# *Combustion Method of Diesel Engine Fueled with Hydrogen for High Efficiency*

30th International Energy Association Task Leaders Meeting

Department of Science and Engineering, Doshisha University

Hajime Fujimoto, Jiro SENDA, Tsukasa Hori

# Contents

# Background

## *Advantage of CI over SI on hydrogen engine*

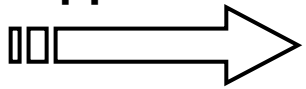
- Thermal efficiency
- Engine size range
- Power output
- Prevention with abnormal combustion

## *Auto-ignition of Hydrogen*

Higher compression ratio

➡ Not only higher mechanical loss
but also higher heat loss
as short quenching distance of hydrogen

Therefore, we propose new approach.



# Background

## Hydrogen

***Auto-ignition temperature of it is much higher than gas oil.***

⇨

***In popular compression ratio engine, it is hard to obtain auto-ignition of $H_2$.***

| | | $H_2$ | $CH_4$ | Gasoline | **Gas oil** |
|---|---|---|---|---|---|
| Minimum ignition energy (equivalence ratio $\phi$) | [mJ] | 0.02 (1.0) | 0.28 (0.9) | 0.25 ( - ) | - ( - ) |
| Adiabatic temperature | [K] | 2380 | 2275 | 2270 | 2350 |
| Flammable range (equivalence ratio $\phi$) | [vol.%] | 4 – 75 (0.1 – 7.17) | 5 – 15 (0.5 –1.7) | 1.3 – 7.1 (0.77 – 4.44) | 0.6 – 7.5 (0.56 – 7.55) |
| Auto-ignition temperature (air-fuel mixture) | [K] | **850** | 918 | 770 | **523** |
| Quenching distance | [mm] | 0.6 | - | 2 | - |
| Molecular change ratio during combustion | [-] | - 0.148 | 0 | + 0.052 | + 0.063 |

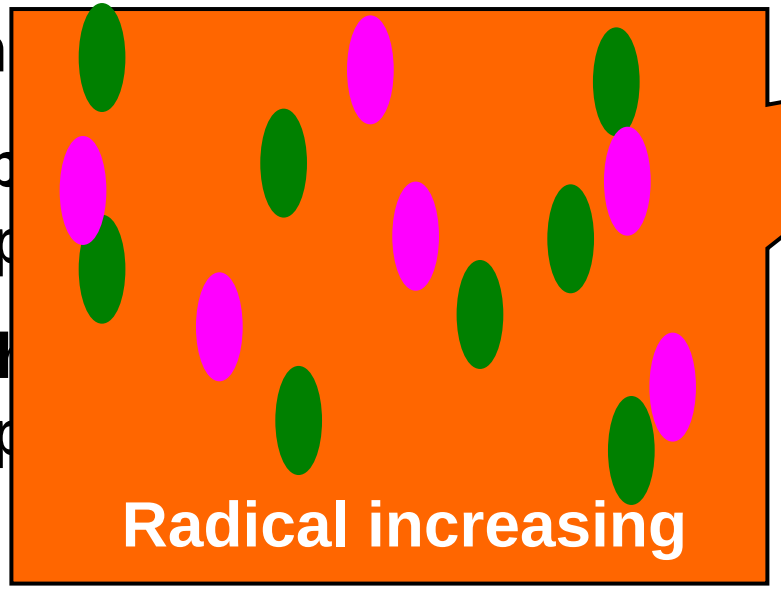
## DME as assist fuel for hydrogen combustion

**Addition DME to intake air**

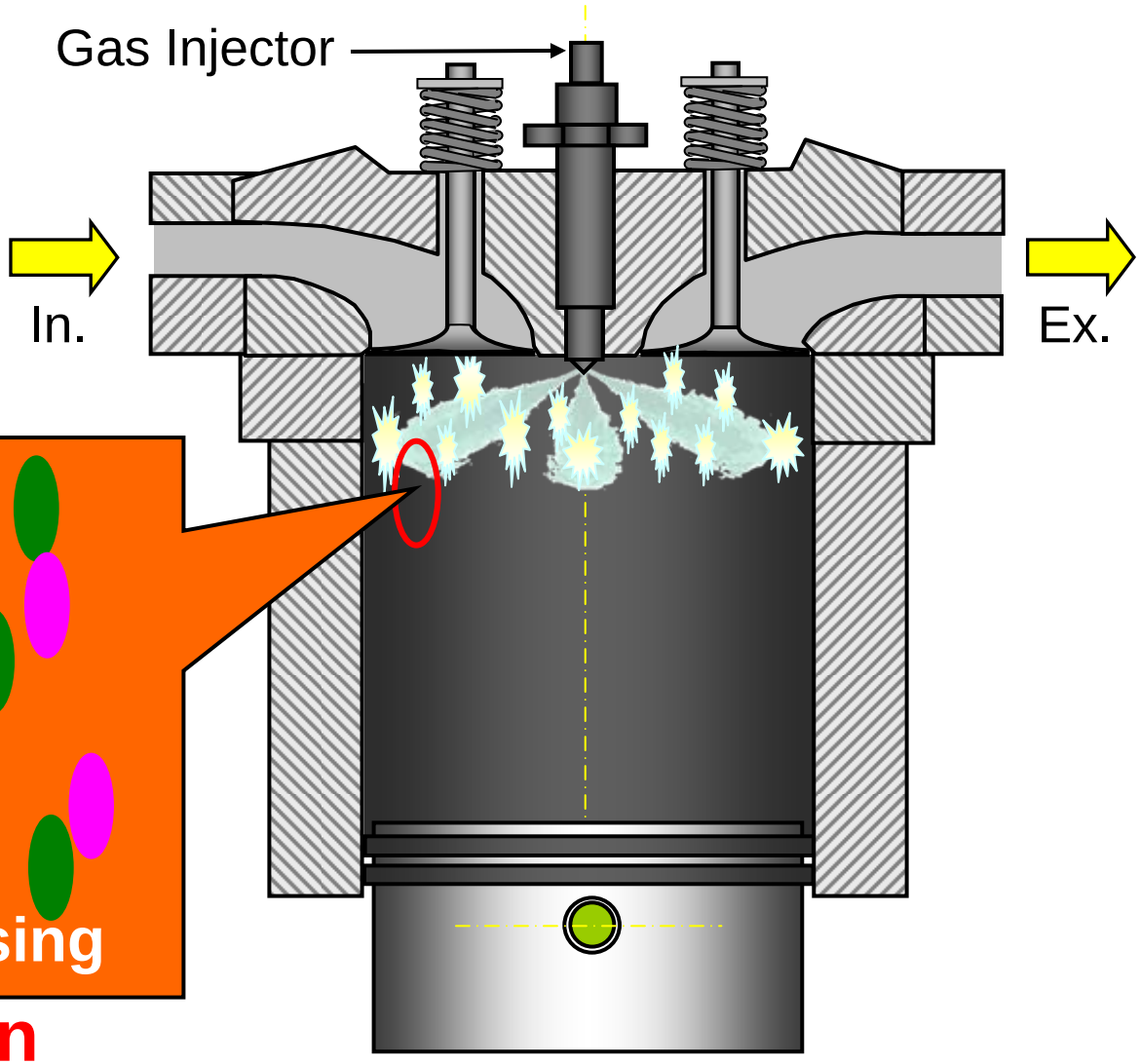
**→Heat release in com**

**→Comp temp**

**→Reach temp**




**Hydrogen combustion**



# Purpose of this study

## Purpose of this study

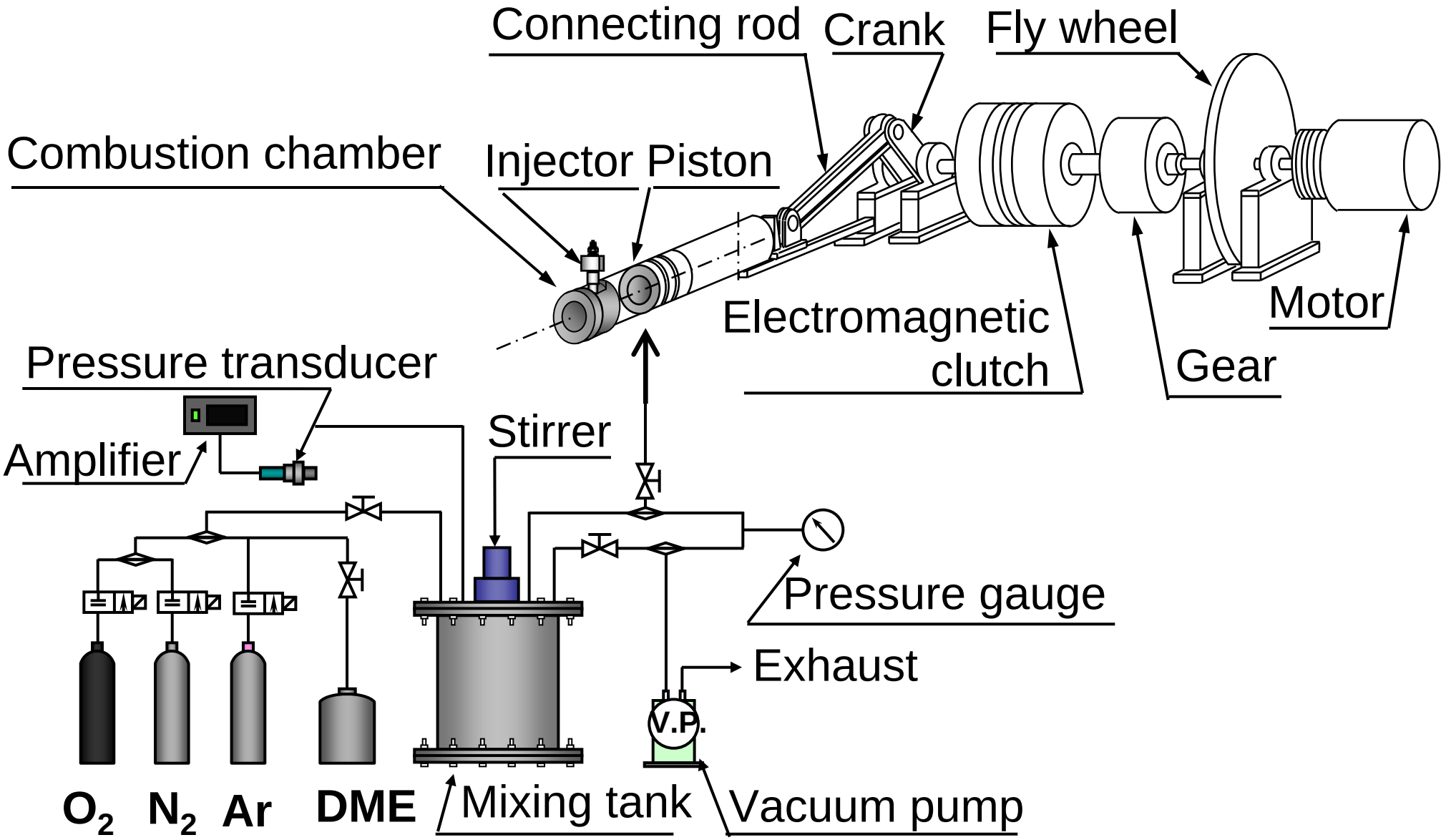
**This hydrogen ignition- assist method will make the diesel engine operation more wide and stable.**

- **To grasp the effects which DME assist method cause to the auto-ignition of hydrogen,**
- **To achieve high efficiency and low emission together,**

**The most effective hydrogen combustion methodology should be established.**

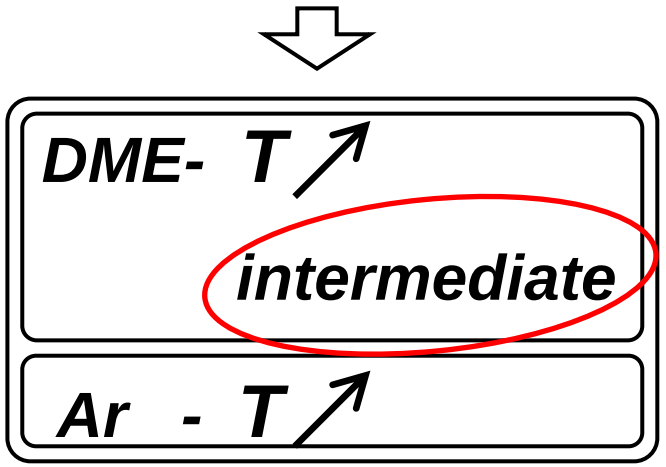
# Schematic diagram of apparatus for producing and charging premixed gas with RCEM

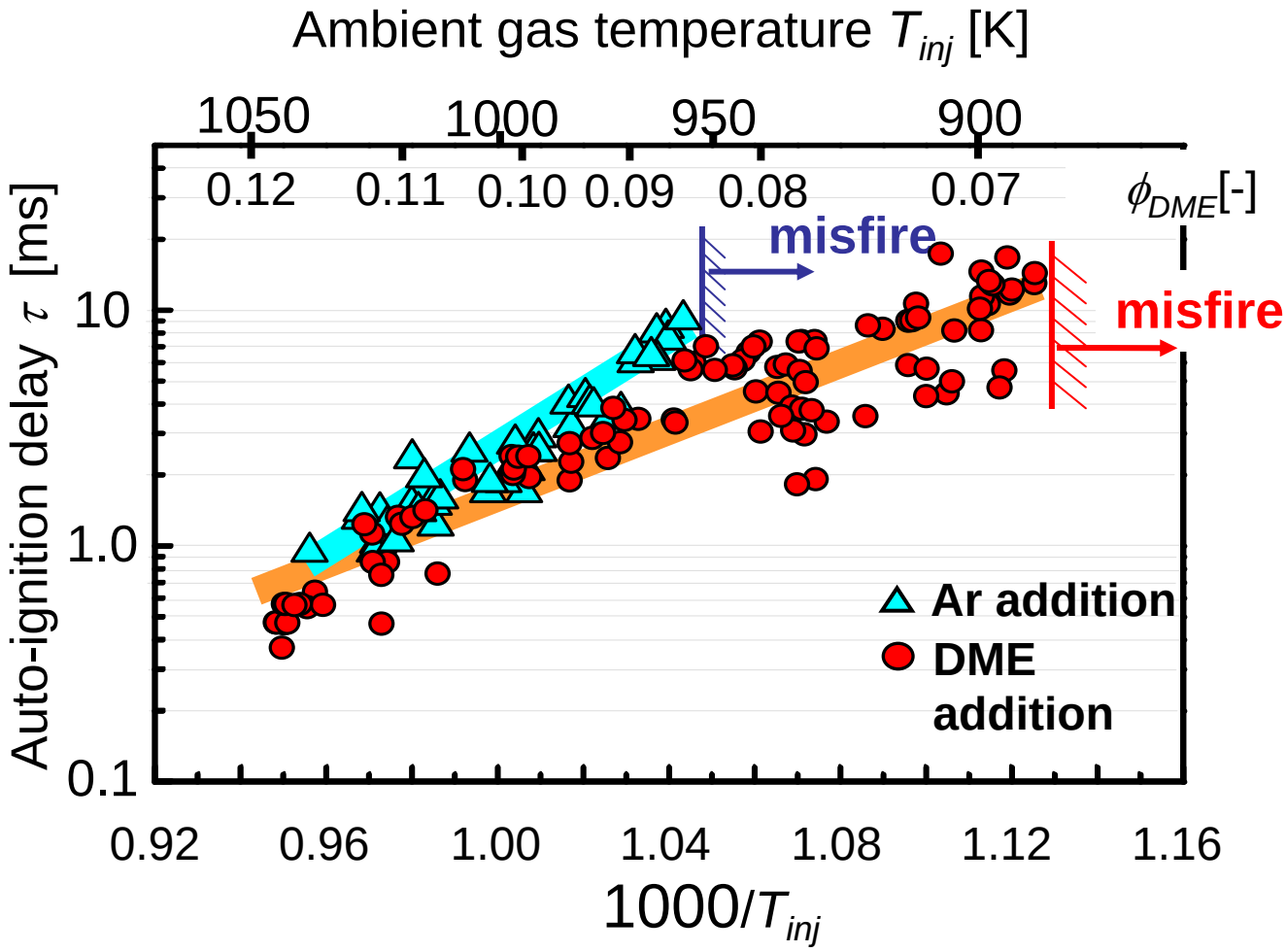




# Effect of DME ignition-assist method on auto-ignition delay of hydrogen

- DME addition
- Ar addition

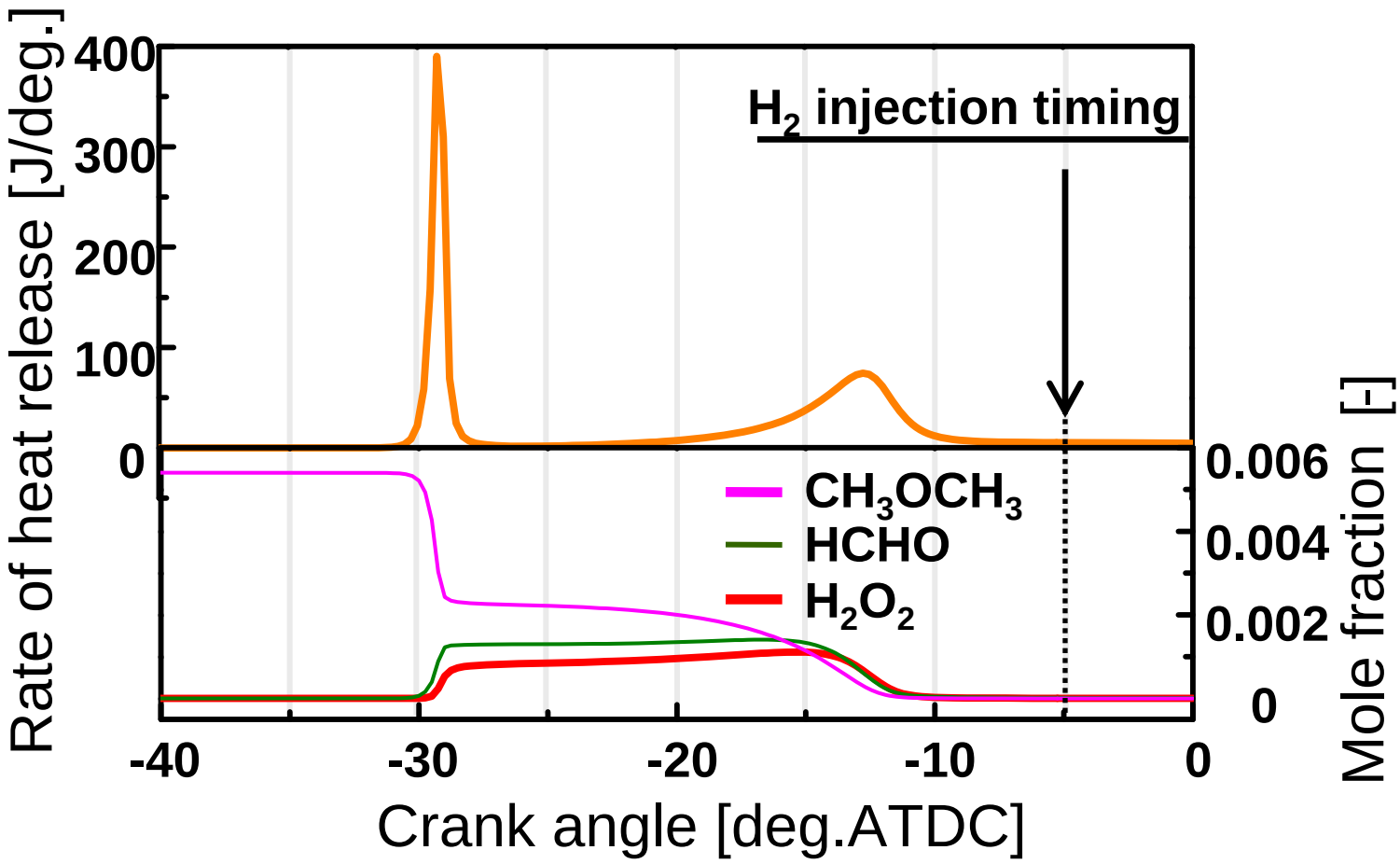



| Injected Gas | $t_{inj}$ [deg.ATDC] | $d_e$ [mm] | $p_{inj}$ [MPa] | $\rho_{inj}$ [kg/m$^3$] | $O_2$[mol/m$^3$] |
|---|---|---|---|---|---|
| $H_2$ | -5 | 0.7 | 12 | 12.6 – 15.2 | 81.8 |

# DME oxidation reaction and intermediate with numeric calculation by chemkin4.0

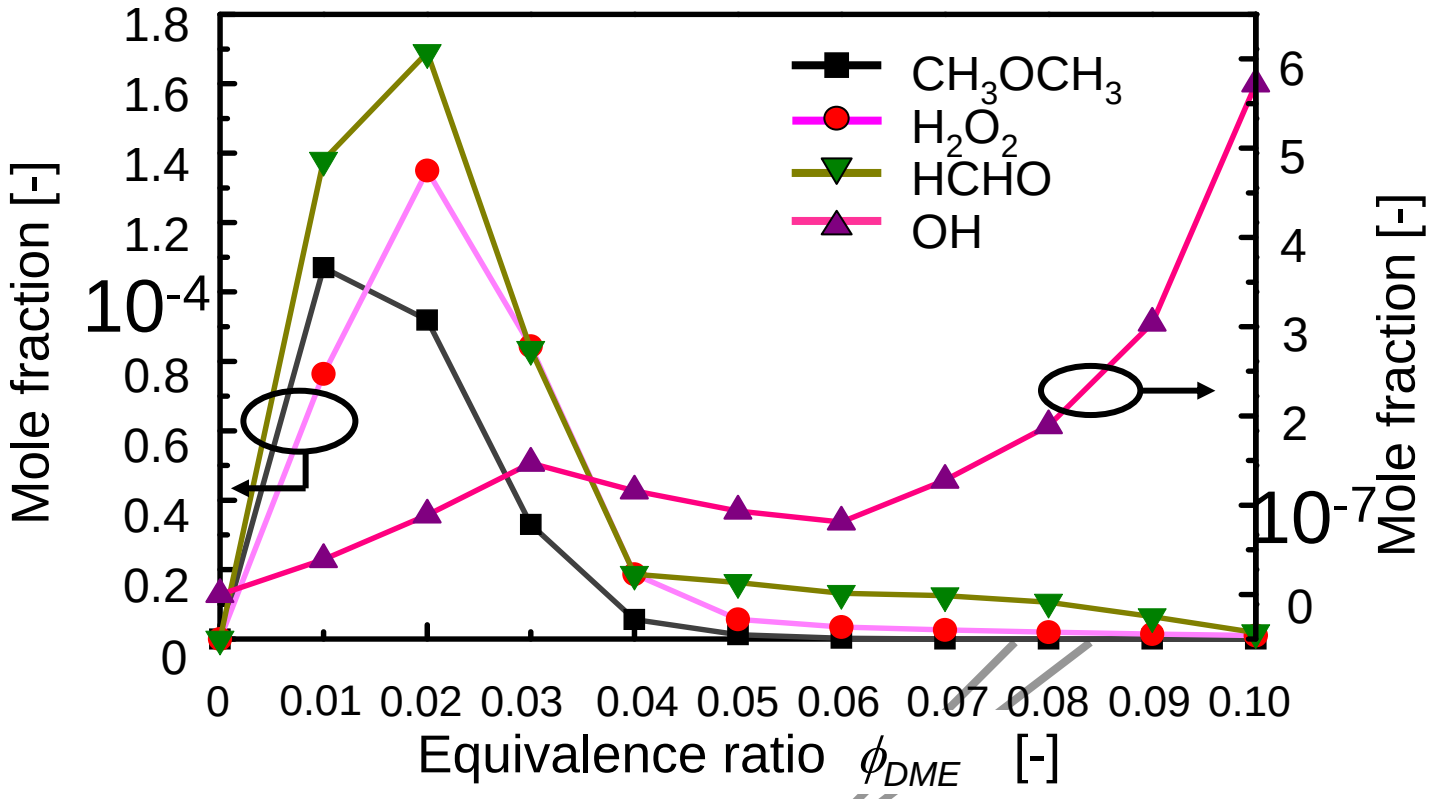


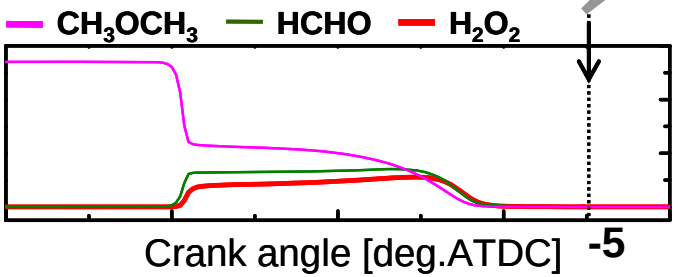



| Calculation condition | $\varepsilon$ [-] | $\phi DME$ [-] | $T_{in}$ [K] | $O_2$ [%] |
|---|---|---|---|---|
| | 13 | 0.08 | 353 | 21 |

# Mole fraction of DME intermediate products at the -5 deg.ATDC





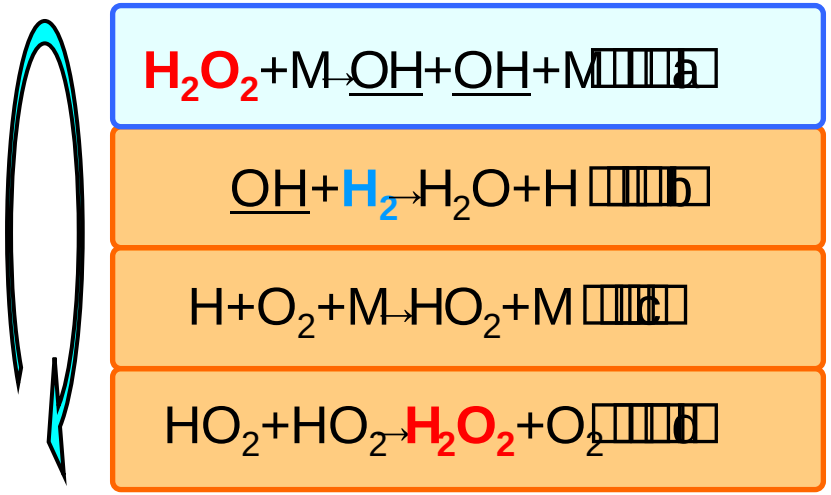



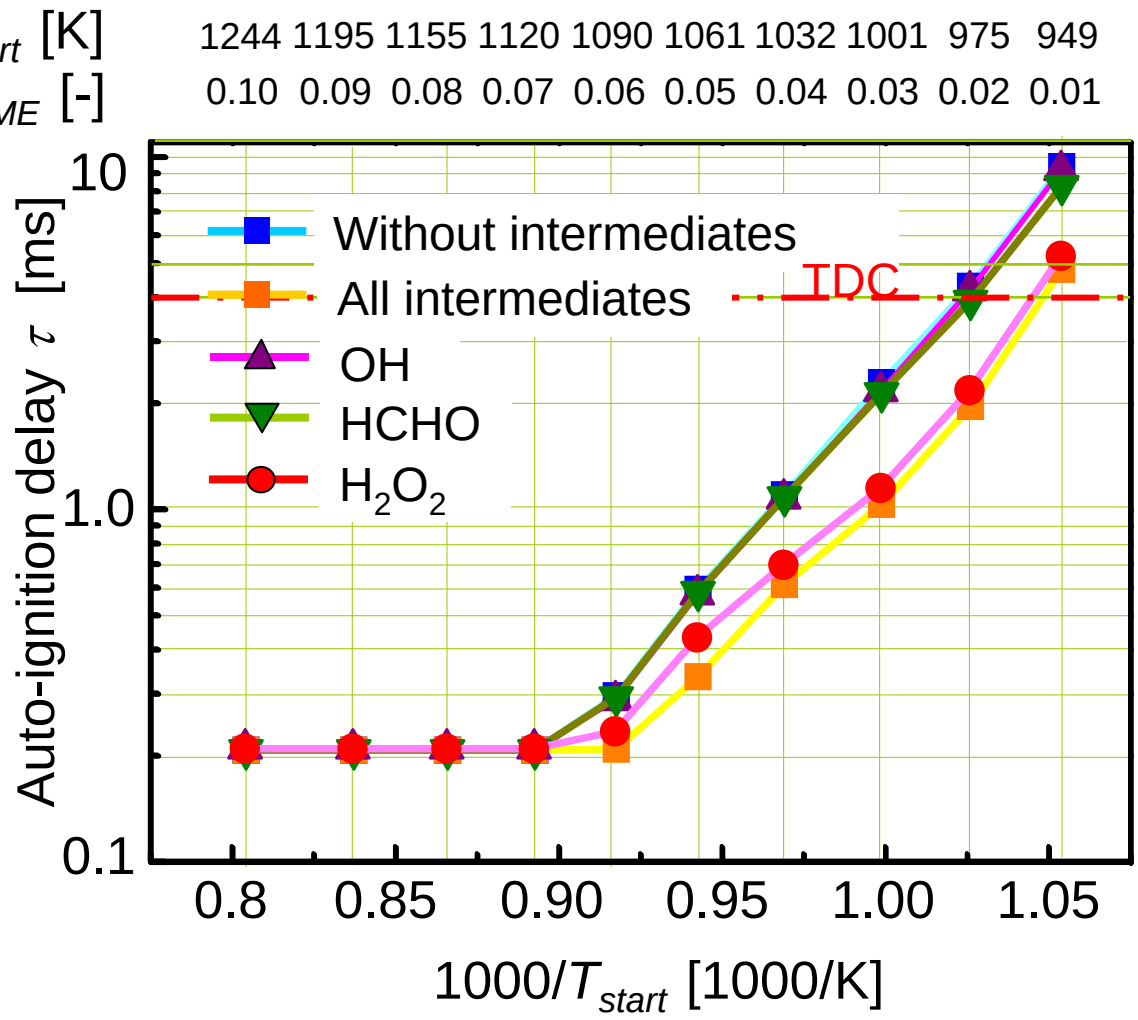

| Engine speed [rpm] |
| --- |
| 200 |
| Compression ratio [-] |
| 13 |
| Bore x Stroke [mm] |
| $\phi$100 x 450 |

# Effect of mole fraction of DME intermediate products on auto-ignition delay of hydrogen

**Chemical process until ignition**

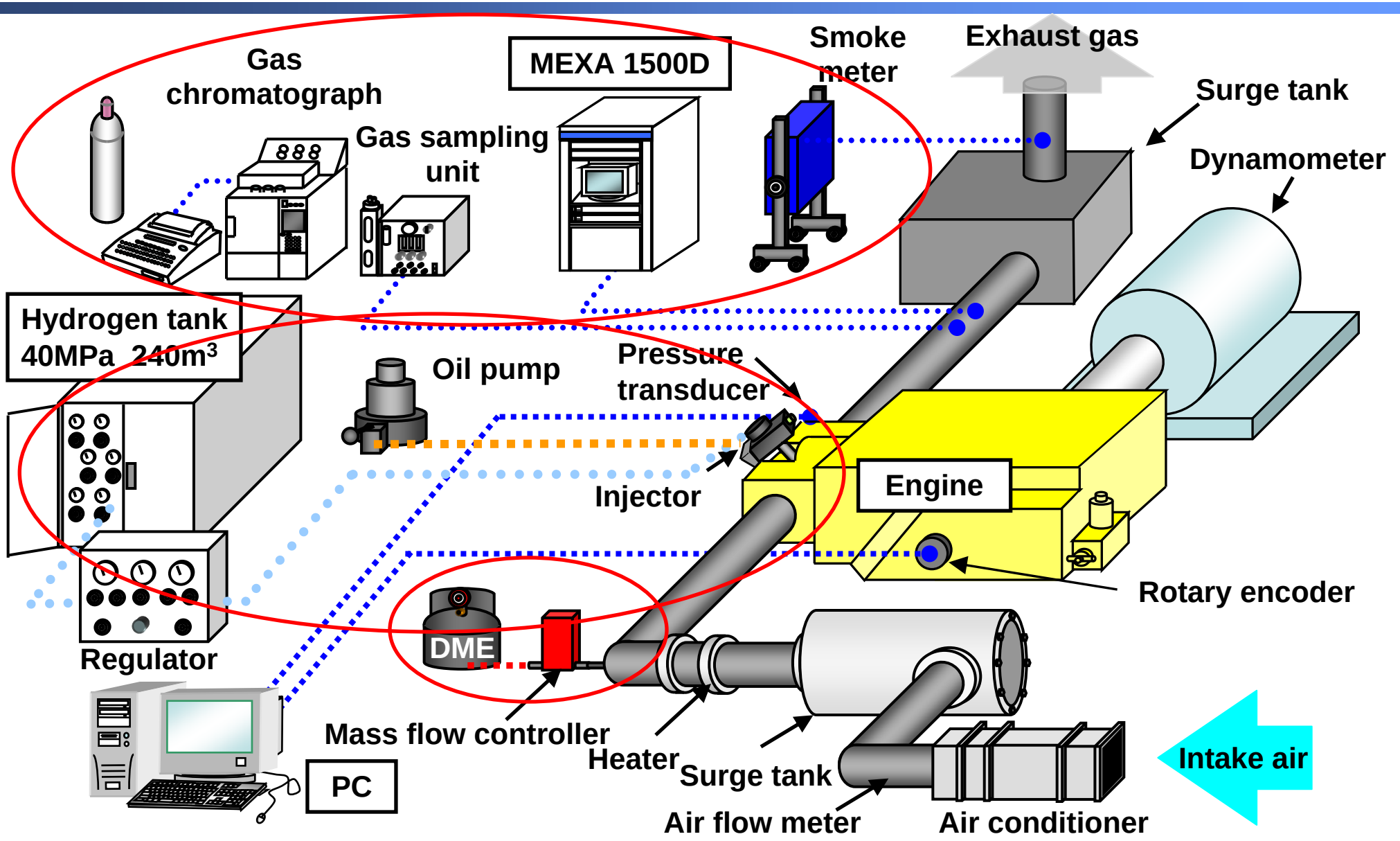
**Most effective: $H_2O_2$**



# Schematic diagram of test engine devices and measurement system

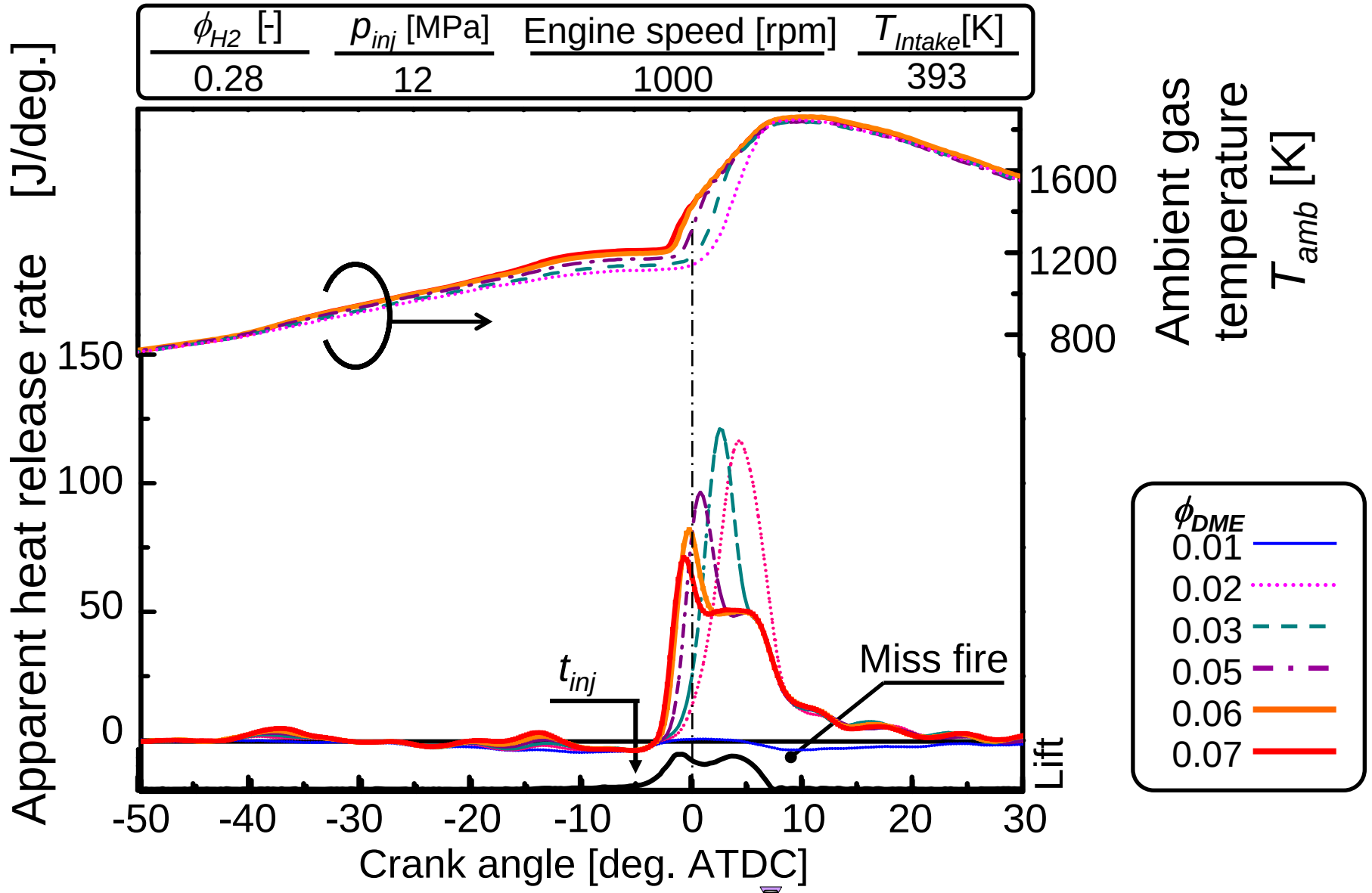




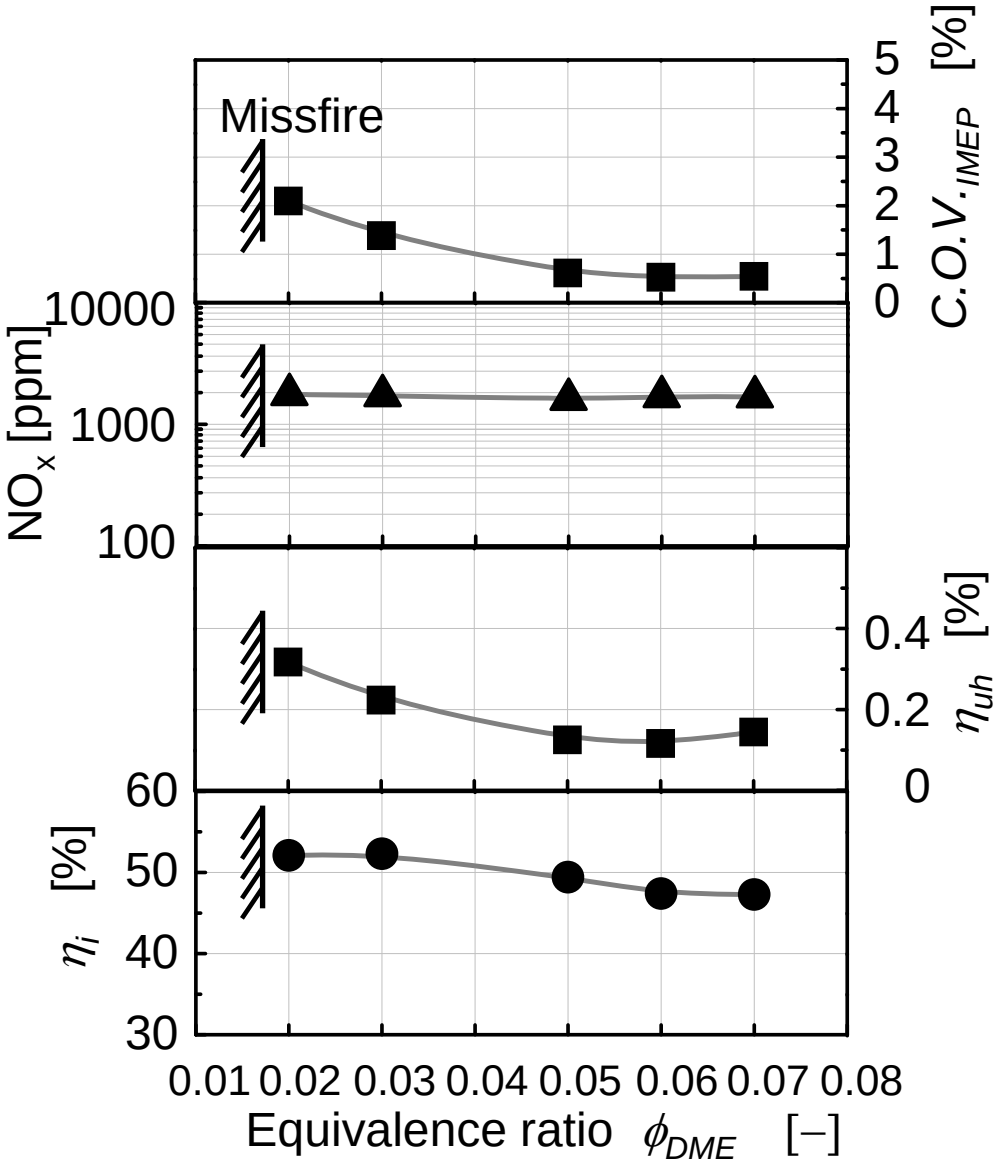
# Engine experimental conditions

| | | |
|---|---|---|
| Engine type | DI Diesel,single cylinder, water cooled,4 stroke cycle,2 valves | |
| Bore×Stroke [mm] | $\phi$110×106 | |
| Displacement [$cm^3$] | 1007 | |
| Compression ratio [-] | 16.3:1 | |
| Combustion chamber | toroidal | |
| Fuel injection system | Hydraulic oil driving gas injector | |
| Nozzle configuration | $\phi$ 0.25 mm × 8 holes angle 140 deg. | |
| Injection timing $t_{inj}$ [deg. ATDC] | -5 | -55 , -50 , -45 , -40 |
| Injection pressure [MPa] | 12 | |
| Equivalence ratio of Hydrogen [-] | 0.28 | |
| Equivalence ratio of DME [-] | 0.01 - 0.07 | 0.07 , 0.06 , 0.05 , 0.04 |
| Engine speed [rpm] | 1000 | |
| Intake air temperature [K] | 393 | 353 |

# Effects of additional DME equivalence ratio on apparent heat release rate



# Effects of additional DME equivalence ratio on C.O.V., NOx, $\eta_{un}$ and $\eta_i$



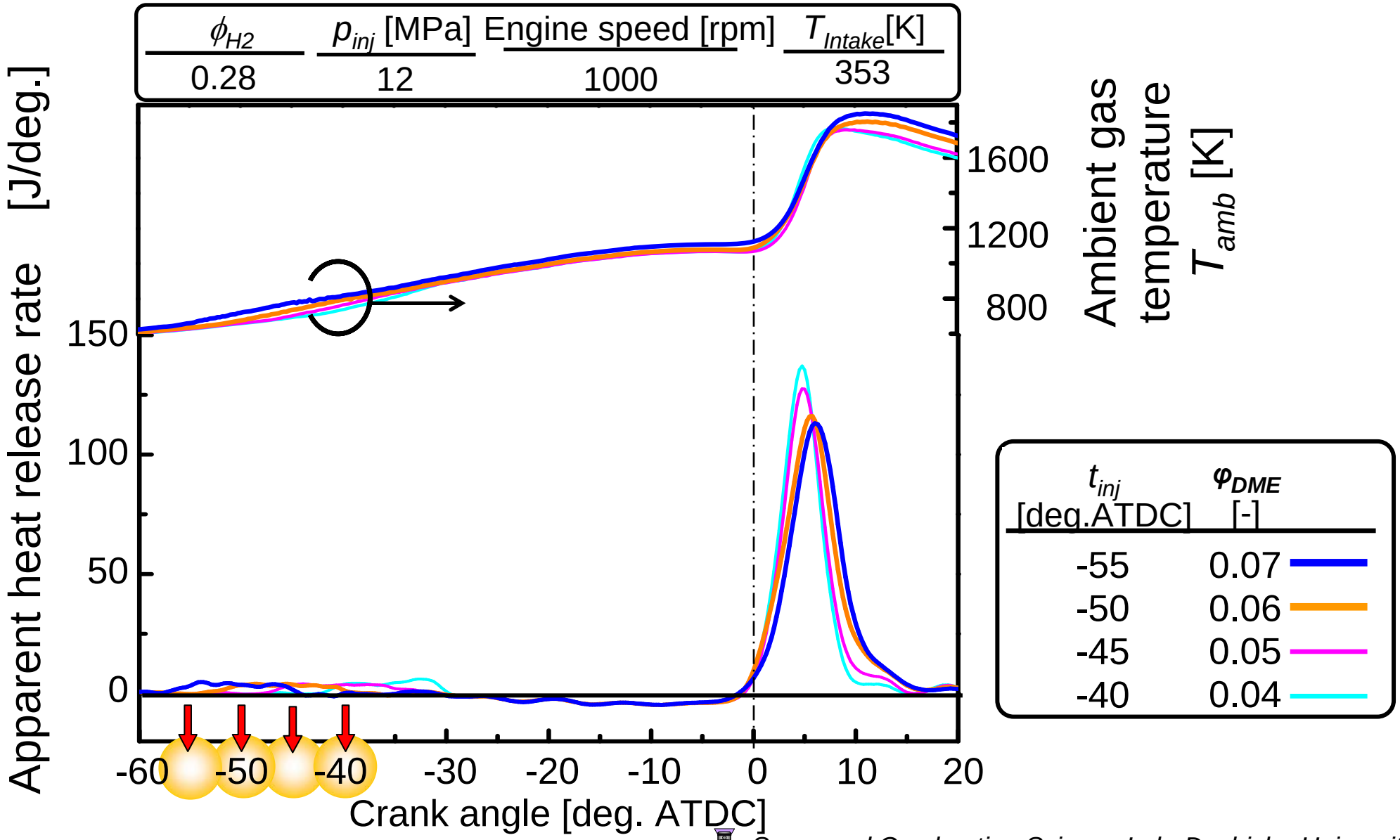

**So stable operation**
**→The oxidation of DME affects as LTR of H2 combustion**

**High NOx Emission Level**
**→This is concerned**

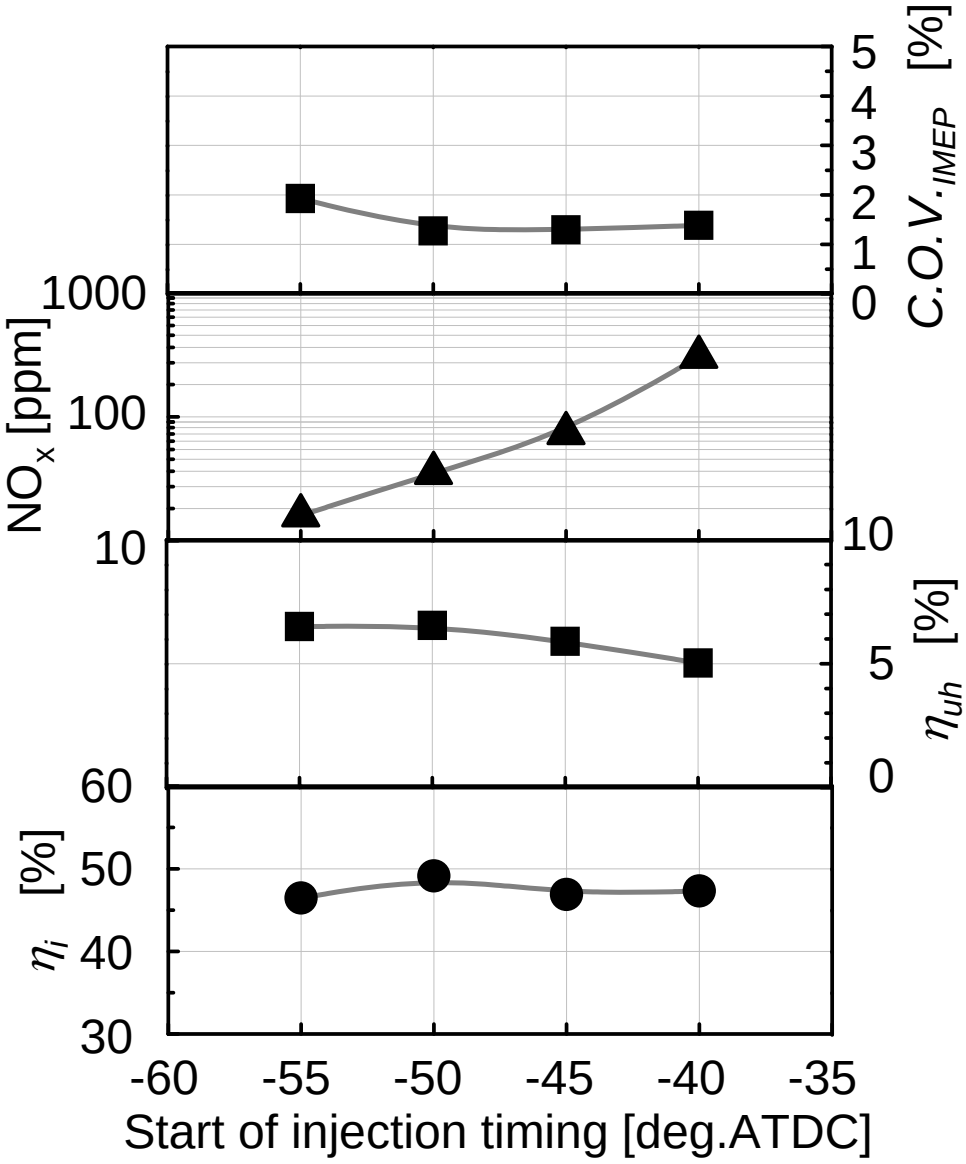
**Unburned Hydrogen is extreme low**

**High indicated heat efficiency**

# Effects of injection timing on apparent heat release rate



# Effects of injection timing C.O.V., NOx, $\eta_{un}$ and $\eta_i$




- **As LTR occur earlier, combustion goes little unstable**
- **Lean combustion leads NOx emission low**
- **Lean combustion and early injection lead unburned hydrogen high**
- **Relatively high indicated heat efficiency**

# Conclusions 1/2

***Hydrogen auto-ignition experiments with ignition-assist method of DME using RCEM.***

- **The oxidation reactions of DME promote auto-ignition of hydrogen with the effects of not only rising temperature but also intermediate products.**

- **The adjusting DME equivalence ratio has a possibility to control hydrogen combustion.**

# Conclusions 2/2

***Hydrogen–fueled diesel engine was operated with ignition-assist method of DME.***

- **The high efficiency operation results in the hydrogen-fueled diesel engine are obtained, but NOx emission should be concerned about its high level in the diffusion combustion.**

- **While the lean combustion peculiar to PCCI combustion realized NOx reduction, it was able to be evaded the decline in efficiency and the increase of cycle variation with too lean combustion.**