The Effects of EGR in Hydrogen-DME PCCI Engine Combustion

IEA Combustion

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CONTENTS

Introduction

Compression Ignition Engine

- High efficiency engine
- Various engine size

Compression Ignition Engine Fuels

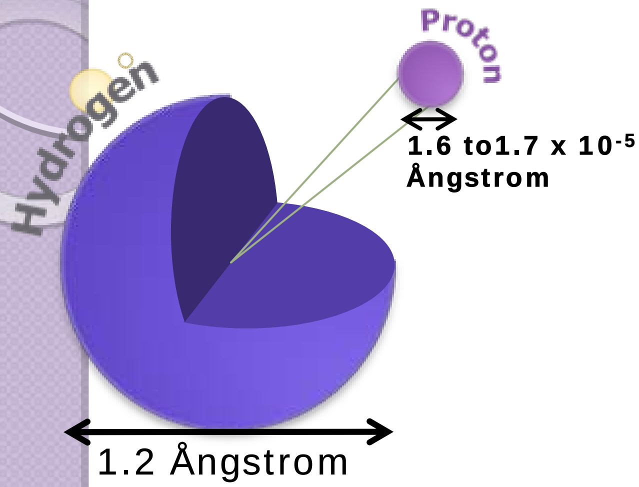
- DME
- GTL(F-T Fuel)
- Biodiesel

Hydrogen Combustion

- Clean combustion
- Unlimited resources

High efficiency and clean combustion

Hydrogen as an ICE Fuel



- Only NOx and water: clean energy source
- Small ignition energy, high octane number: Spark ignition engine
- Wide flammability limit: stable operation at lean condition

Fuel Properties at 25℃ and 1atm

Property	H_2	CNG	Gasoline
Density (kg/m^3)	0.0824	0.72	730[a]
Flammability limits (Φ)	0.1-7.1	0.4-1.6	≈0.7-7
Auto ignition temperature in air (K)	858	723	550
Minimum ignition energy (mJ)[b]	0.02	0.28	0.24
Burning velocity (ms^{-1})[b]	1.85	0.38	0.37-0.43
Adiabatic flame temperature (K)[b]	2480	2214	2580
Stoichiometric fuel/air mass ratio	0.029	0.069	0.068
Lower heating value (MJ/kg)	119.7	45.8	44.79

[a]Liquid at 0
[b]At stoichiometry

C.M. White, R.R. Steeper, A.E. Lutz
The hydrogen-fueled internal combustion engine: a technical review
International Journal of Hydrogen Energy 31 (2006) 1292-1305

Hydrogen CI Operation

High auto ignition temperature of Hydrogen

Intake temperature control

- Low minimum ignition energy: probability of backfire and knocking

High compression ratio : 22 (conventional diesel: 17~18)

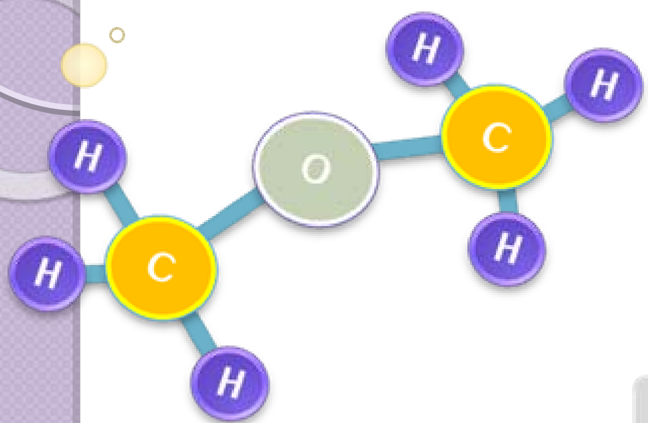
- High in-cylinder pressure
- Vibration and noise
- Engine can be damaged

High auto ignition temperature

- Impossible to operate with low compression ratio without spark source

→ **Need of ignition promoter**

DME as an Ignition Promoter



- Low auto ignition temperature
- Low boiling point
- High cetane number fuel
- Oxygenate fuel – low soot emissions

Physical Properties of DME and Diesel

	DME	Diesel	Note
Chemical structure	CH_3OCH_3	$C_nH_{1.8n}$	Oxygenated fuel
Bulk modulus (×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

DME as an Ignition Promoter

Low combustion enthalpy

27.6 MJ/kg (66% compared to diesel)

: Due to the oxygen content of the molecule

Low viscosity

Causing leakage and intensified surface wear of moving parts

Low modulus of elasticity

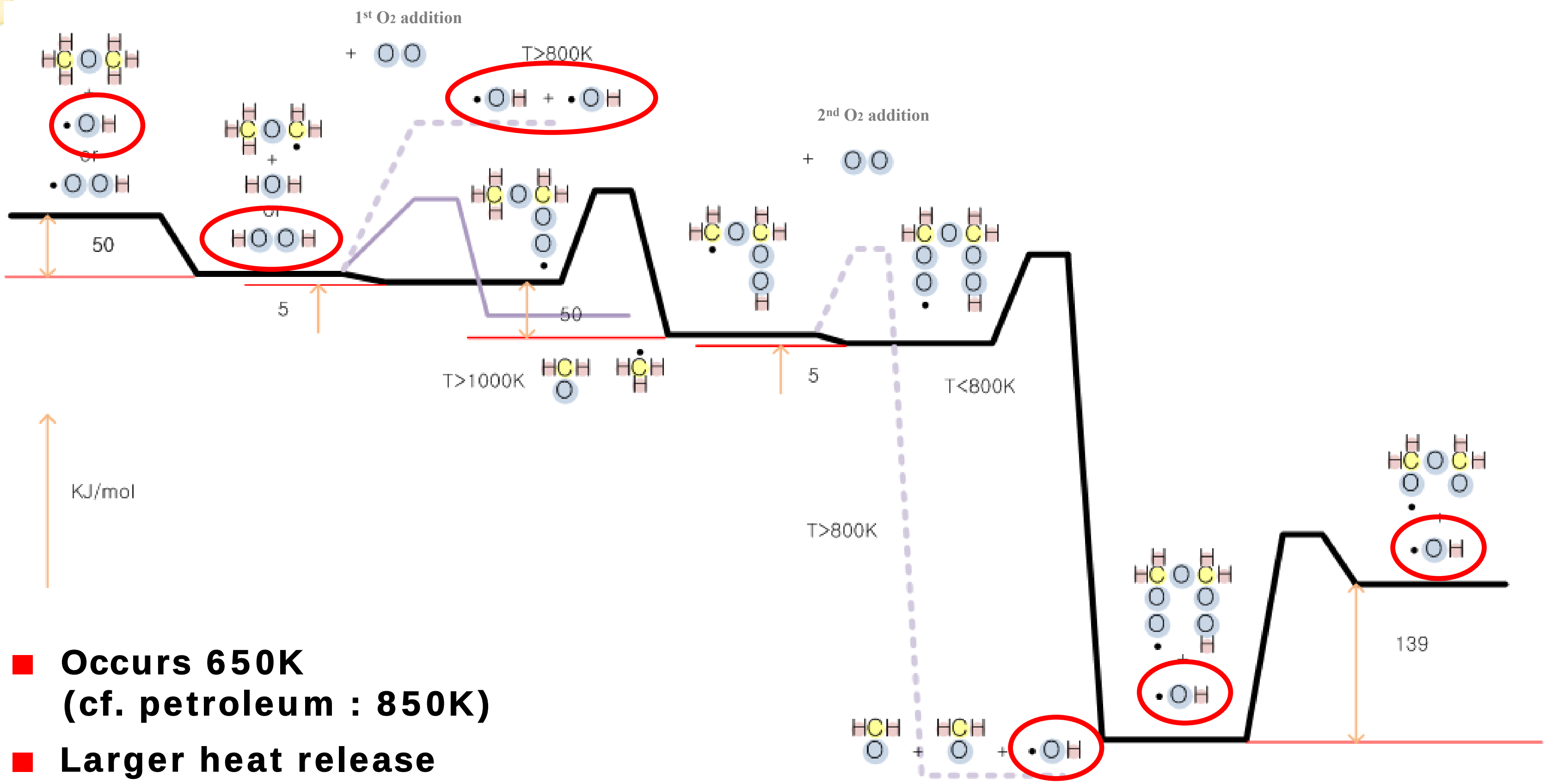
Compressibility of DME is 4 to 6 times higher than that of diesel

Rubber corrosion

Careful selection of materials is necessary to prevent deterioration of seals

Hydrogen and DME Oxidation

■ DME Low temperature reaction



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

H. Yamada, et al., 2003

HCCI Combustion

disadvantages

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

advantages

- High efficiency
- Low NOx and soot emissions
- Use various fuels

Thermal stratification

Exhaust gas recirculation

Injection strategies

Dual fuel HCCI

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Objective

Homogeneous charge + Compression ignition

Advantages

High efficiency
Low NOx and soot emissions

Disadvantages

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

Difficult to control the combustion	Control DME injection timing and quantity
High HC and CO emissions	Using H_2
Narrow operating range	EGR control

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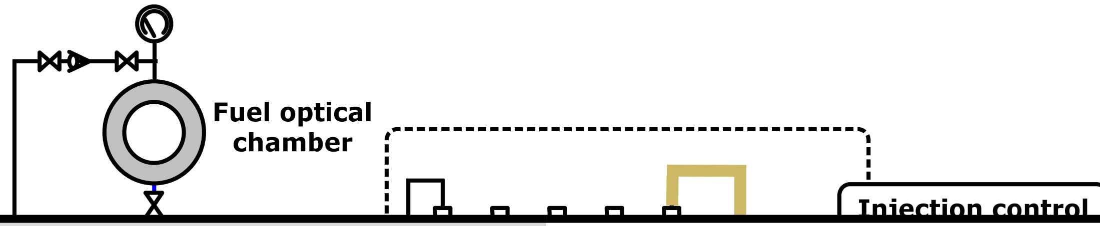
- Experimental Setup
- Results
- Conclusions

Experimental Setup



Research engine type	Single-cylinder direct injection compression ignition engine
Valves per cylinder	4 (2 intake and 2 exhaust)
Bore x Stroke	83 mm x 92 mm
Connecting rod length	145 mm
Displacement per cylinder	498 cm^3
Compression ratio	14.8:1
Intake valve timing	Open at 23 BTDC / Close at 65 ABDC
Exhaust valve timing	Open at 75 BBDC / Close at 45 ATDC

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

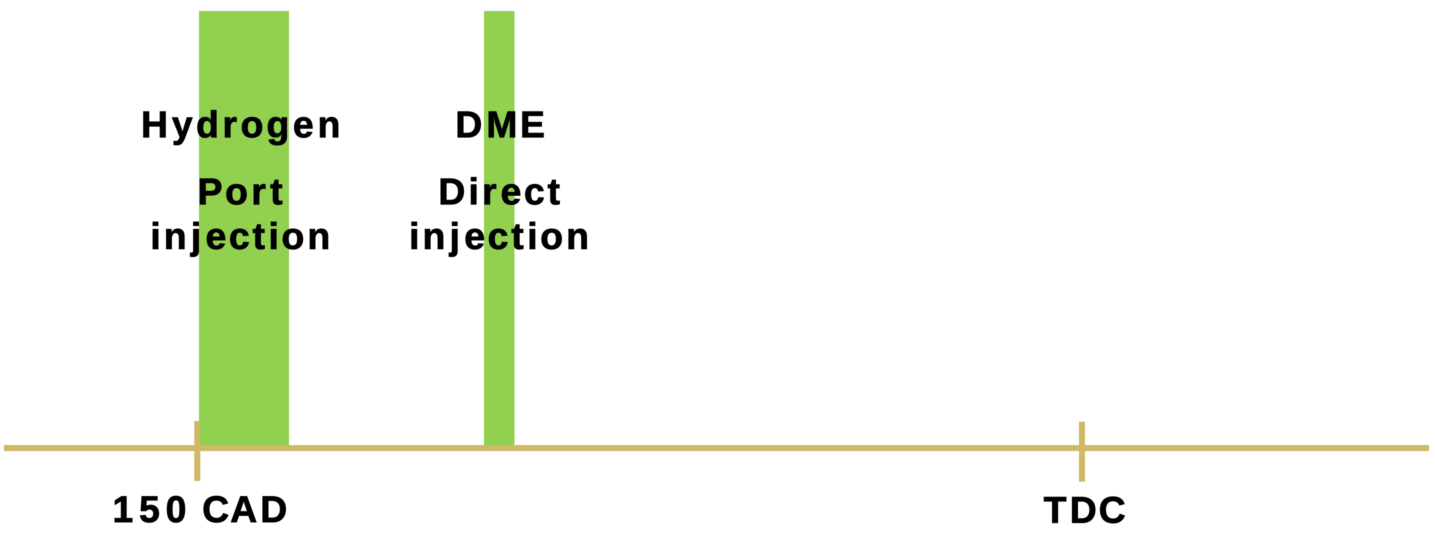
Operating Conditions

Fuel	H_2 DME(with lubricity additive, 500 ppm)	
Intake air temperature	300 ± 1 K	
Coolant temperature	353 ± 2 K	
Engine speed	1200 rpm	
EGR(O_2 percent)	20%, 18%	
Injection pressure	H_2	DME
	0.5MPa	30MPa
Injection timing	H2	DME
	150 CAD /intake TDC	240 CAD to 355 CAD

	total Q	DME Quant.(mg)	H2 Quant.(mg)
Fuel injection Q.	800	5	5.5
	1000	5	7.2
	1200	5	8.9
	800	7	5.0
	1000	7	6.7
	1200	7	8.4
	800	9	4.6
	1000	9	6.2
	1200	9	7.9

Fuel Injection Timing

- **Premixed / Direct injected HCCI combustion**
  - **Port injection: main fuel supply, create homogeneous charge**
  - **Direct injection: Controlling HCCI combustion (make locally fuel rich region)**
  - **Charge stratification: altering the ratio of direct injected fuel to fuel supplied to the intake system / retarding direct injection timing**



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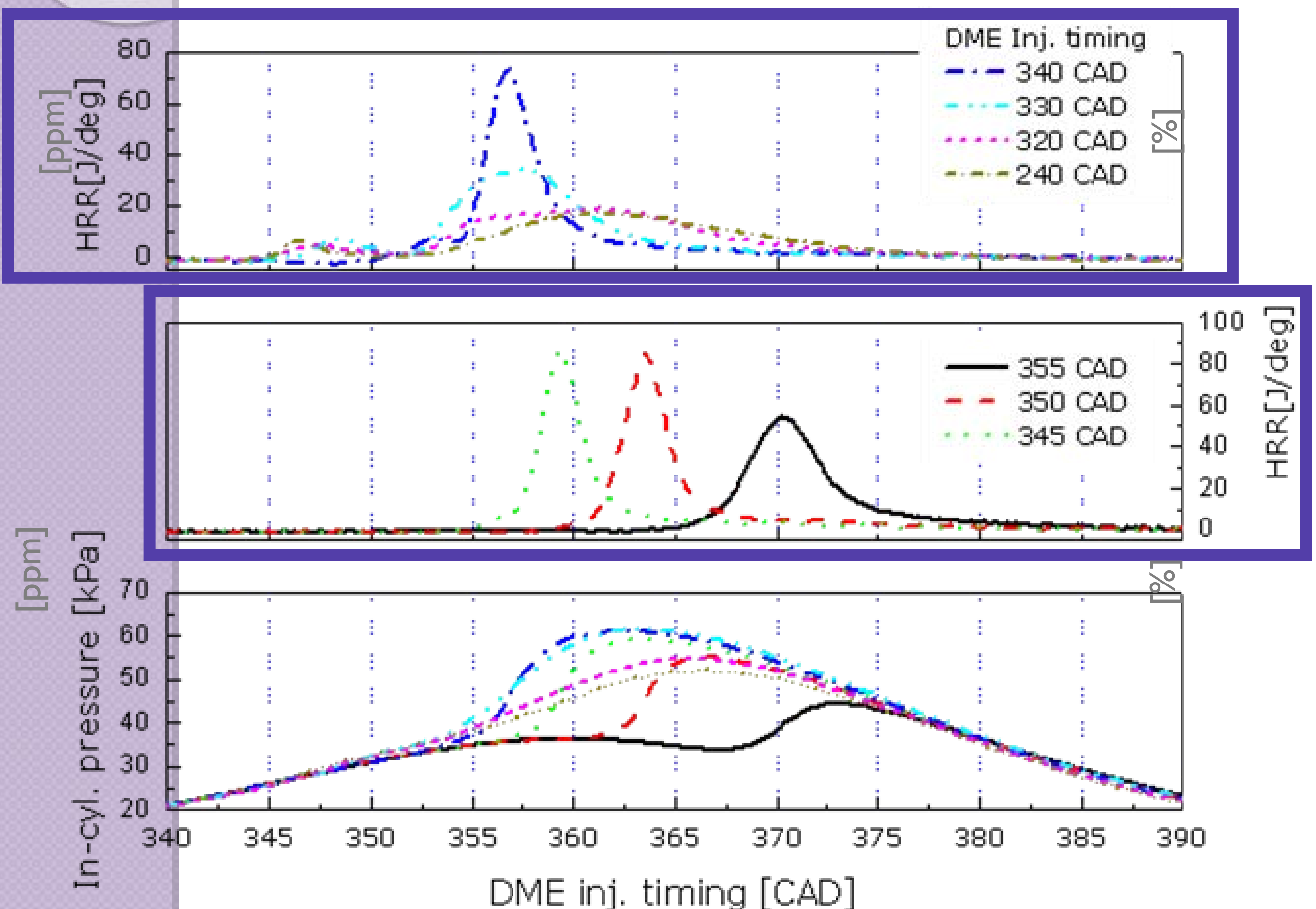
DME Injection Timing Effects
-Indicated mean effective pressure, heat release rate

Engine speed:	**1200rpm**
Fixed Q_{Fuel} :	**1000J**
Hydrogen injection quantity:	**7.9mg**
DME injection quantity:	**9mg(255J)**
H_2 injection timing :	**150 CAD**



Advanced DME injection

Leaner homogeneous charge

Intermediate species effects

Retarded DME injection

High in-cylinder pressure & Temperature

Only HTR occurs

DME Injection Timing Effects
-Exhausts

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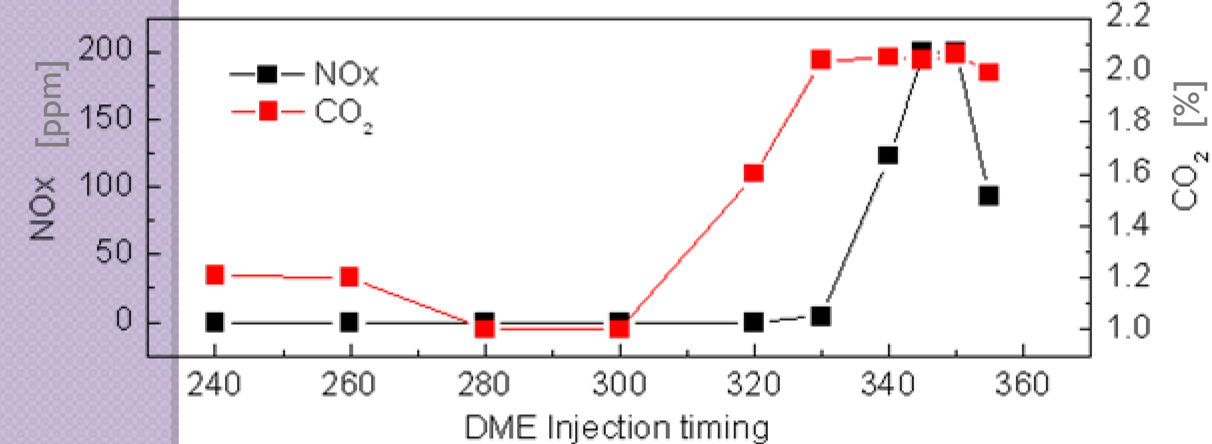

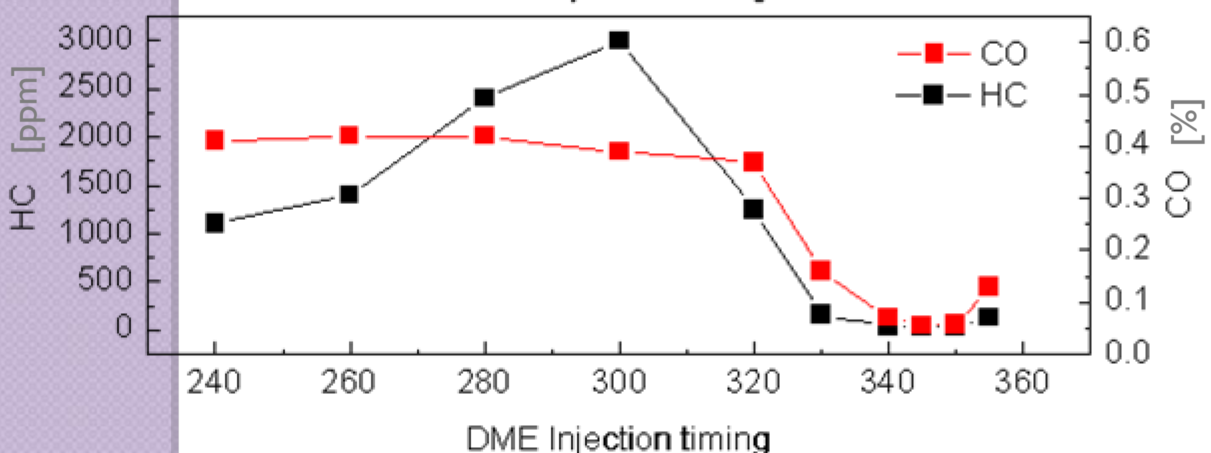

Advanced DME injection

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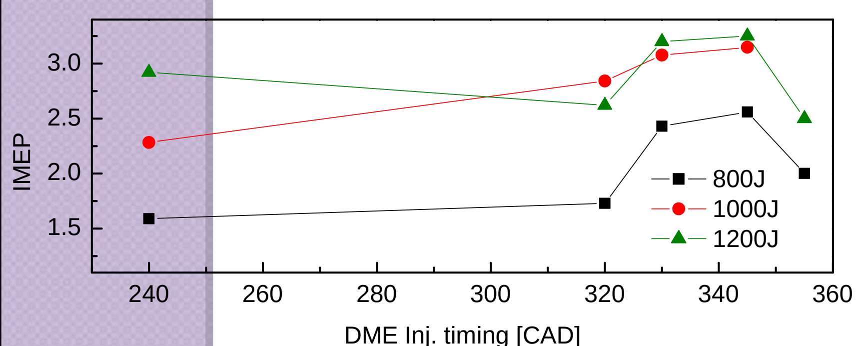
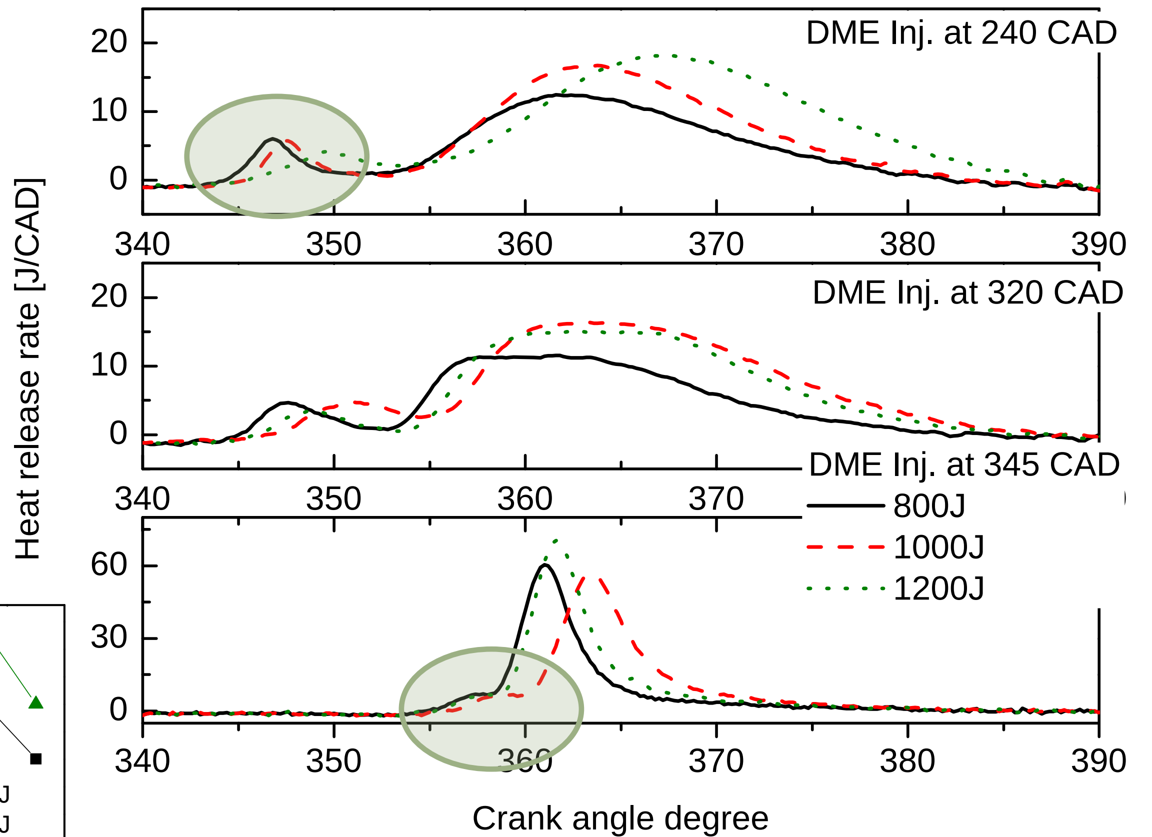
Hydrogen Effects
-Indicated mean effective pressure, heat release rate

Engine speed:	**1200rpm**	**DME injection quantity:**	**9mg(255J)**
Fixed Q_{Fuel} :	**800J/1000J/1200J**	**Oxygen ratio with EGR:**	**18%**
H_2 injection timing:	**150 CAD**		

- **with higher hydrogen quantity ratio, LTR was retarded**
- **LTR at 345CAD injection was less affected by the hydrogen ratio**

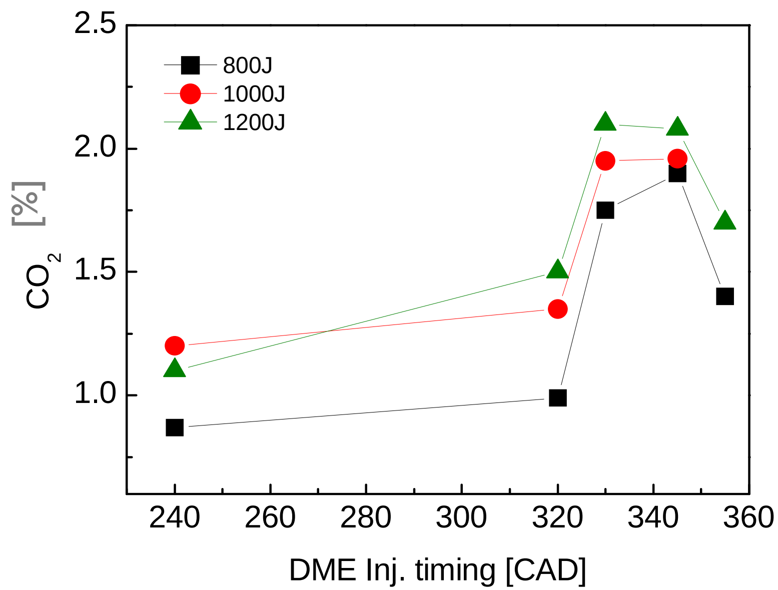
Hydrogen quantity

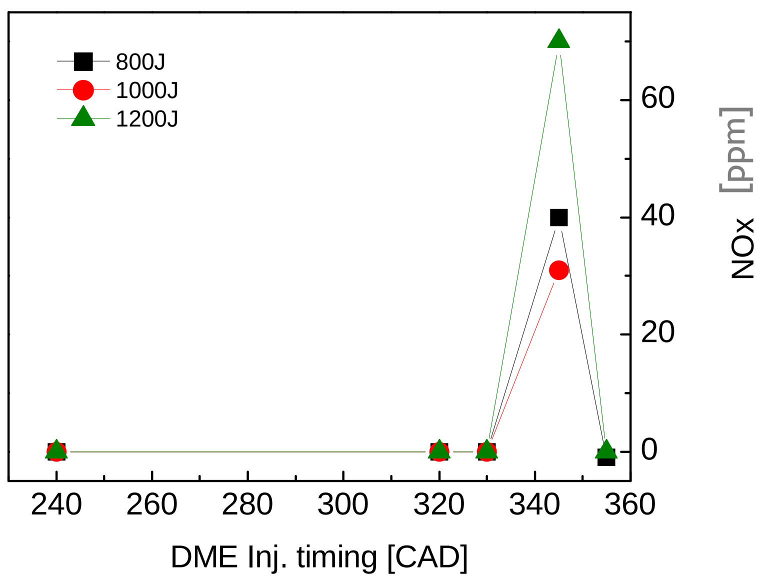




Hydrogen Effects
- Exhausts

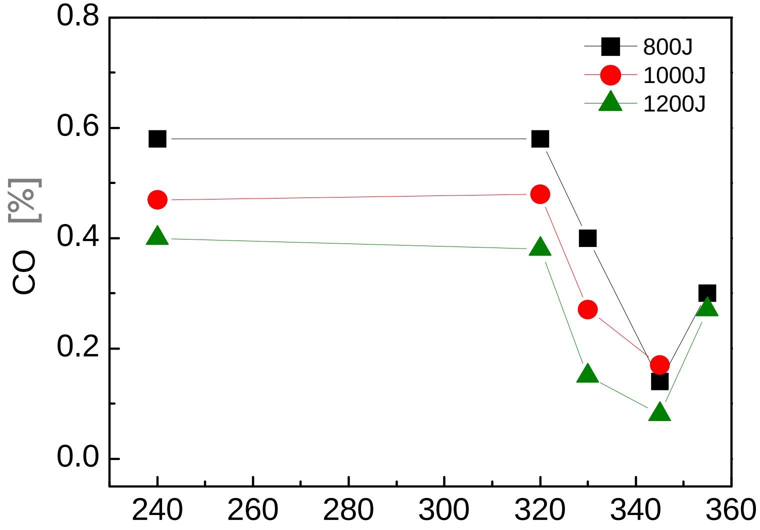
- **NOx and CO_2 emissions were increased with larger amount of hydrogen injection quantity**
  - -The hydrogen combustion assisted the DME combustion again.
  - -Higher combustion temperature created higher NOx emission and CO_2 emissions

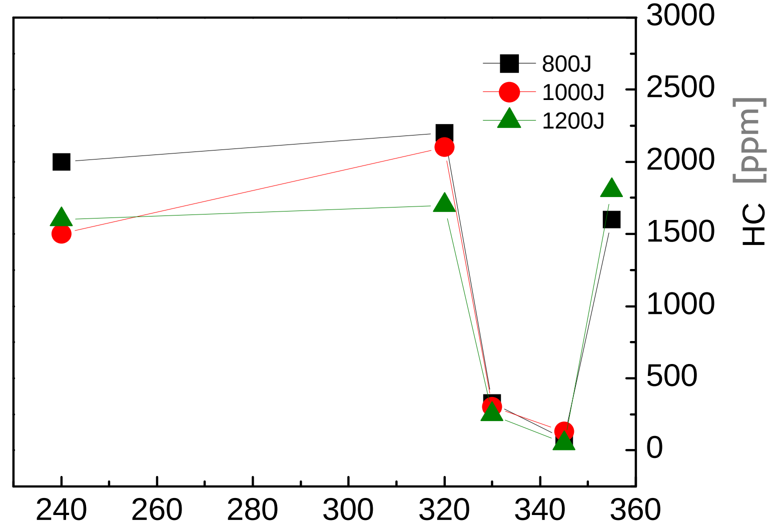




Hydrogen Effects

- Exhausts





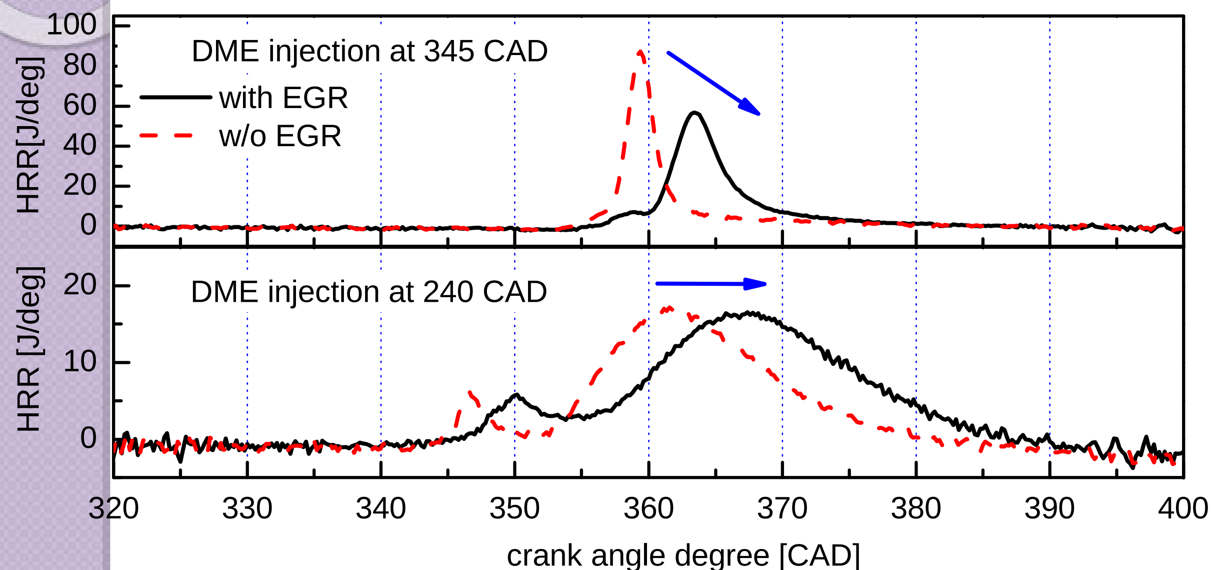
- **HC and CO emissions, as the DME injection quantity was increased, were decreased**

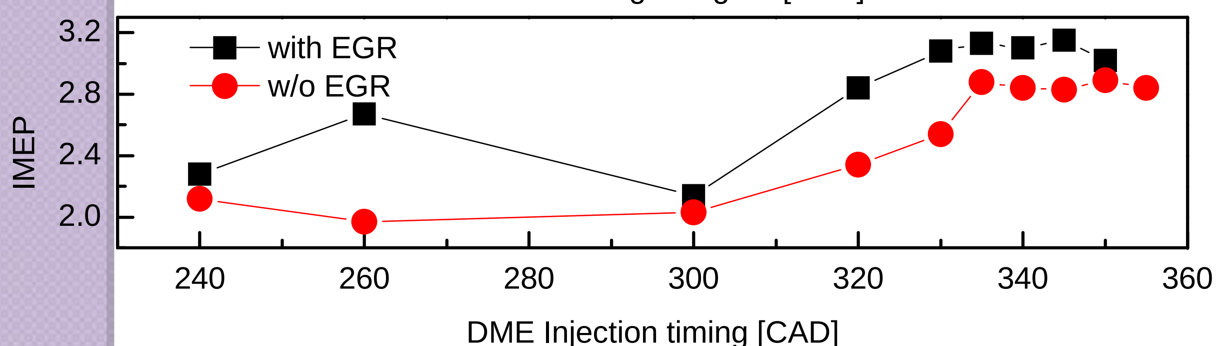
  -Higher combustion temperature created lower HC and CO emissions

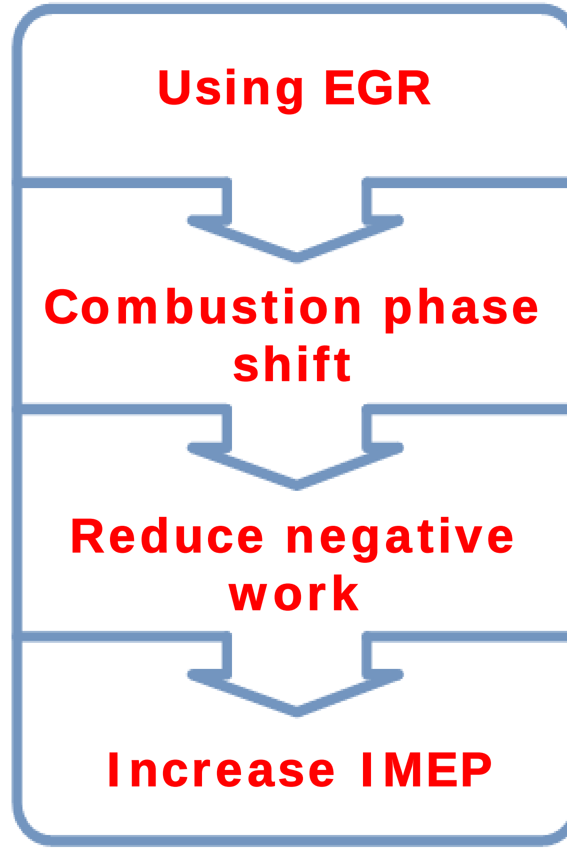
Effect of EGR

-Indicated mean effective pressure, heat release rate

Engine speed:	**1200rpm**	**DME injection quantity:**	**9mg(255J)**
Fixed QFuel :	**1000J**	**Oxygen ratio with EGR:**	**18%**
H_2 injection timing:	**150 CAD**	**EGR* rate:**	**69%**



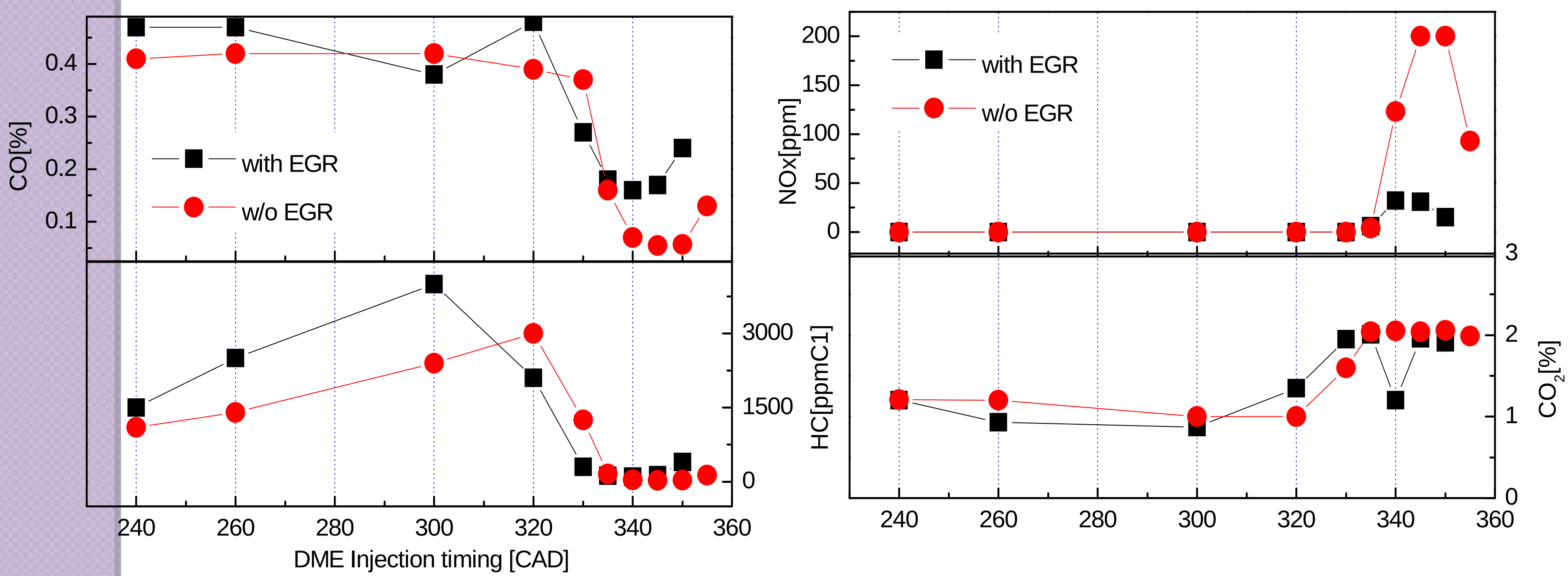




$$* \quad EGR_{O_2} = \frac{\dot{N}_{egr}}{\dot{N}_{f.air} + \dot{N}_{egr}} = \frac{[O_2]_{f.air} - [O_2]_{in,w}}{[O_2]_{f.air} - [O_2]_{egr}}$$

Effect of EGR
-Exhausts

Using EGR, IMEP increase
with small increase of CO, HC emission,
and large decrease of NOx emission



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Conclusions

This study investigated a hydrogen-fueled HCCI strategy in which DME was used as an ignition promoter in a single-cylinder CI engine

- DME injection strategy could act as an ignition promoter of hydrogen HCCI engine combustion
- Advanced injection timing of DME showed low temperature reaction. The indicated mean effective pressure(IMEP), pressure rise, and heat release rate, caused by retarded injection timing, were attributable to partially rich region that helped DME and hydrogen combustion
- Using EGR, IMEP was increased due to retarded combustion phase with small exhaust increase

Vision for a clean engine combustion;

Dual-fuel HCCI with alternative fuels

(Hydrogen; High octane-number fuel & DME; high cetane-number fuel)

Thank you for your attention.

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