Homogeneous Charge Compression Ignition (HCCI)

Dual fuel HCCI combustion
- High octane and high cetane number fuels -

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1) Previous study ---- HCCI

a) HCCI combustion of DME: Spectrum analysis of chemiluminescence was performed in an HCCI engine.
(SAE Paper, No.2003-01-1828)
Nobuyuki Kawahara, Eiji Tomita, Hisashi Kagajo

b) Ion Current Measurement in a Homogeneous Charge Compression Ignition Engine,
International Journal of Engine Research, Vol.6, (2005), pp.453-463.
Tatsuya Tanaka, Kazuaki Narahara, Michihiko Tabata, Sadami Yoshiyama and Eiji Tomita
----- gasoline based HCCI

c) Dual fuel HCCI:

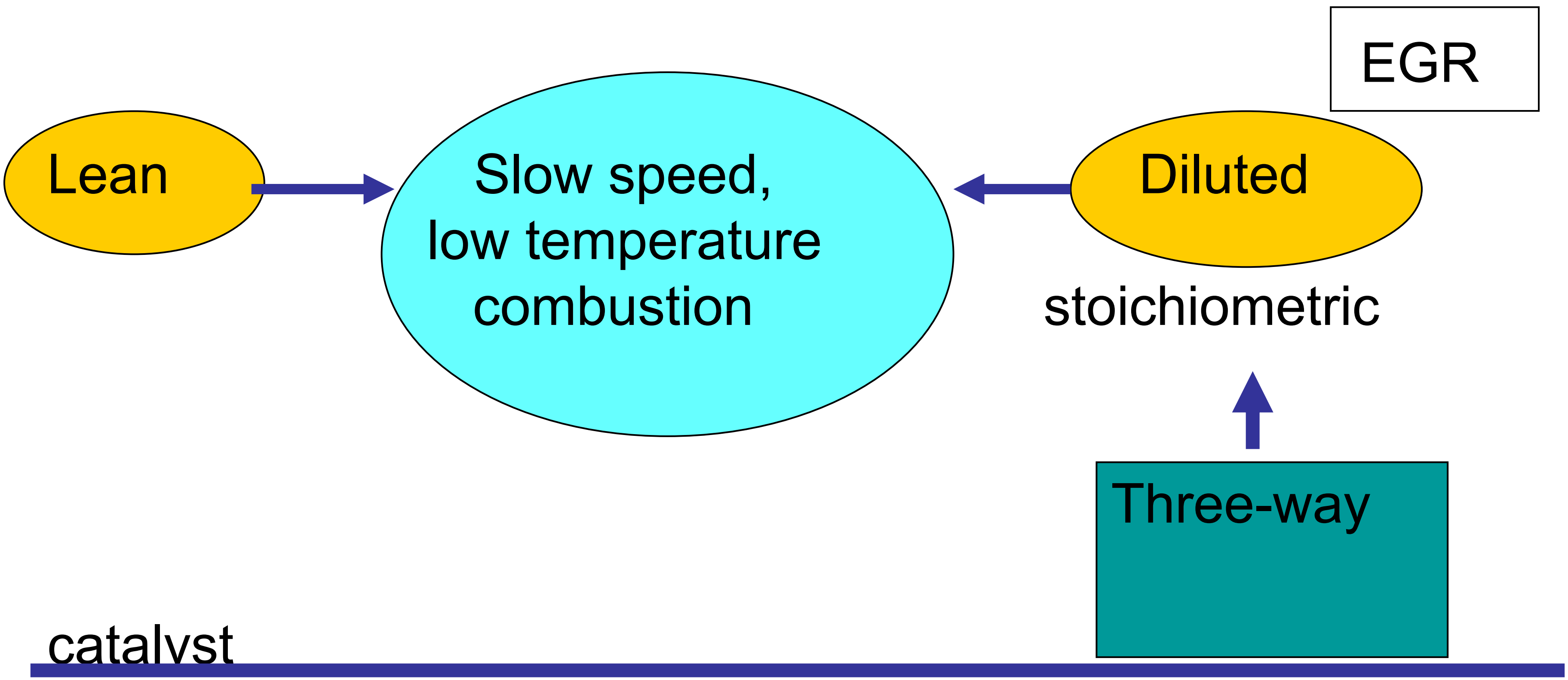
* Hydrogen is induced from intake port and gas oil is injected into the cylinder and combustion characteristics and exhaust emissions were investigated.
  (SAE Paper, No.2001-01-3503)

* Methane is induced from intake port and gas oil is injected into the cylinder and combustion characteristics and exhaust emissions were investigated. The effect of diluted gas was also investigated. The high dilution condition enables stoichiometric combustion with no smoke and very low NOx.
  (SAE Paper, No.2002-01-2723)
  (HCCI symposium in Berkeley, 2004)

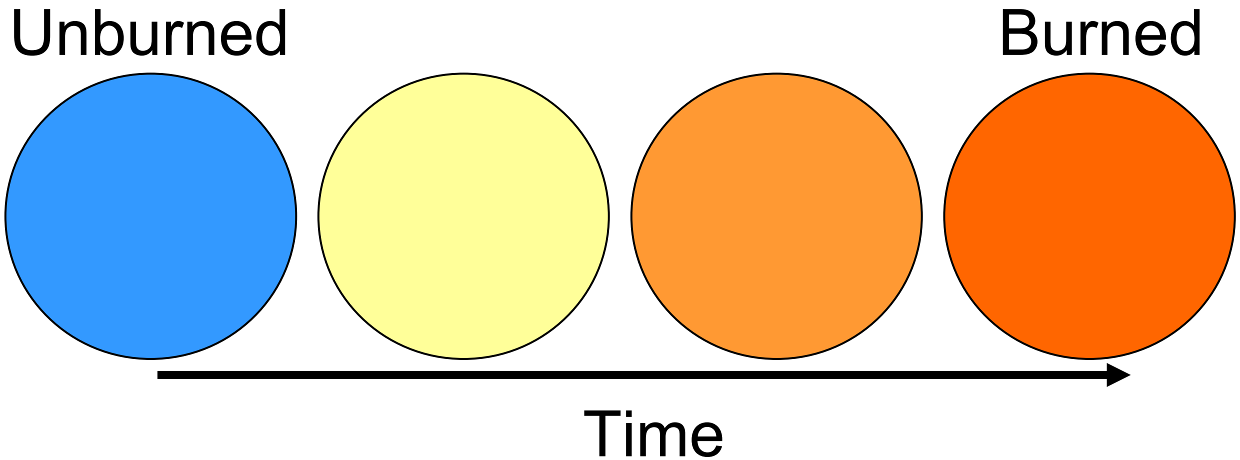
Demand from the society

- Increasing thermal efficiency (reducing CO_2)
- Reducing pollutant emissions

HCCI : low NOx, no smoke : new Diesel



Background

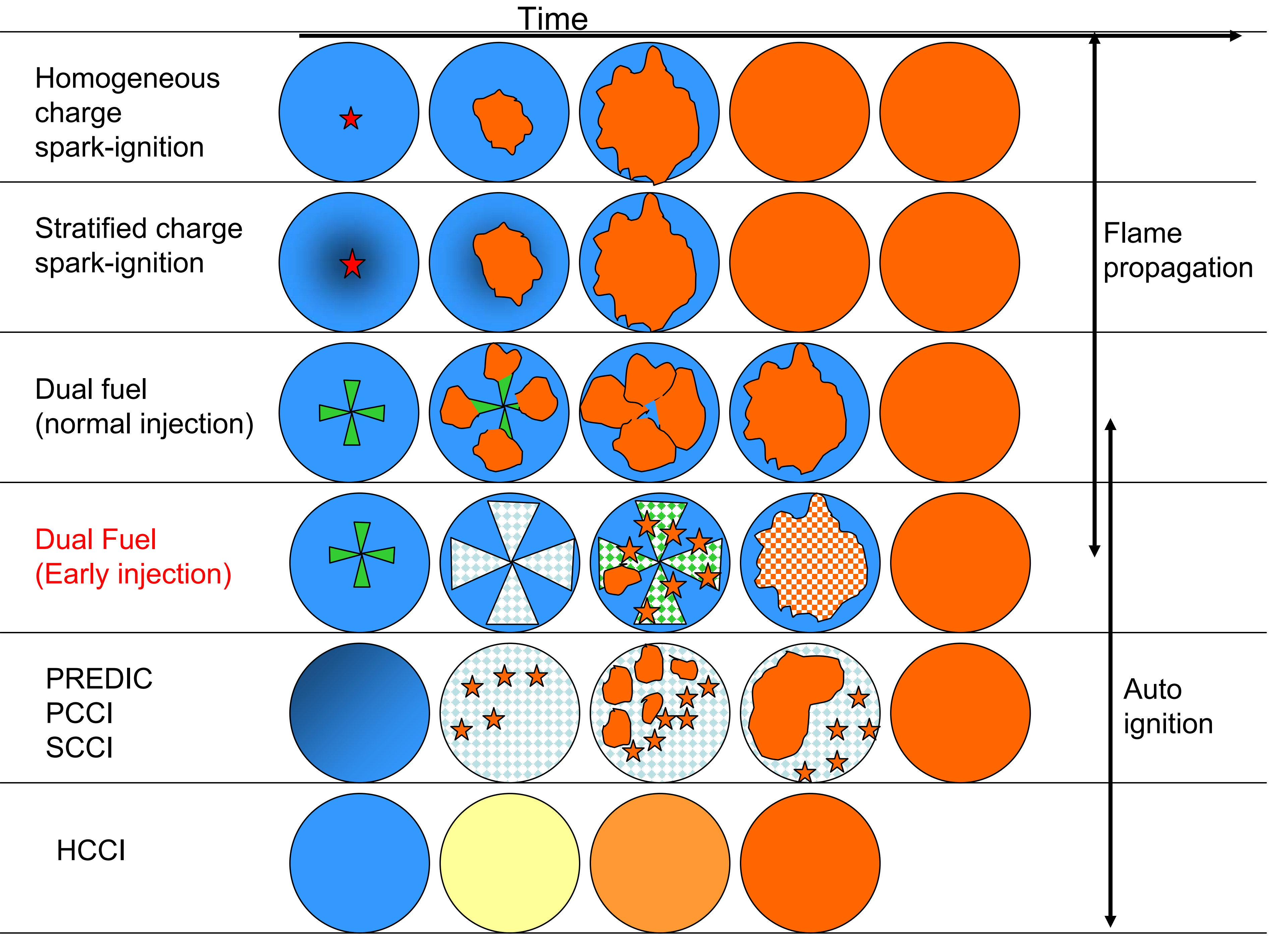


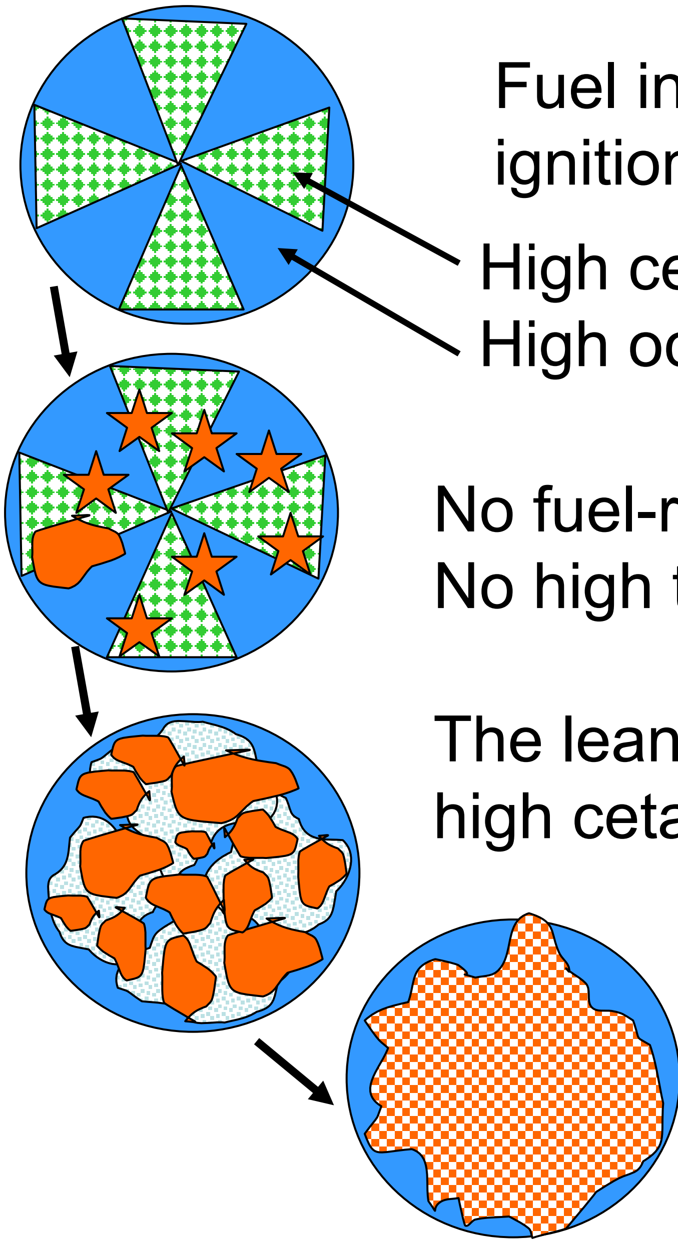
-No smoke, Low NOx

-Problems to be solved

* Ignition control under transient operation
  Temperature, pressure and concentration of fuel, EGR
  Variable valve timing
* Higher load without knock
  Degree of stratification
  * how to supply the fuel
  * in-cylinder flow

Homogeneous Charge Compression Ignition combustion


Time
Homogeneous charge spark-ignition
Stratified charge spark-ignition
Dual fuel (normal injection)
Dual Fuel (Early injection)
PREDIC
PCCI
SCCI
HCCI
Flame propagation
Auto ignition



Fuel injected is dispersed widely without ignition because of early injection.

High cetane number fuel for ignition source

High octane number fuel

No fuel-rich region leads to no smoke.

No high temperature region leads to less NOx.

The lean fuel surrounded with burned gas of high cetane number fuel is expected to be burned.

Concept of this study

-Dual fuel engine (methane + diesel fuel)

combination of high octane number fuel & high cetane number fuel using a DI diesel engine

- Early injection (40-50 deg.BTDC) : HCCI concept

low NOx, no smoke

but rapid combustion with high NOx in high load

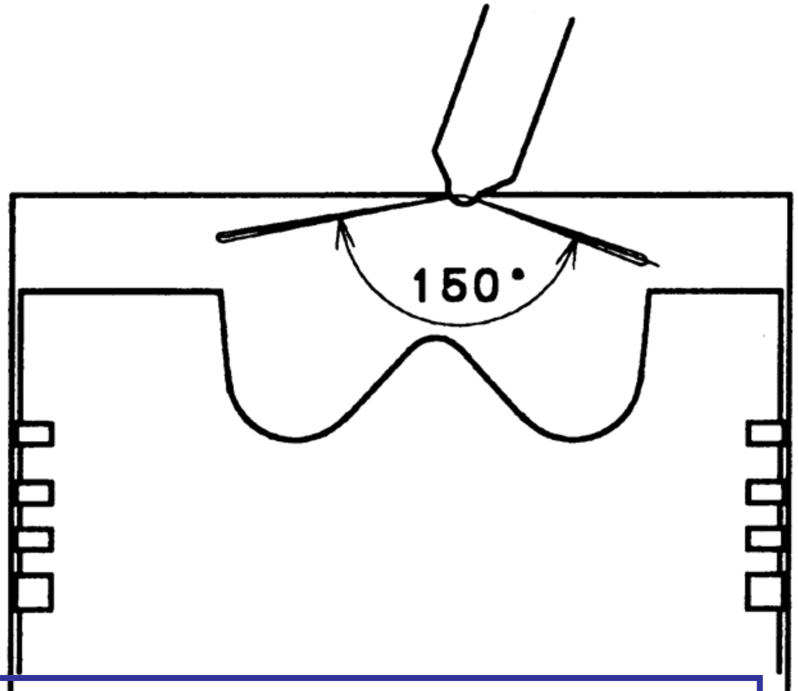
- EGR (N2-dilution)

achieving mild combustion in high load

- Stoichiometric combustion

- ROHR and Exhaust emissions

Experimental method



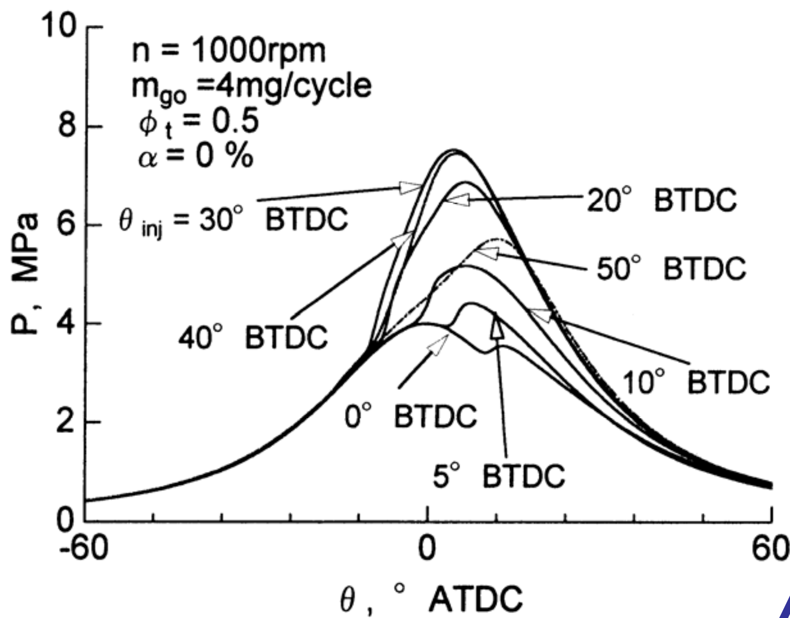
Single cylinder,
4 stroke cycle
Direct injection (diesel fuel)
+ induction from intake port
(methane)

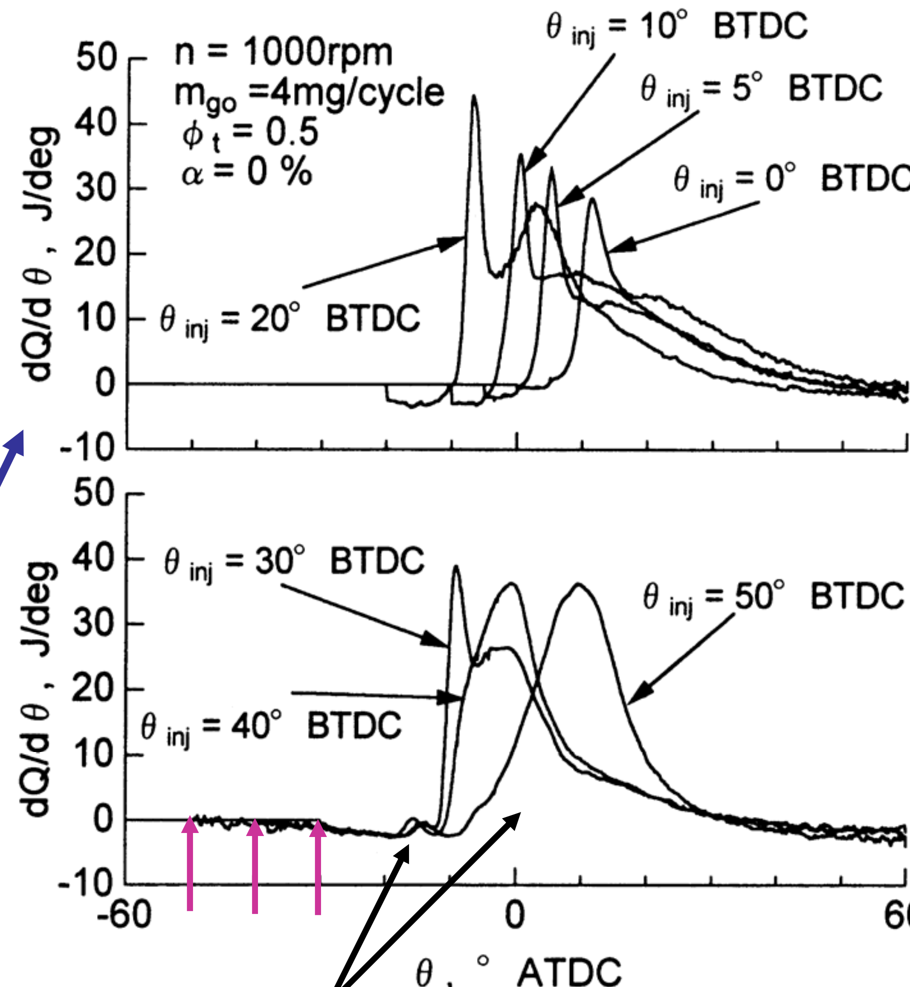
Bore x stroke: 92 x 96 mm
Displacement: 638 cm^3

Engine speed: n =1000rpm
Injection timing:
θ_{inj}=TDC~50 deg.BTDC
Equivalence ratio:
ϕ_t =0.4~1.1
N_2 dilution ratio: α=0~37.5%

Compression ratio: 17.7:1
Injector: 4 holes (ϕ 0.26mm),
Spray angle: 150°
Combustion chamber: Deep dish

Engine specifications and combustion chamber





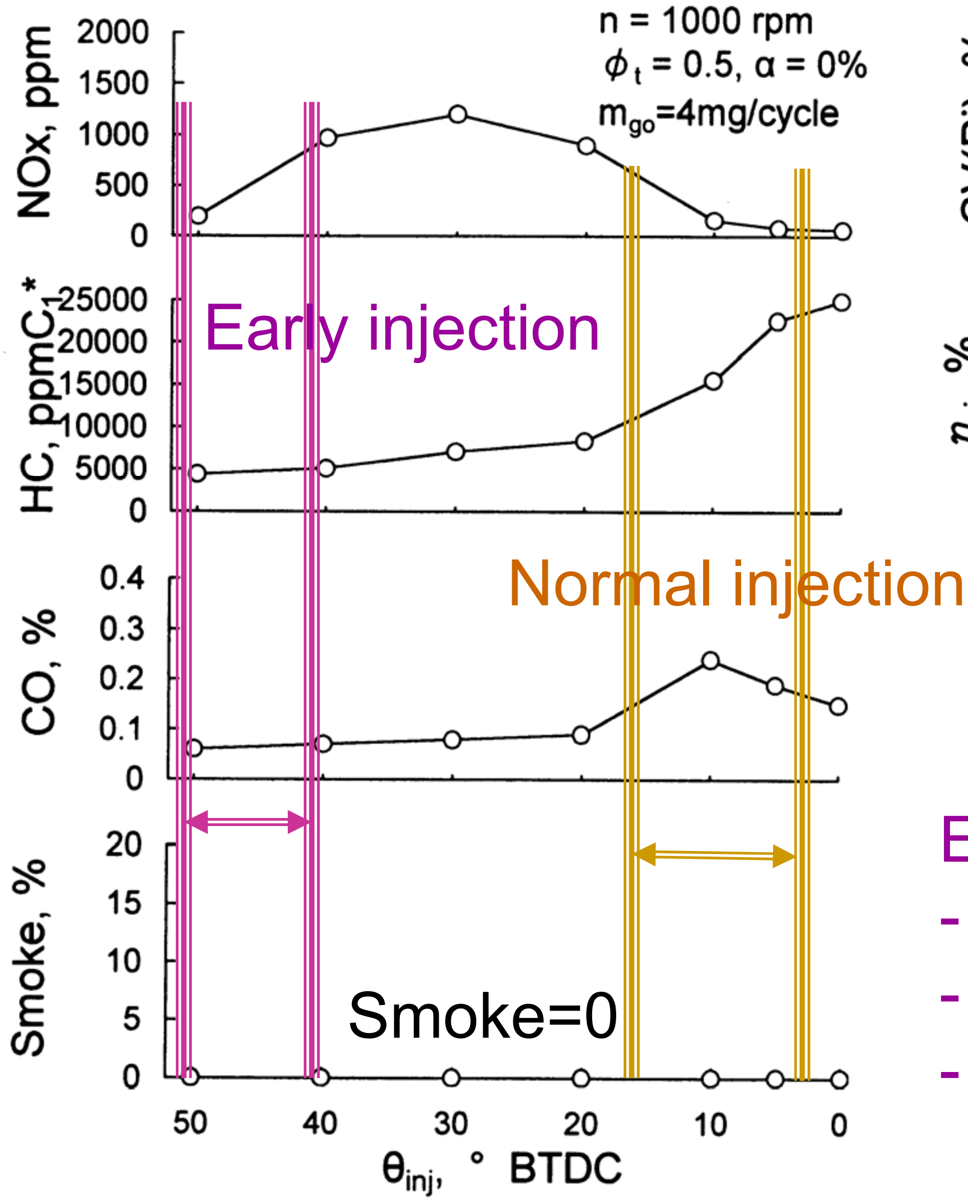
Normal injection
(θ_{inj}=0~20deg.BTDC)

Early injection
(θ_{inj}=30~50deg.BTDC)

Low temperature reaction due to diesel fuel

One large peak with retarded combustion

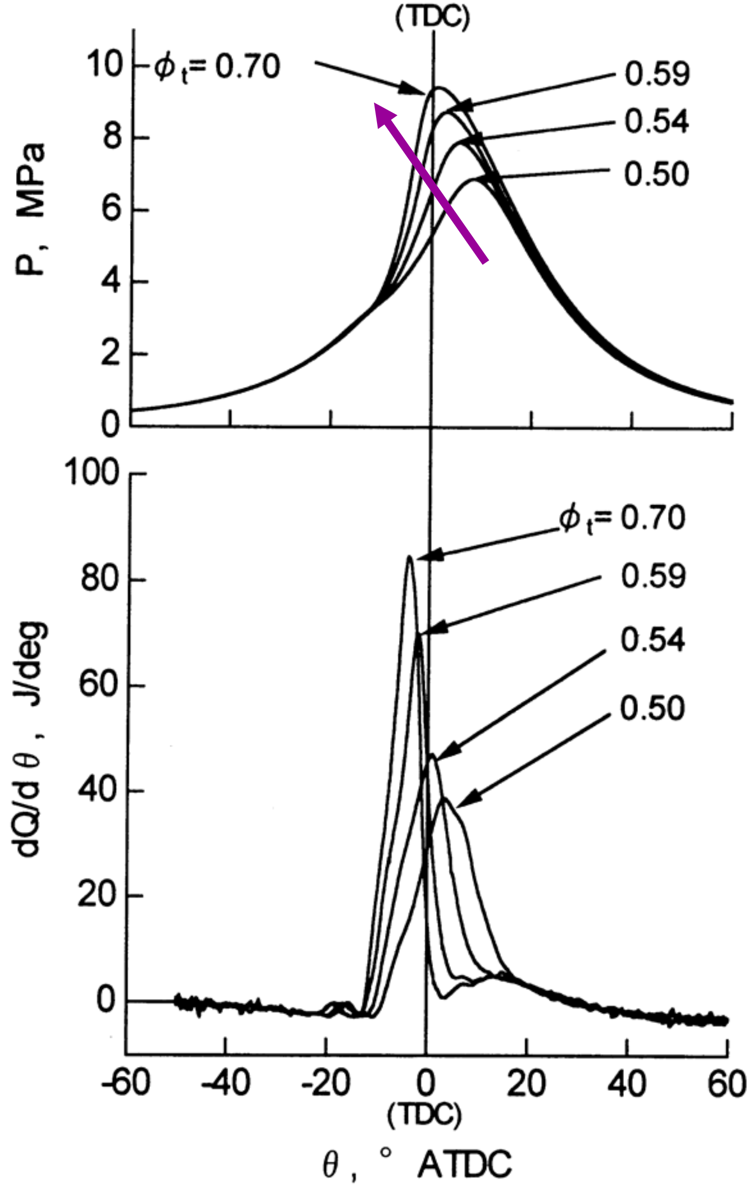
Pressure and ROHR without N_2-dilution (α=0%)



ϕt=0.5

Early injection
- Low NOx, low HC, Low CO
- Low cycle-to-cycle fluctuation
- High thermal efficiency

Exhaust emissions and thermal efficiency w/o N_2-dilution (α=0%)



Increase in load

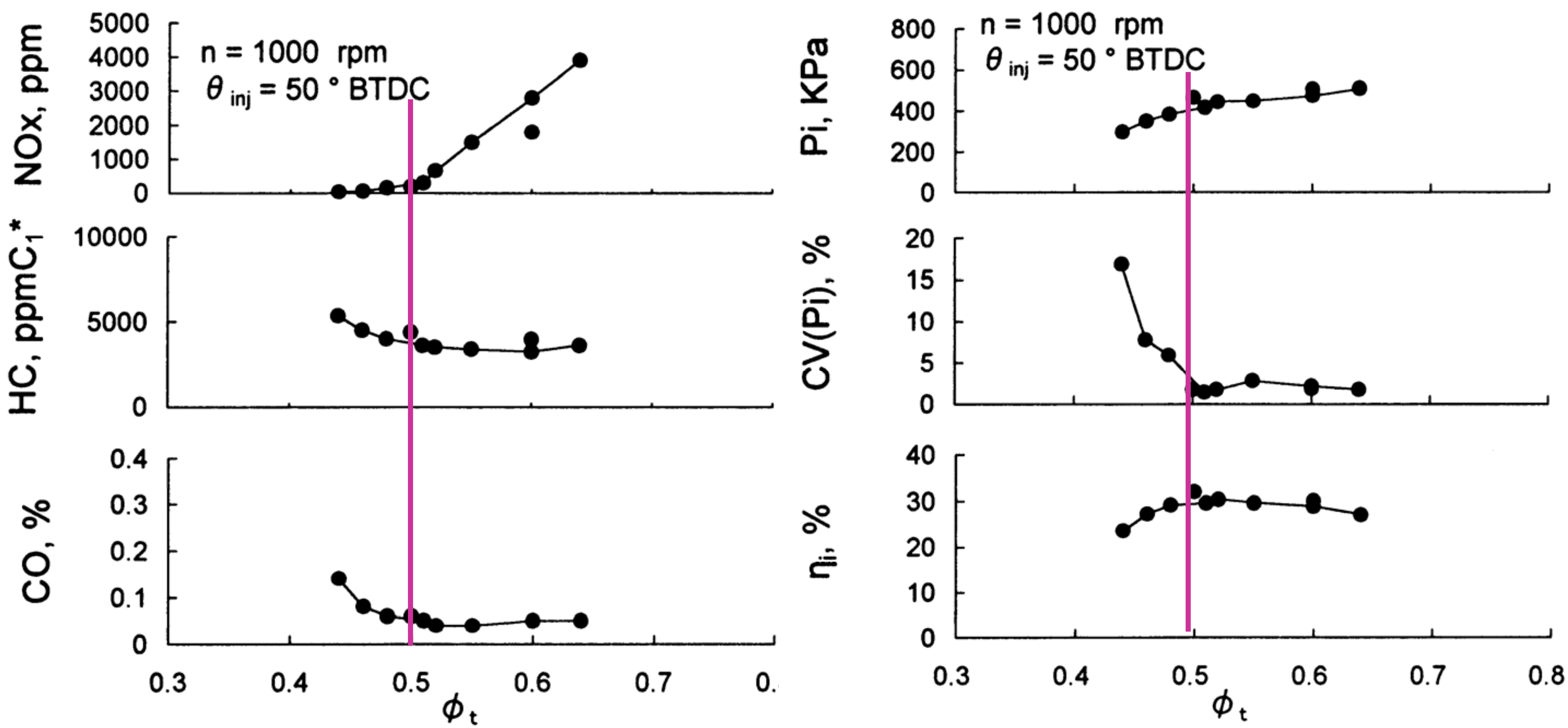
--> - increase in P_{max} and $(dQ/d\theta)_{max}$ and advance in the timing of P_{max} and $(dQ/d_q)_{max}$

- decrease in effective work

θ_{inj}=50 deg.BTDC

(m_{go}=4 mg/cycle, α=0 %)

Pressure and ROHR with increasing load w/o N_2-dilution



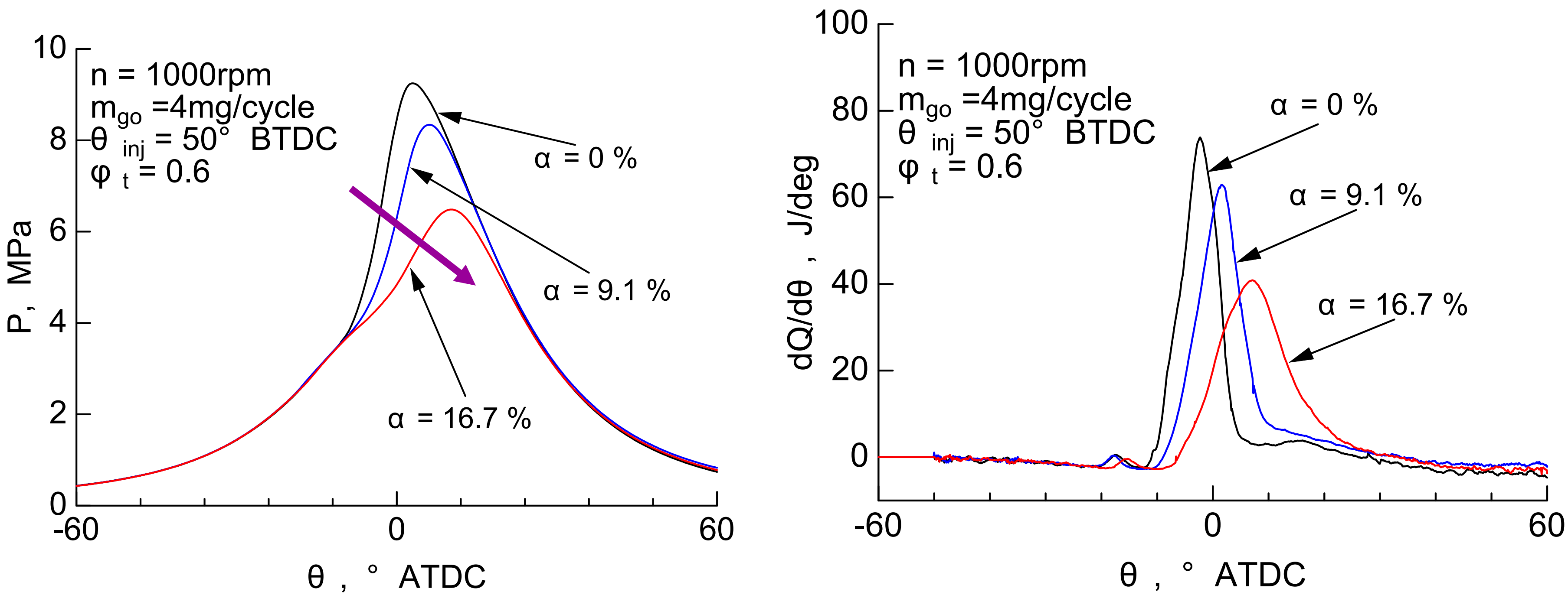
Smoke=0

In ϕt <0.5, combustion is incomplete and bad.

In ϕt>0.5, NOx increases while HC and CO are lower, and combustion becomes stable.

m_{go}=4mg/cycle

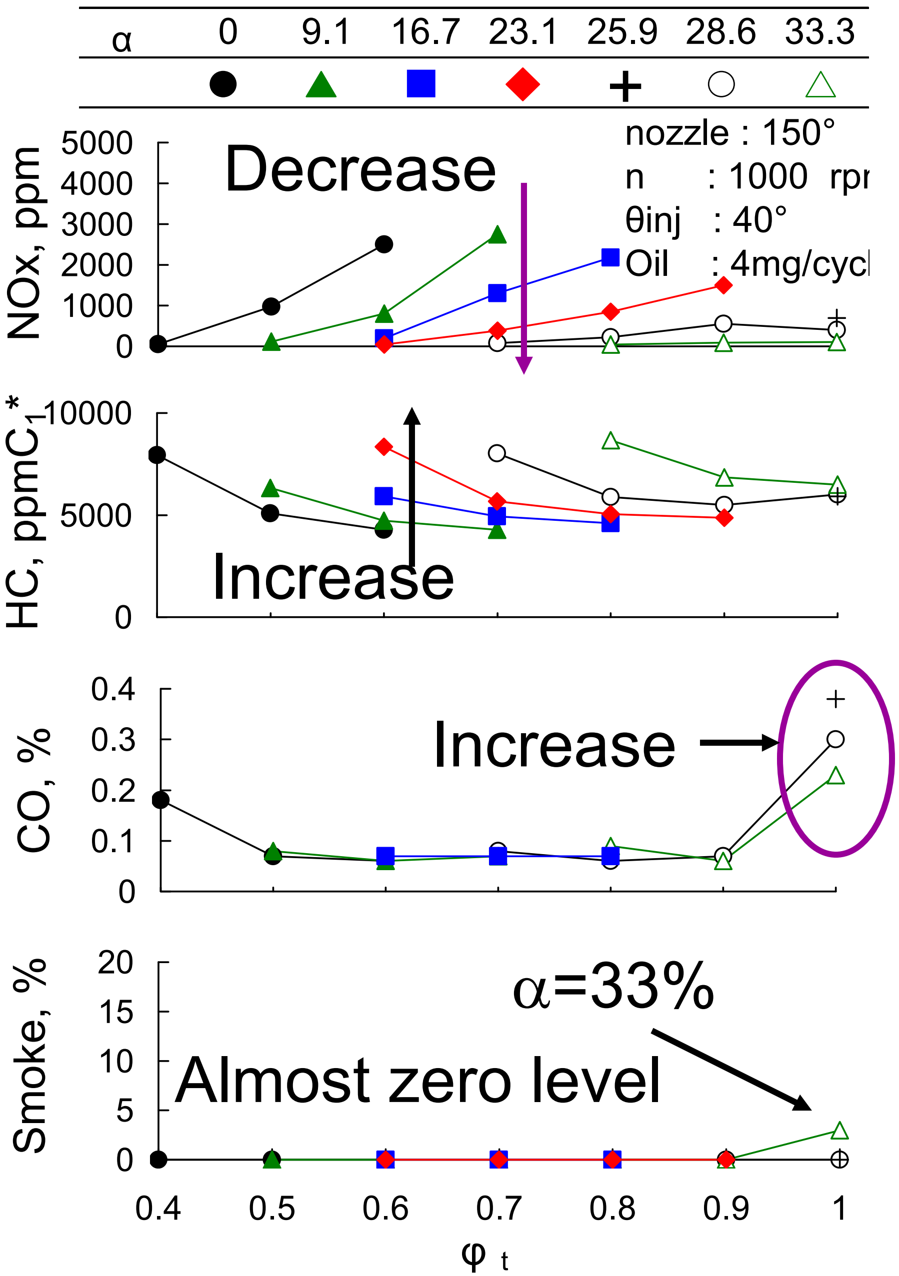
Exhaust emissions and thermal efficiency w/o N_2-dilution

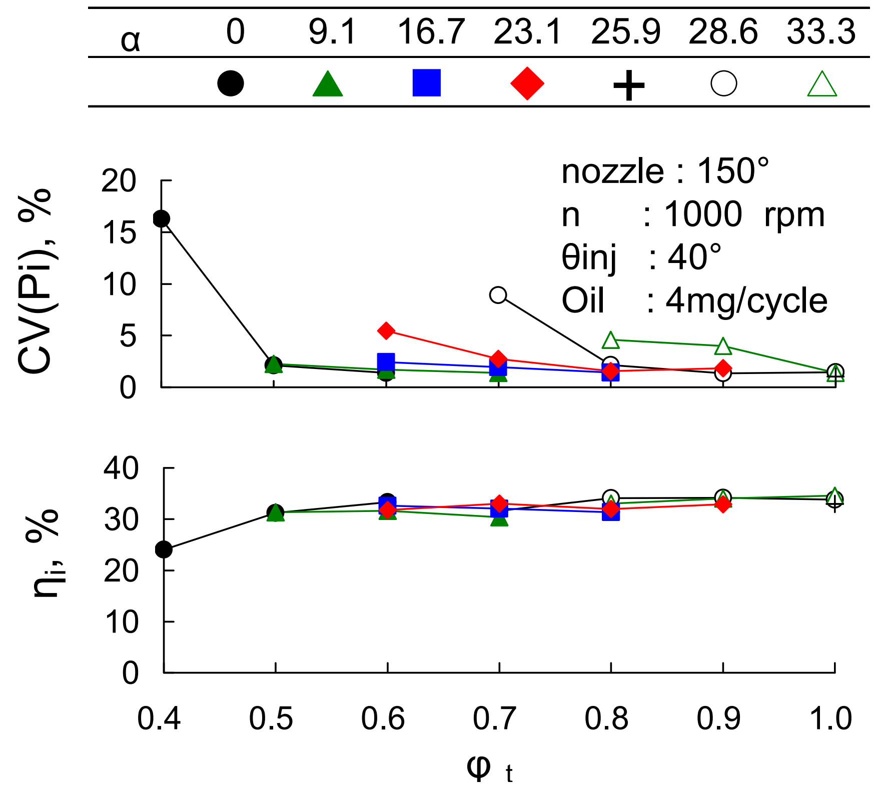


N2 dilution ratio, α=0, 9.1%, 16.7%

When dilution ratio becomes larger, the combustion becomes milder.

Pressure and ROHR





Ratio of N2-dilution was changed according to equivalence ratio.

θ_{inj}=40°BTDC
(early injection)

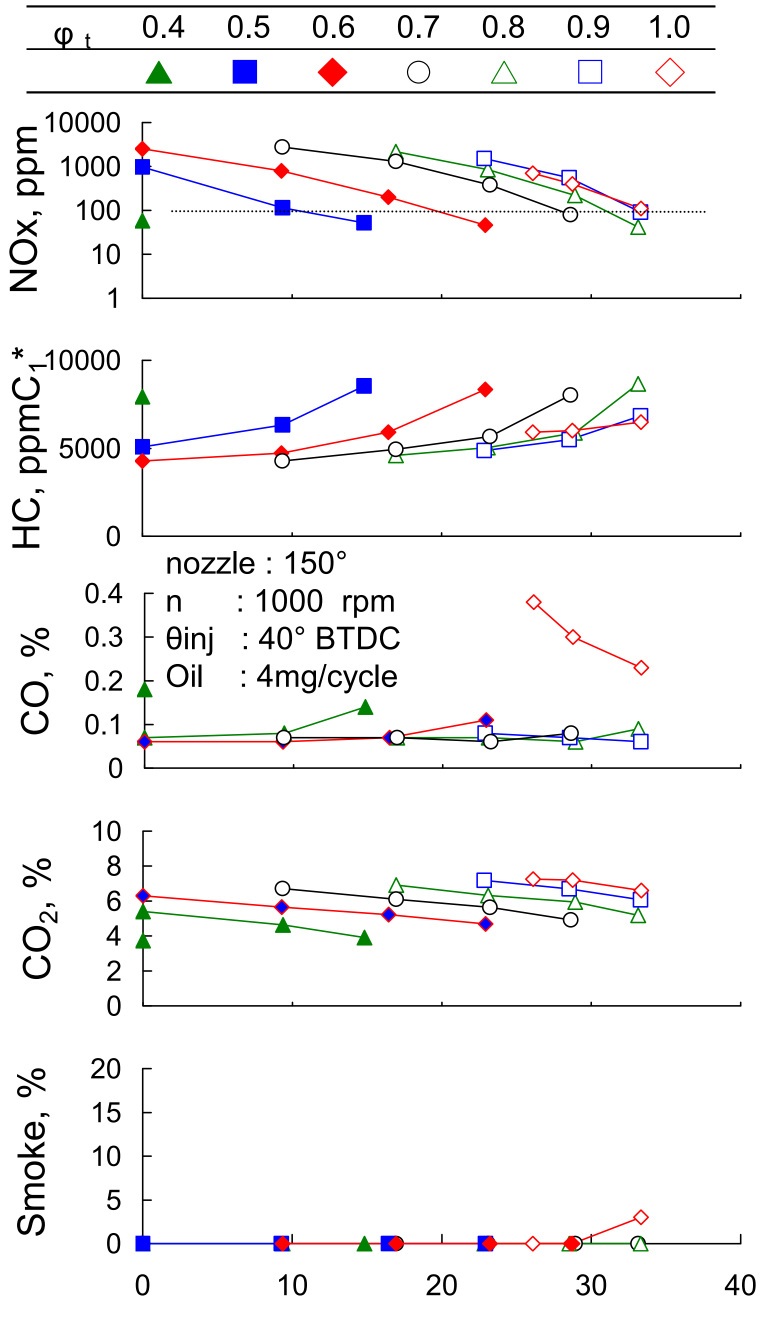
Exhaust emissions, thermal efficiency and CV(Pi) with N_2-dilution

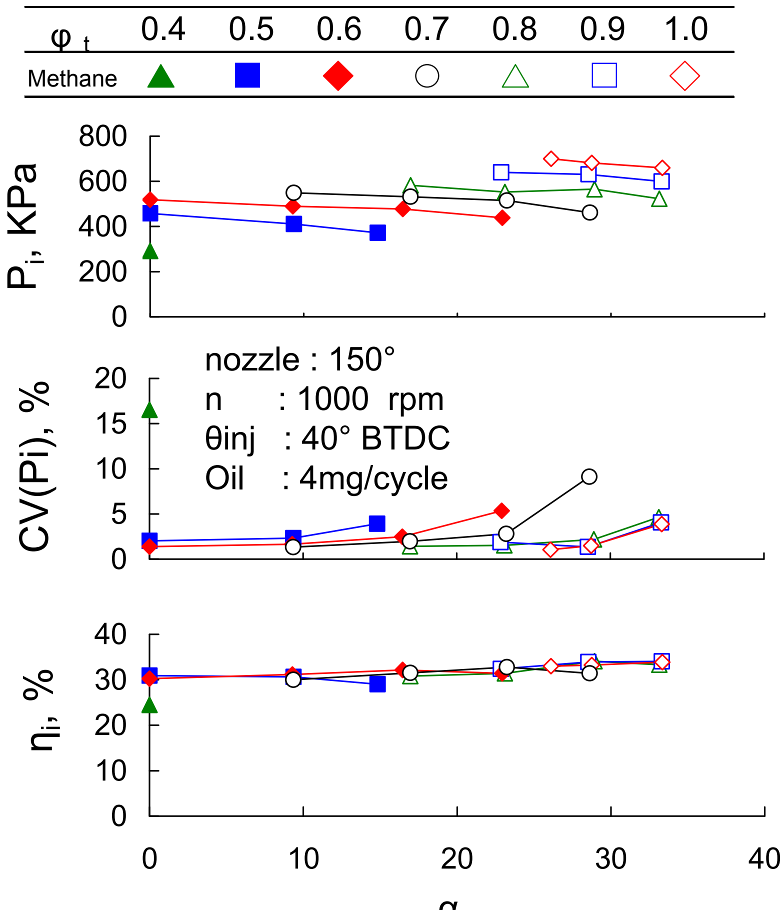
The same data are used.

Abscissa: Ratio of N_2 dilution

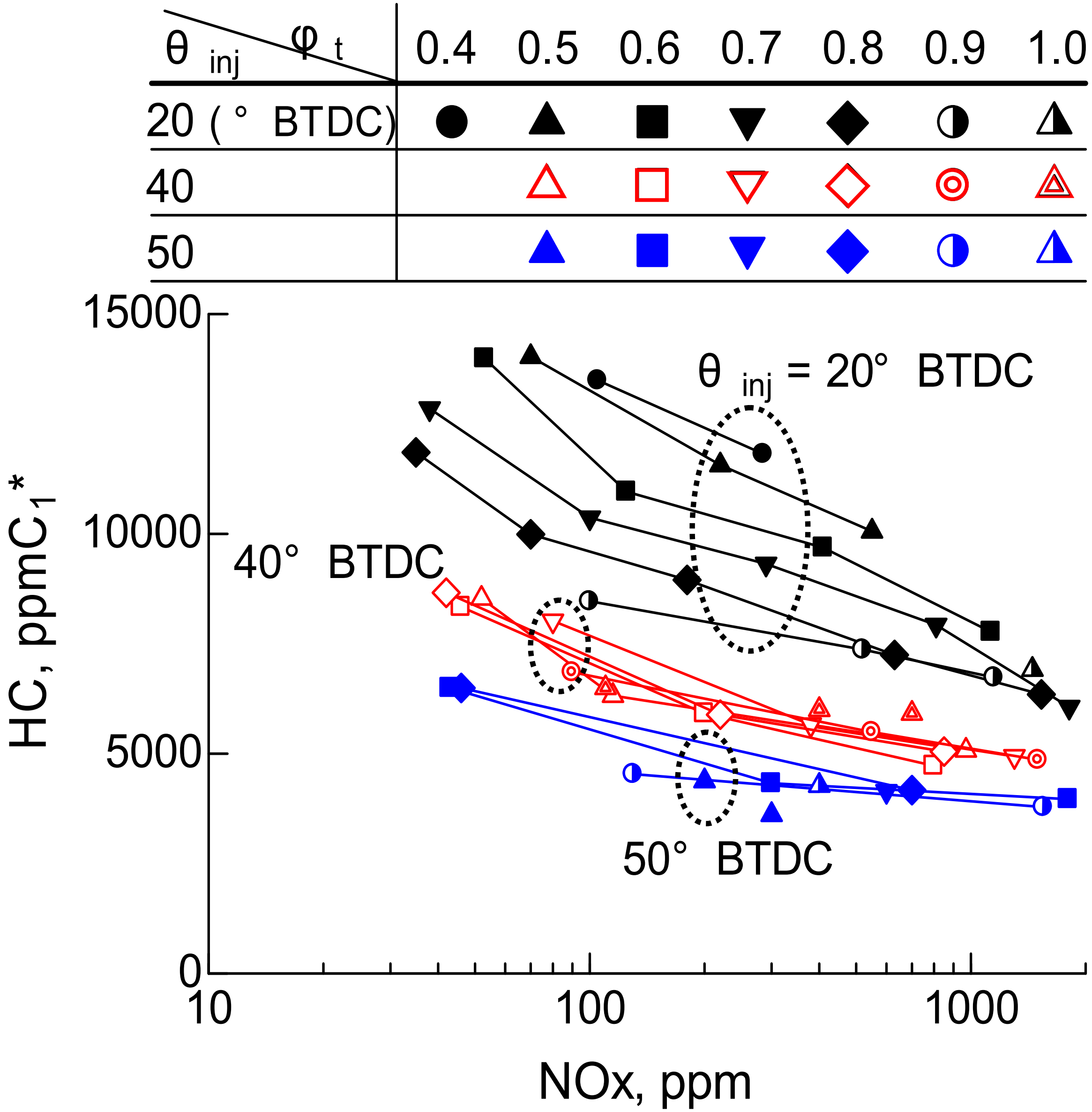
(← Equivalence ratio)

NOx : log scale





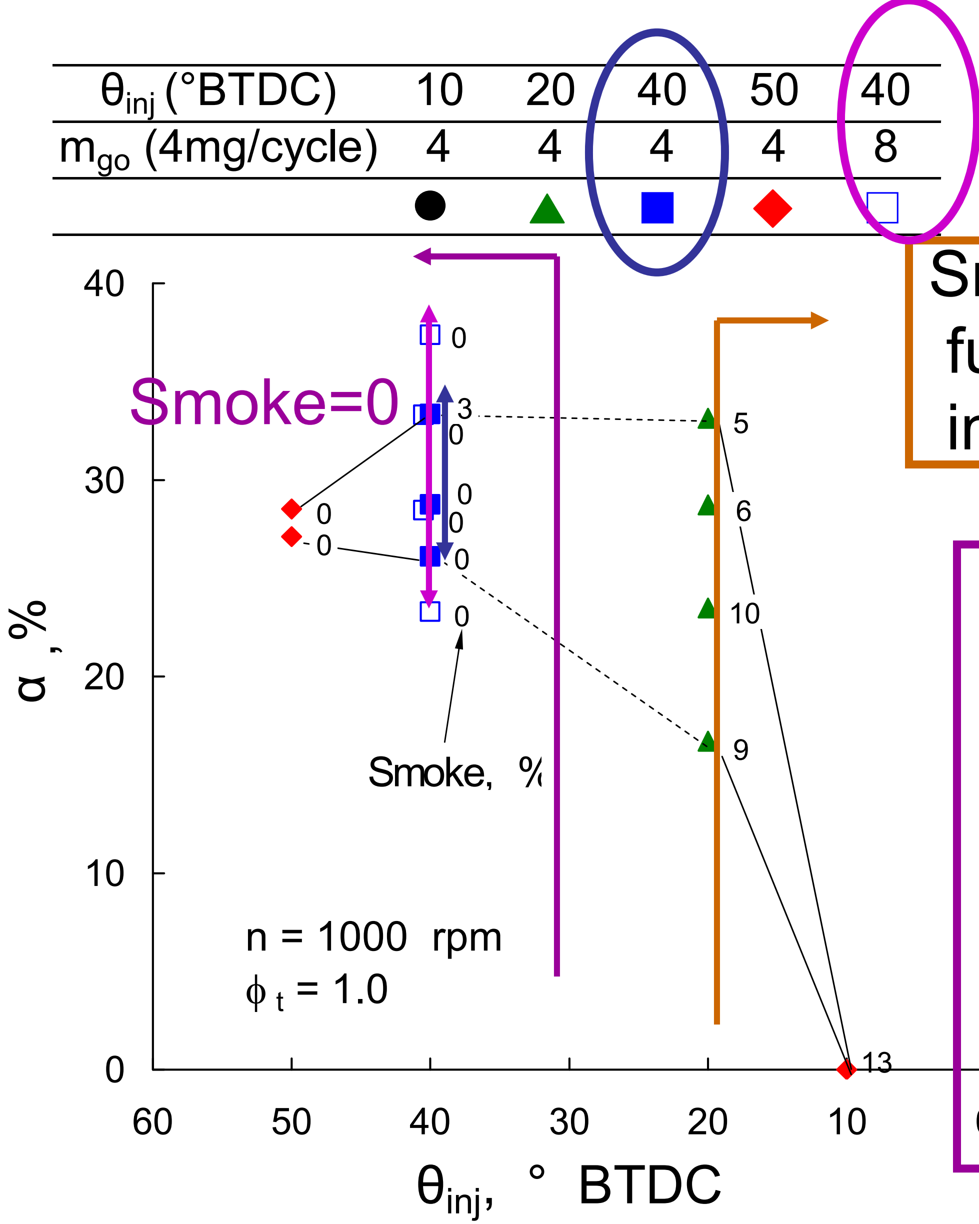
Exhaust emissions with N_2-dilution



Trade off of HC and NOx

Early injection
(20→40→50
deg.BTDC)
-Lower HC

Relation between HC and NOx



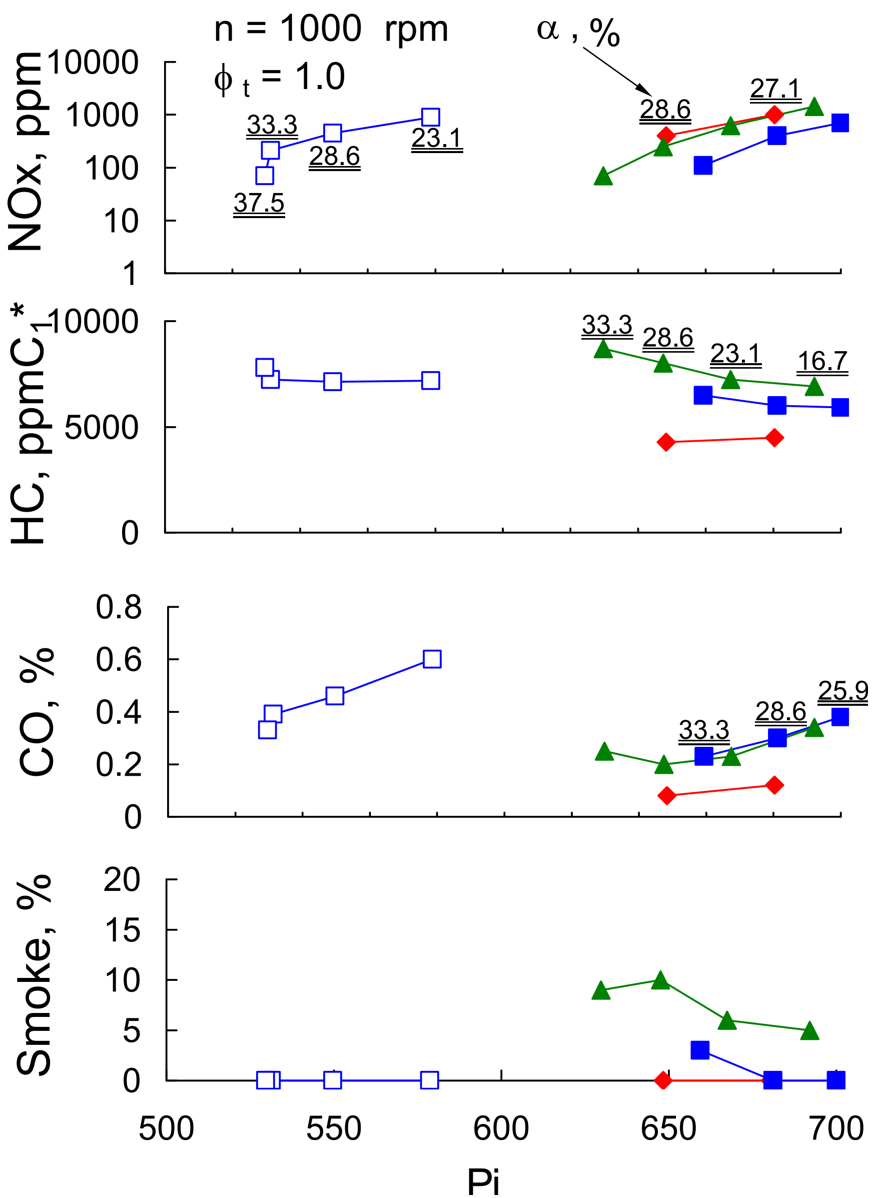
Smoke could be seen due to fuel-rich region in normal injection .

In early injection, smoke level is almost zero and operating range becomes narrow.

When diesel fuel increases, the operating range in ϕt=1.0 becomes wider.

Operating range of stoichiometric conditions

θ_{inj} (°BTDC)	10	20	40	50	40
m_{go} (4mg/cycle)	4	4	4	4	8
	●	▲	■	◆	□



θ_{inj} (°BTDC)	10	20	40	50	40
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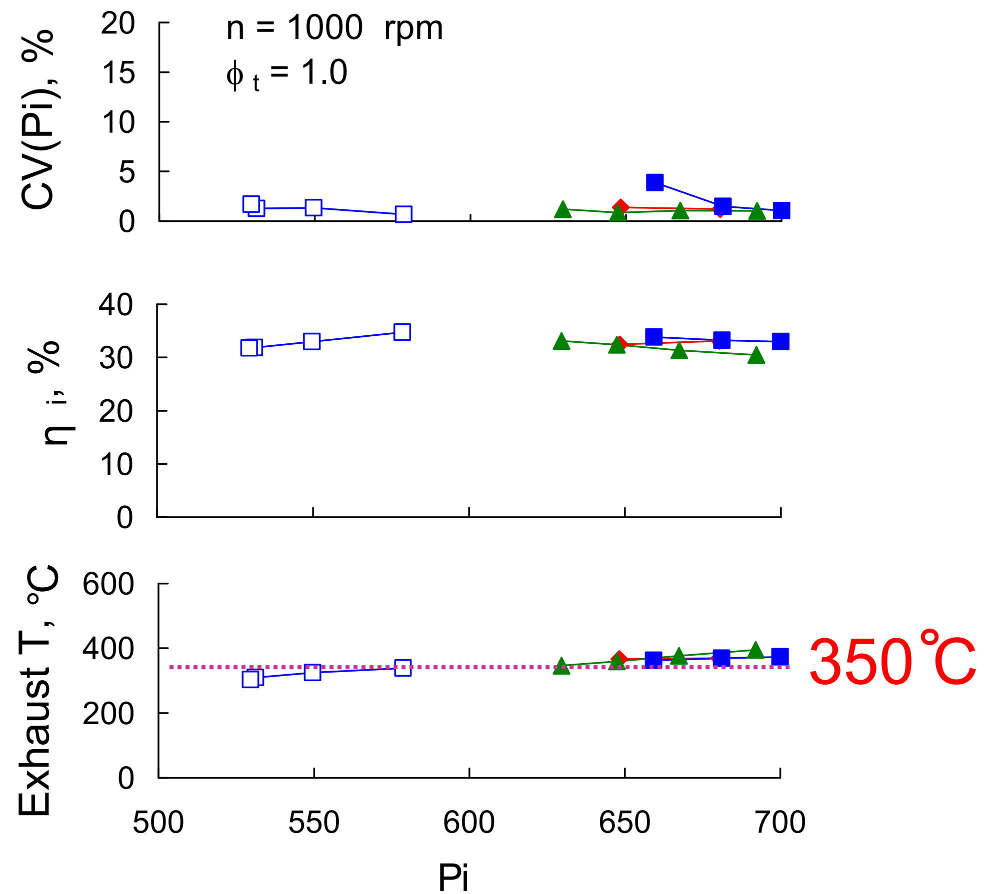
	●	▲	■	◆	□



Stoichiometric conditions

(1) When the injection timing of diesel fuel is advanced, the range of equivalence ratio for the engine operation becomes narrow.

However, the engine can operates even in stoichiometric mixture owing to N_2-dilution.

Under the condition of stoichiometric mixture, smoke can be seen when the injection timing is 20 degrees BTDC though smoke is not seen when the injection timing is 40 and 50 degrees BTDC.

This is because there is no rich region of fuel due to the diffusion of the diesel fuel in the early injection.

Conclusions (1)

(2) The peak of the rate of heat release is retarded in the early injection timing. The exhaust emissions of NOx are very low and HC and CO are almost the same while thermal efficiency increases slightly.

(3) In the early injection timing without N_2-dilution, when the equivalence ratio increases, the effective work decreases because the maximum value of the heat release is advanced and thermal efficiency decreases.

(4) The value of the hydrocarbons in the early injection is smaller than those in the normal injection timing though the absolute value seems to be large.

Conclusions (2)

3) Recent research and tools

a) Spectroscopic analysis of burned gas

Small fiber optics is used for local spectroscopic analysis. OH, CH and C_2 radicals are detected and combustion characteristics such as heat release rate, flame developing speed.

b) Local gas temperature measurement using interferometry system

Interferomerty technique is applied to measure temperature history of the gas with a small sensor that is developed in my laboratory. The degree of homogeneity of the temperature in the cylinder can be obtained.