPa IMEP
Intake air temperature	30□
Coolant temperature	80□

Operating Conditions

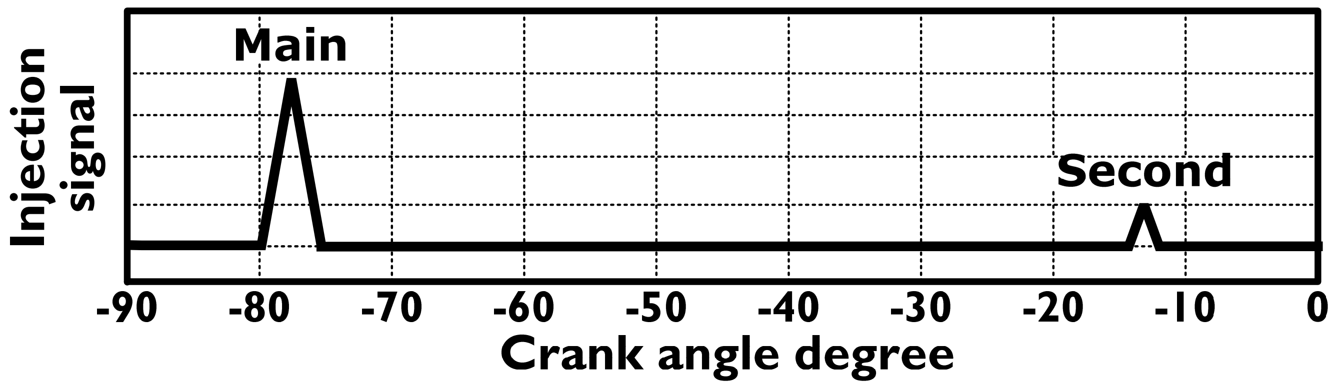
Injection timing and quantity

Injected fuel quantity

Main injection	Adjusted to the fixed load 0.2 MPa IMEP
Second injection	0 / 1 / 3 / 5 mg

Injection timing

Main injection	-80 CAD
Second injection	-19 CAD
	-16 CAD
	-14 CAD
	-11 CAD
	-5 CAD
	0 CAD (TDC)



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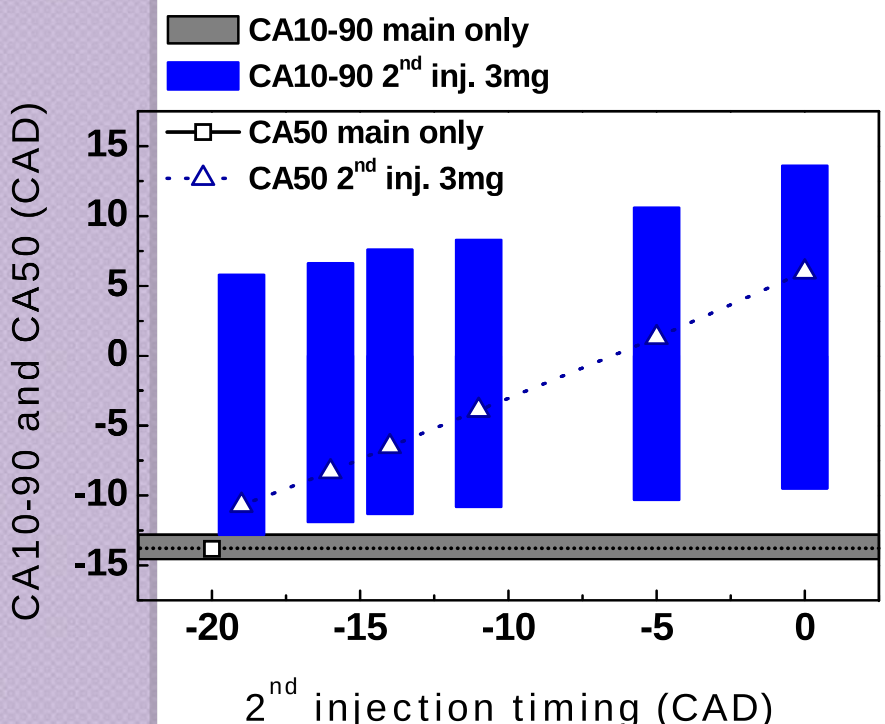
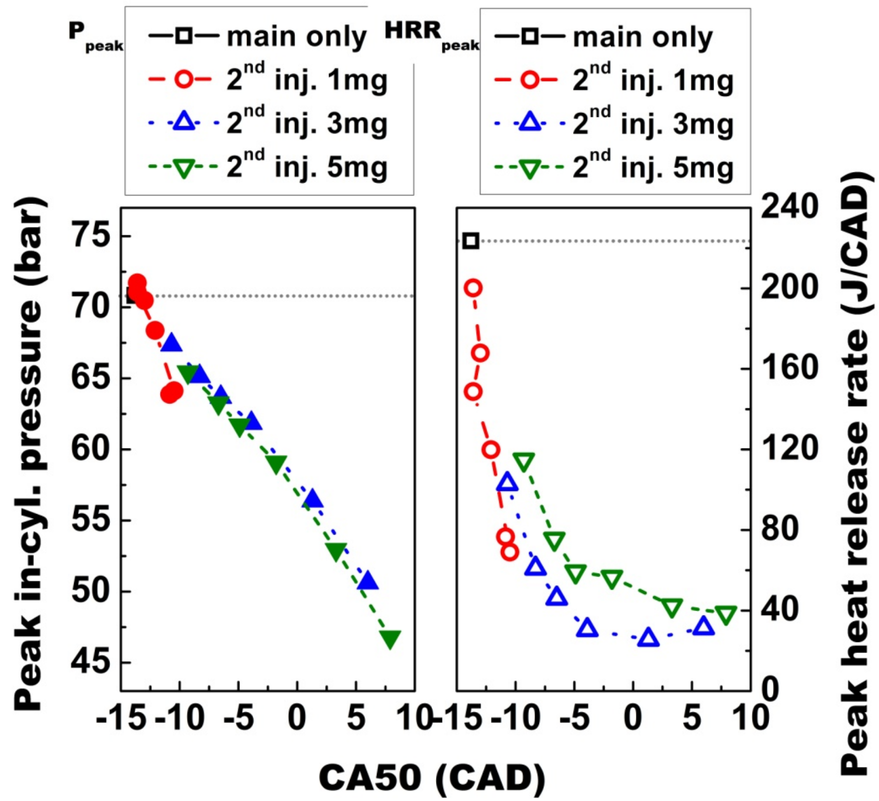
Effect of 2nd inj. on Combustion Phase

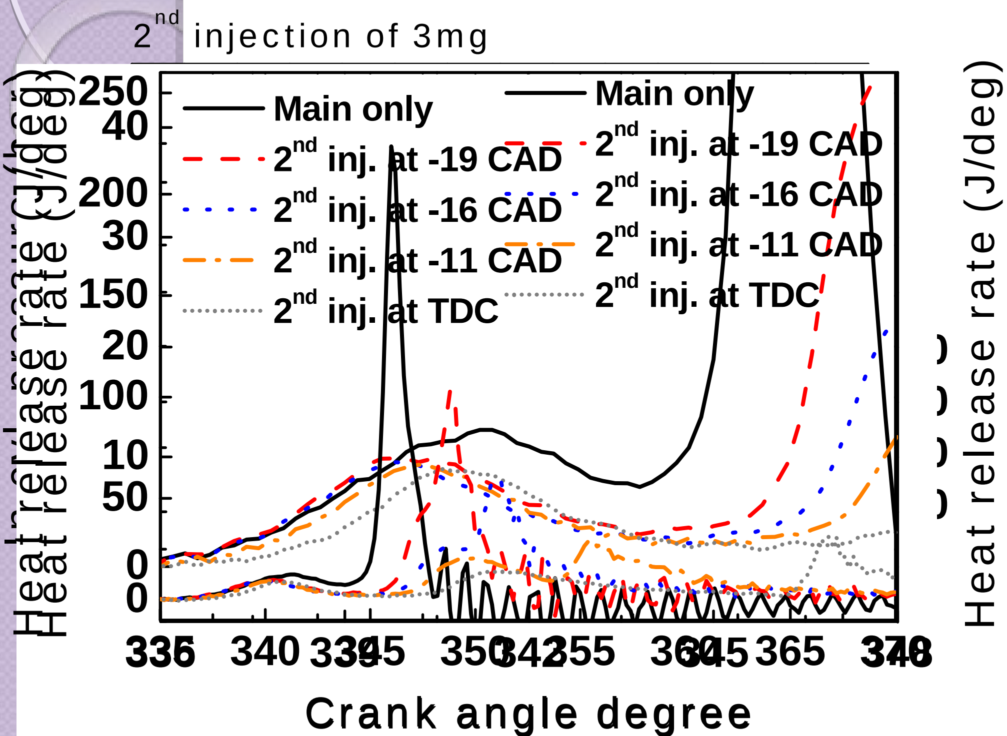
- **Combustion phase was retarded and burn duration was lengthened.**
- **Decrease of maximum in-cylinder pressure and peak heat release rate.**
- **Late 2nd injection → Combustion phase retard → Reduction of Negative work**
  → Increase the fuel conversion efficiency
  → Decrease the fuel consumption for fixed IMEP (0.2 MPa)
  → Reduction of premixed mixture concentration

➔ The effects of 2nd injection became more prominent with the retarded and increased second injection.





Effect of 2nd inj. on Combustion Phase



- Decrease of maximum pressure rise rate and in-cylinder pressure.
- Retard and decrease of HRR

with second injection

Decrease of premixed charge concentration

Reduction of heat release of LTR

- Decrement ≈ 1 J/CAD
- Start of LTR retard ≈ 1 CAD

→ Very small difference in LTR, but sufficient to change the HTR phase.

Delayed and lengthened HTR

More homogeneous and leaner premixed mixture can be formed

Decrease of heat release of HTR

N = 1200 rpm
P_{inj} = 30 MPa
Main injection timing = - 80 CAD
2nd injection timing = -19 ~ 0 CAD
2nd injection quantity = 3 mg

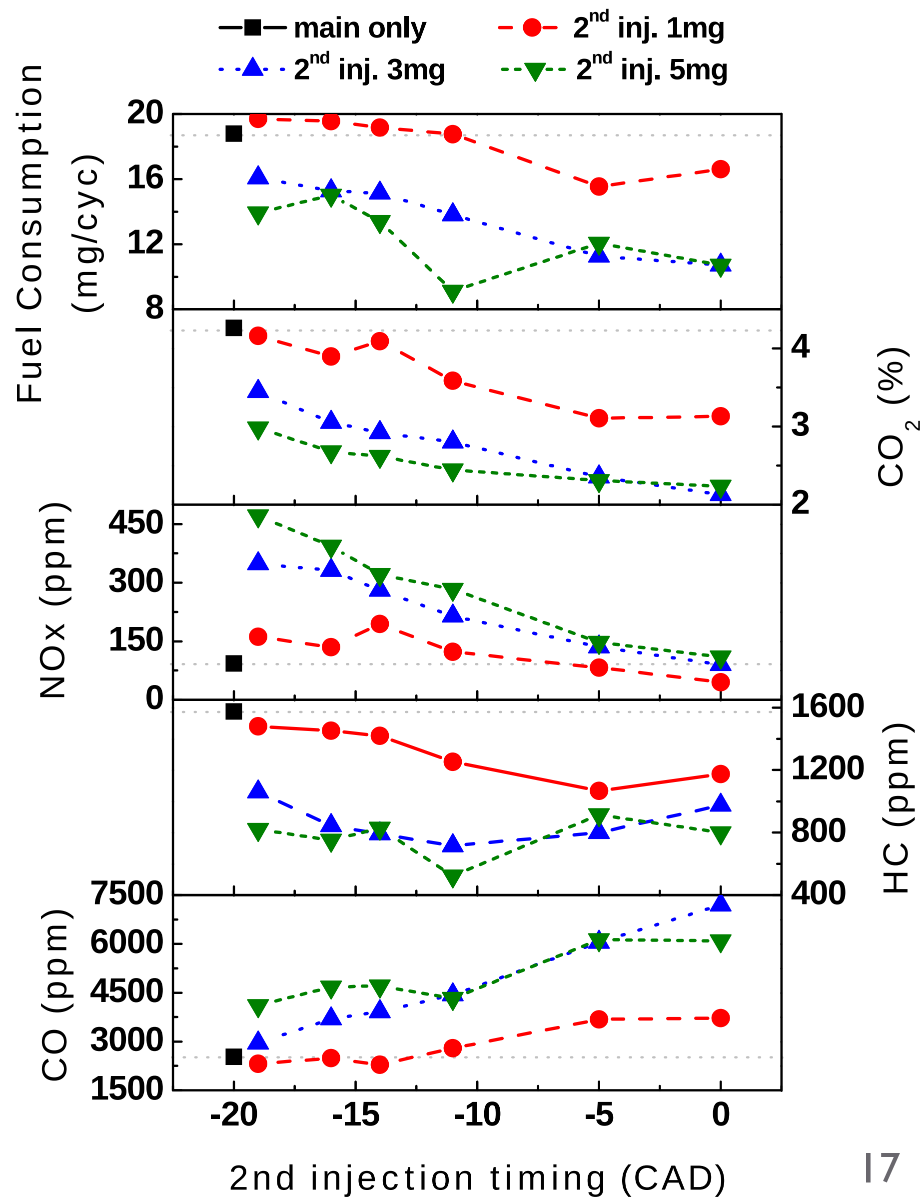
Effect of 2nd inj. on Emissions

With second injection,

Fuel consumption
CO_2 emission
HC emission
} Decreased

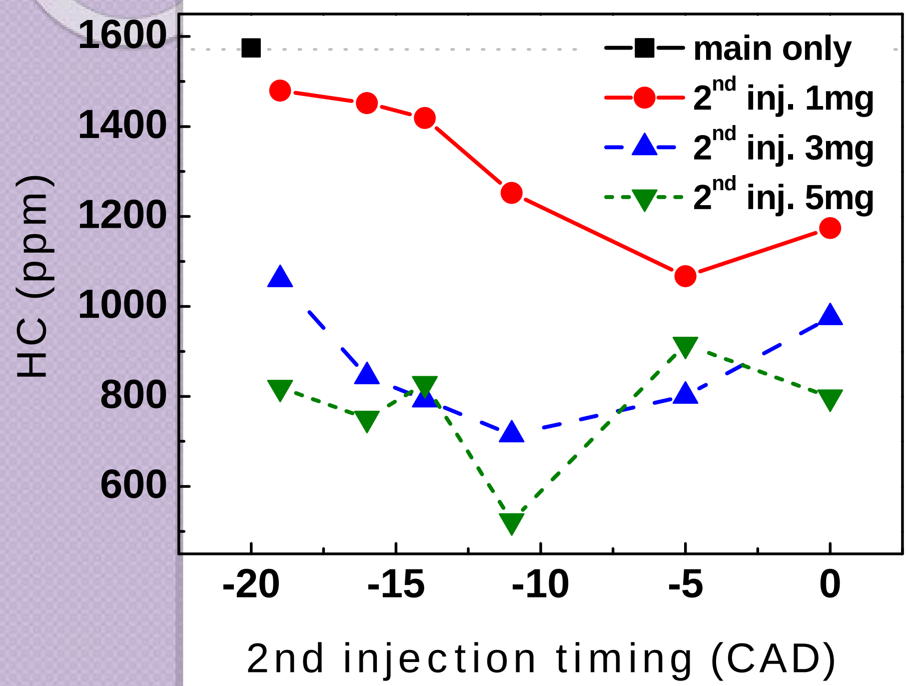
CO emission
NOx emission
} Increased

compared to HCCI combustion w/o second injection



Effect of 2nd inj. on Emissions

Reduction of HC emission



Decrease of premixed charge concentration

↓

Decrease of fuel portion near cylinder wall & crevice volume

2nd injection at late timing

↓

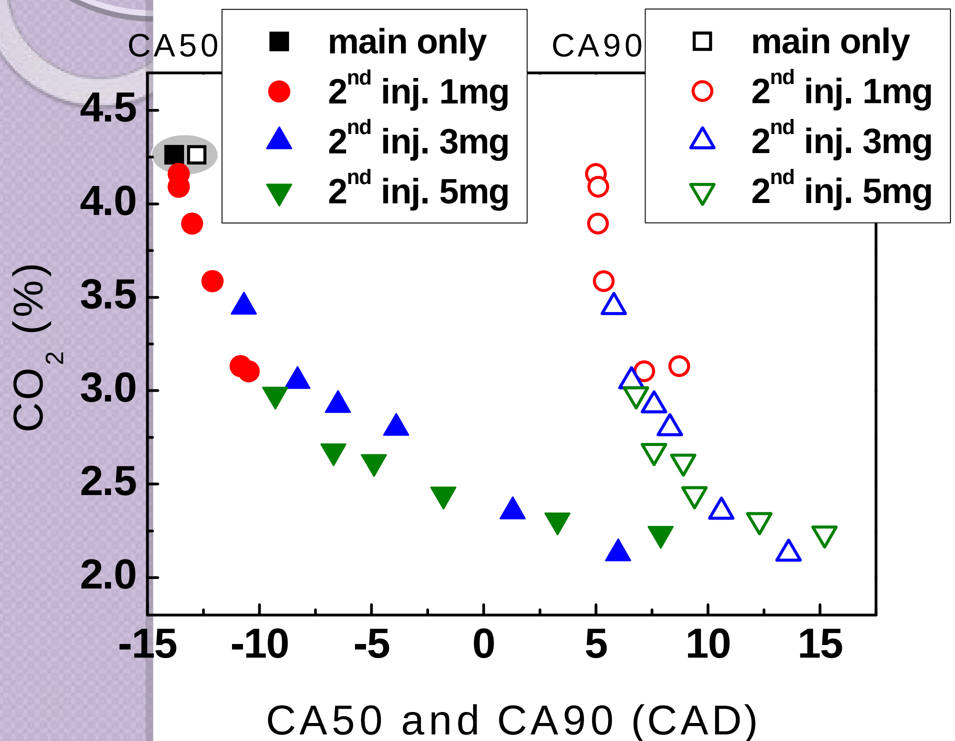
Helped to burn unburned HC from premixed combustion

↓

Reduction of HC emission

Effect of 2nd inj. on Emissions

Reduction of CO_2 emission



with second injection

Combustion phase was retarded & Burn duration was lengthened

Decrease of negative work during compression stroke

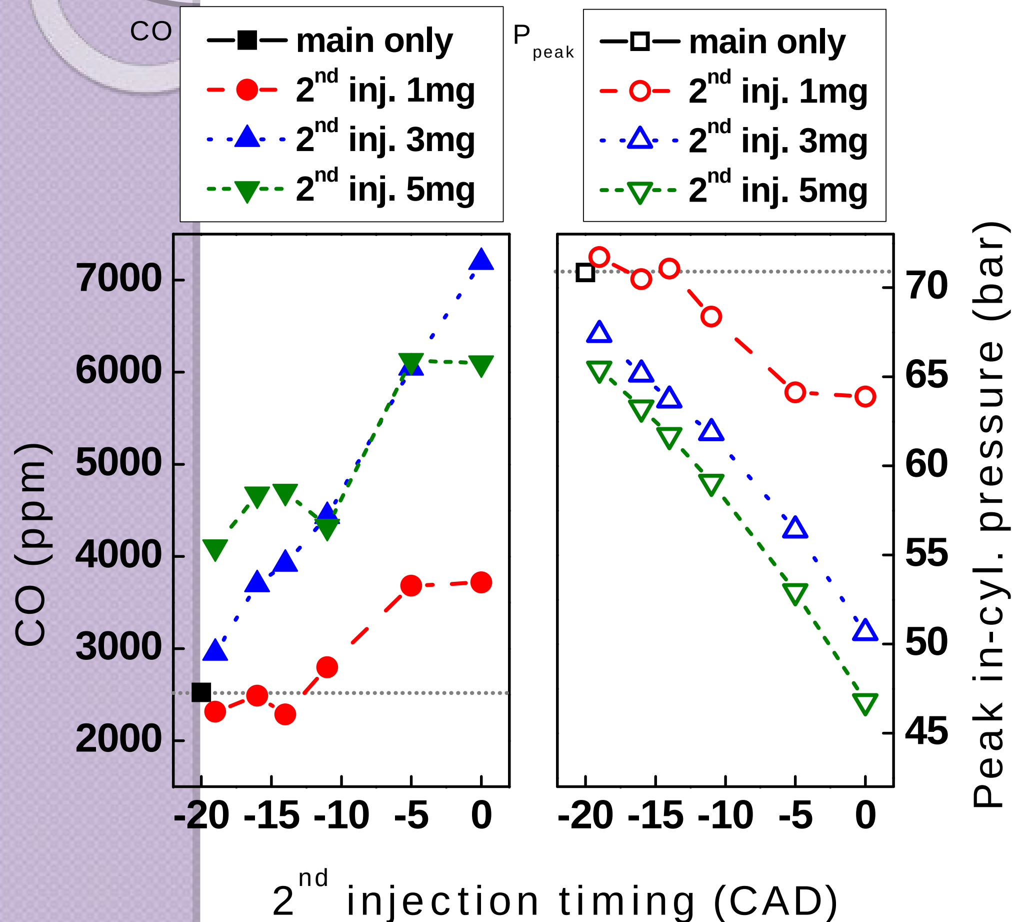
Reduction of fuel consumption

- **Supplied total carbon was decreased.**

→ CO_2 emissions was reduced.

Effect of 2nd inj. on Emissions

CO emission increment



with second injection

Reduction of in-cylinder pressure

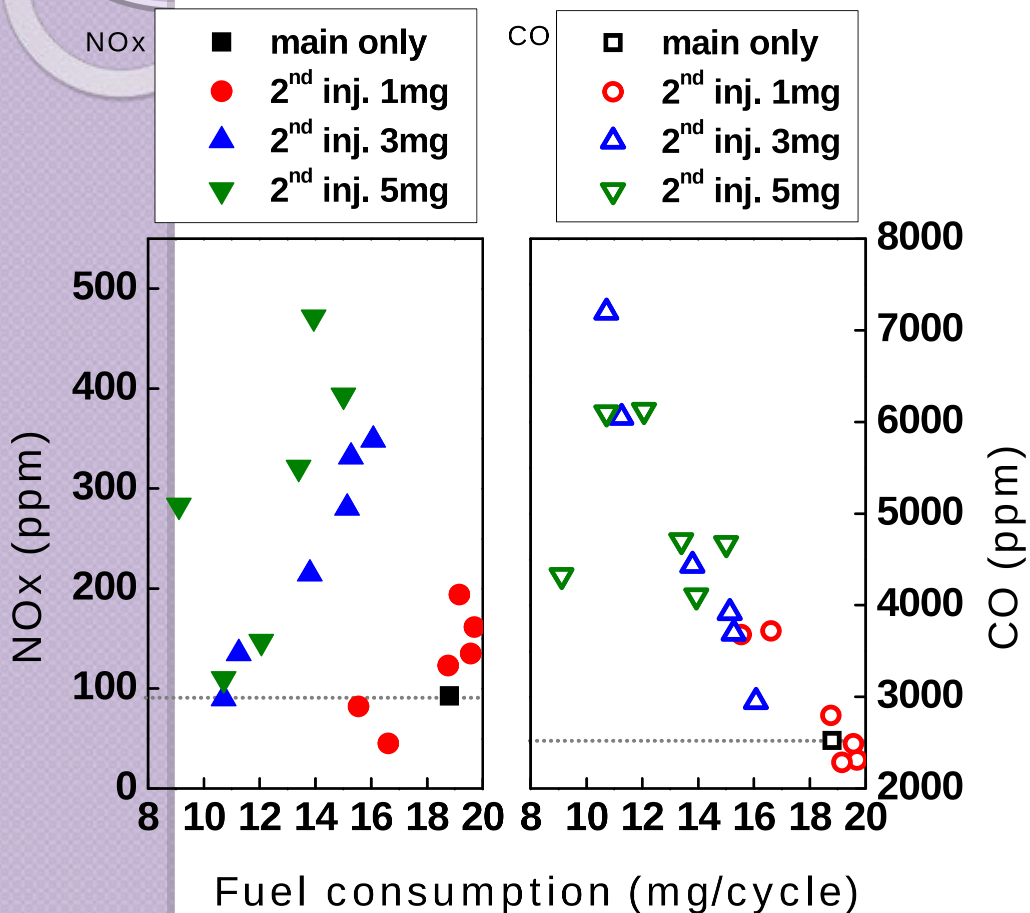
Drop in the bulk gas temperature less than the CO oxidation condition (1500K, Iida, *et al.***)**

Suppress of CO oxidation

➔ CO emission increased as in-cyl. pressure decreased.

Effect of 2nd inj. on Emissions

NOx and CO emissions vs. Fuel consumption



With 2nd injection, NOx and CO increased, but showed opposite trend to 2nd injection timing and fuel consumption.

For late 2nd injection timing

NOx was decreased with CO_2 by longer ignition delay of 2nd injected fuel.	CO was increased with decreased in-cylinder pressure.

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Summary

- **Heat release rate and pressure rise rate was reduced with second injection. Decreased premixed charge concentration lowered the heat release from low temperature reaction and high temperature reaction in HCCI combustion.**

- **The increased heat release after TDC contributed to power stroke, and reduced CO_2 emission by fuel consumption reduction.**

- **As the combustion phase delayed and burn duration was lengthened, the portion of heat release after TDC increased, and pressure rise rate was reduced.**

- **Fuel consumption and HC / CO_2 emissions were reduced with second injection. However, NOx and CO emissions were increased.**

On the emission reduction side, CO emissions can be oxidized by catalyst,

The second injection could be the effective way for emission reduction.

Thank You

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