Studies for High-Efficiency Clean Natural Gas Engines

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Kyoto University**

Contents

1. Background and purpose of our research

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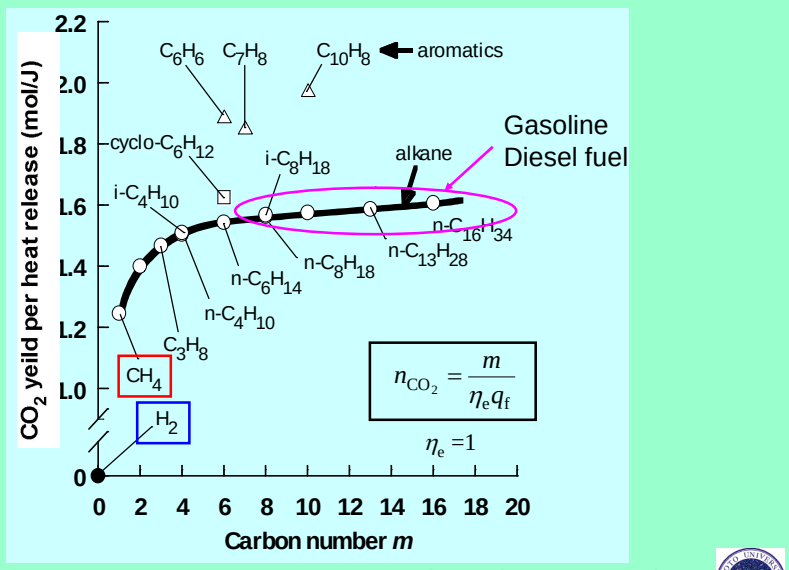

CO_2 emission from combustion of hydrocarbons

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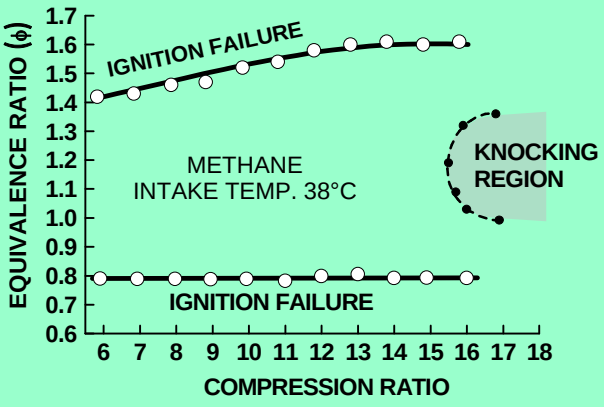
Properties of fuels

	Methane	Natural Gas (13A*)	Gasoline	Diesel fuel (Light oil)
Density (kg/m³)	0.652	0.779	770	840
Theoretical Air-Fuel ratio	17.2	16.7	15.1	14.5
Flammability limit (vol%)	5~15	4~14	1.4~7.6	0.6~5.5
C/H (mol/mol)	0.25	0.27		0.53
Octane number (RON)	–	117	90	(20)
Cetane number	–	–	(10)	55
Heat value (LHV) (MJ/kg)	50.2	49.3	46.7	44.6

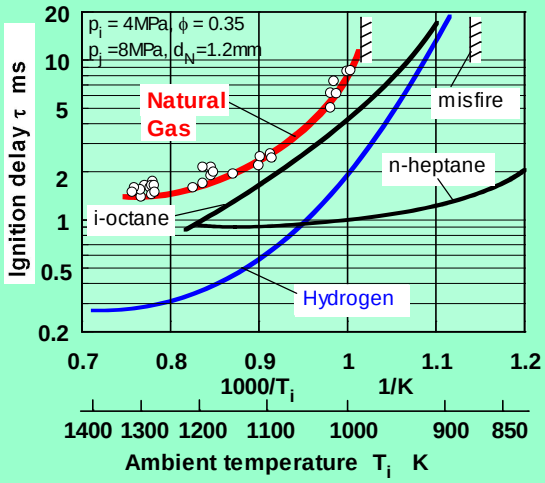
*Typical composition: CH_4:88%, C_2H_6:6%, C_3H_8:4%,C_4H_{10}:2%

Available operating range of a NG-SI engine



Karim,G.A., The Dual Fuel Engine of the Compression Ignition Type, SAE Paper No. 831073, (1983), pp.3.569-3.577.

Ignition delay of a natural gas jet



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Classification of gas engines

Type			Fuel supply	Ignition	Characteristic
Stoichiometric-burning			Premixed charging (Mixer, port injection)	Spark ignition	3-way catalyst knock
Lean burning	Homogeneous premixed charge		Premixed charging (Mixer, port injection)	Spark ignition	oxidation cat.
				Pilot fuel ign.	
				Compression	intake heating, supercharging, low NOx
	Stratified combust.	Sub-chamb.	Premixed charging (Mixer, valve in sub-chamber)	Spark ignition	ultra lean, low NOx
		Direct injection	Gas injection (in-cylinder)	Spark ignition	high compress. ratio, reduced pumping loss, high-press. gas
				Pilot fuel ign.	
				Glow-plug ign.	

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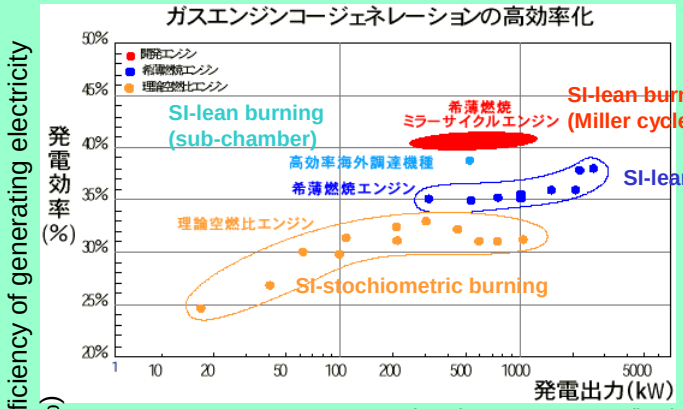
Engine type and thermal efficiency



Osaka Gas home page: http://www.osakagas.co.jp

Research in our lab

For higher thermal efficiency:

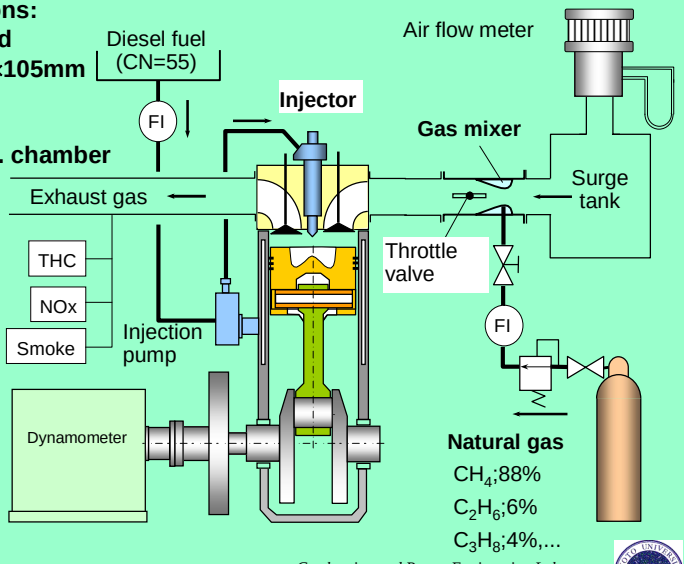
Higher compression ratio
Non-throttling operation

- **Dual-fuel engines**
- **Direct-injection glow-plug ignition engines**
- **PCCI engines**

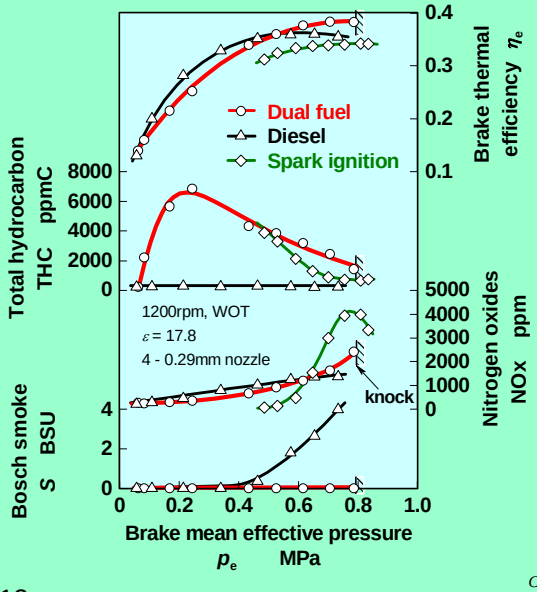
2. Dual-fuel natural gas engine

Test engine system (Dual fuel operation)

Engine specifications:
Naturally aspirated
Bore×stroke=102×105mm
Comp.ratio=17.8
Swirl ratio=2.6
Toroidal combust. chamber
4×0.24mm nozzle
7.5mm plunger



Basic characteristics of performance and emissions (Dual fuel)



compression ratio:
Dual fuel : 17.8
Diesel : 17.8
Spark ign.: 11.5

Higher loads:
- >Remarkable reduction of smoke
- >High thermal efficiency
- >Onset of knock

Lower loads:
- >THC emission
- >Low thermal efficiency

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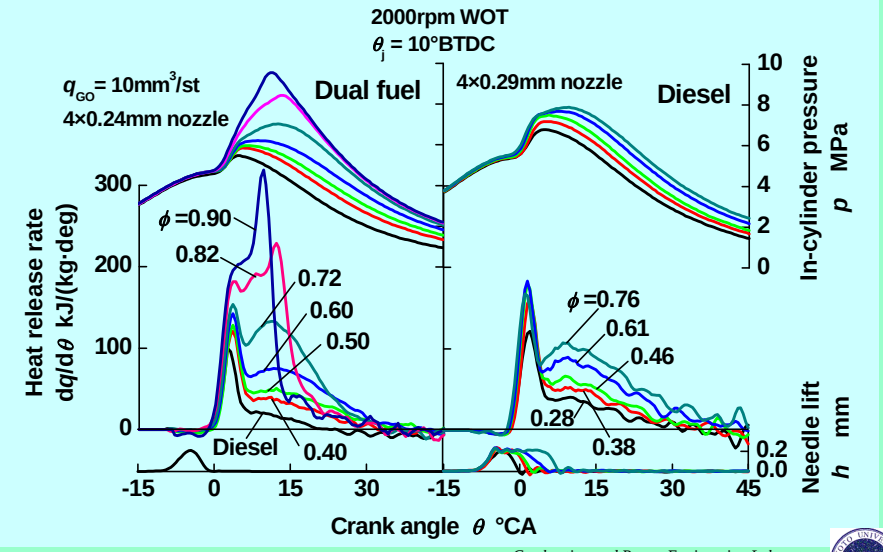
Heat release rates (Dual fuel)



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Strategy for improving performance

	Higher engine output	Lower engine output
Problem:	Onset of knock	Low thermal efficiency high HC emission level
Cause:	Excessive energy input into natural gas mixture	Incomplete combustion of lean natural-gas mixture
Measures:	Reducing pilot fuel amount Retarding pilot fuel injection timing	Avoiding too lean mixture by throttle valve control Enhancing ignition by increase in amount of pilot fuel

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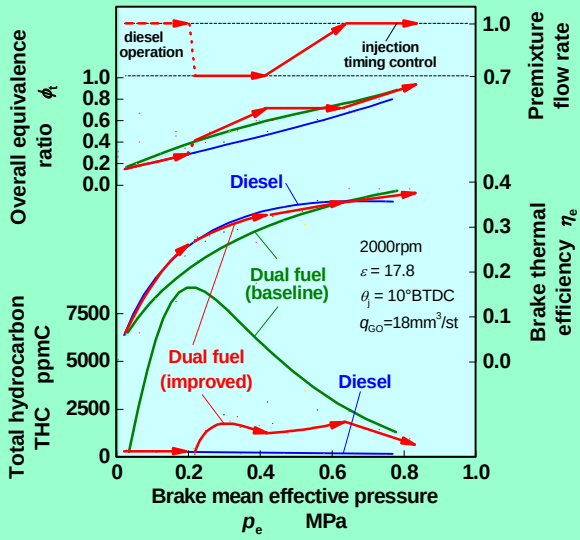
Demonstration of improved operation



>Diesel operation for low loads

>Weak throttling for middle load range (using richer mixture)

>Pilot injection timing control to suppress knock

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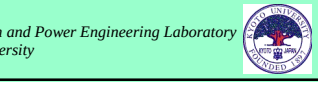
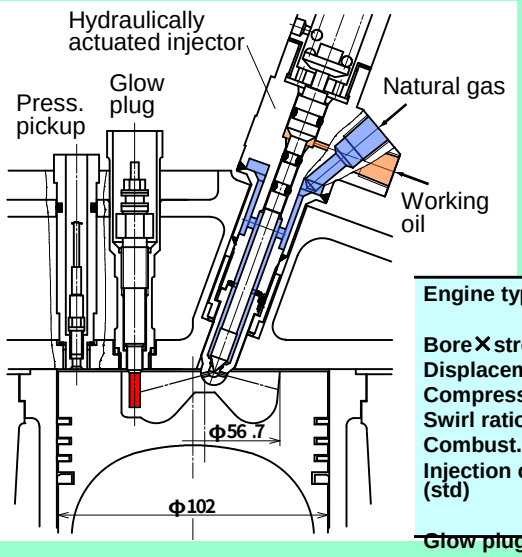
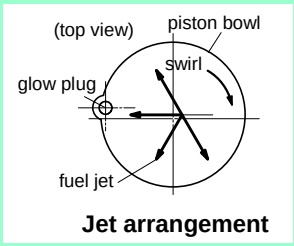
3. Direct-injection glow-plug ignition engine



Test engine (Glow-plug ignition)

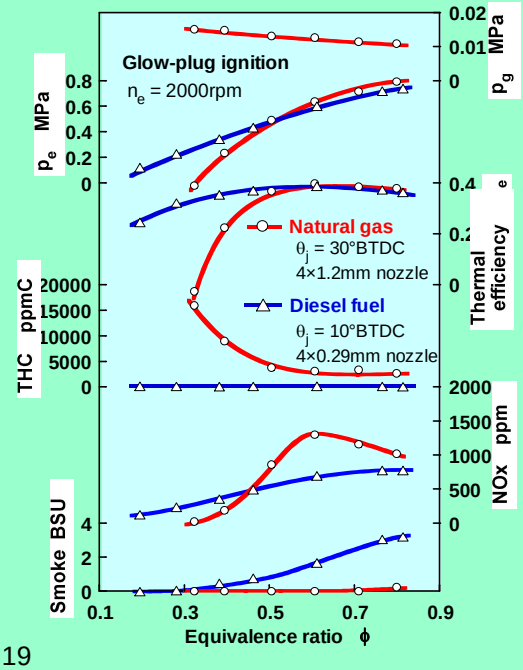




Jet arrangement

Engine specifications

Engine type	**4 stroke-cycle, Single-cylinder, Water-cooled**
Bore×stroke	**102mm×105mm**
Displacement	**857cm^3**
Compress. ratio	**17.8 : 1**
Swirl ratio	**2.6**
Combust. chamber	**Deep-bowl toroidal**
Injection cond. (std)	**4×1.2mm nozzle NG press.=8MPa**
Glow plug temp.	**1625K**



Basic characteristics of performance and emissions (Glow-plug ignition)

Higher loads:
>Very low smoke
>High thermal efficiency
>High NOx level

Lower loads:
>THC emission
>Low thermal efficiency

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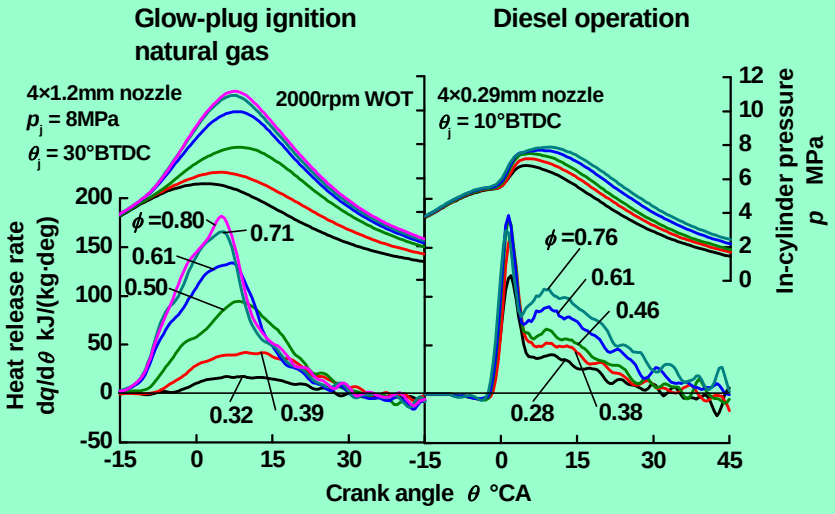
Heat release rates (Glow-plug ignition)



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Strategy for improving performance

Problem: **Higher engine output**

High NO emission level

Lower engine output

Low thermal efficiency high HC emission level

Cause:

High temperature due to high heat release rate

Incomplete combustion of lean natural-gas mixture

Measures:

Exhaust Gas Recirculation

Retarding injection timing Reduced swirl ratio

Keeping combustible mixture around a glow plug

Enhancing ignition by increase in injection pressure

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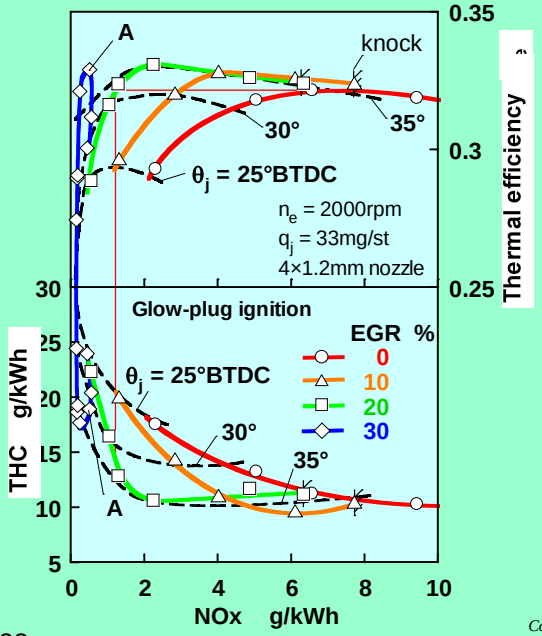

NOx reduction by EGR

> NOx reduction without penalty of thermal efficiency (no increase in smoke)

> Increase of unburned species

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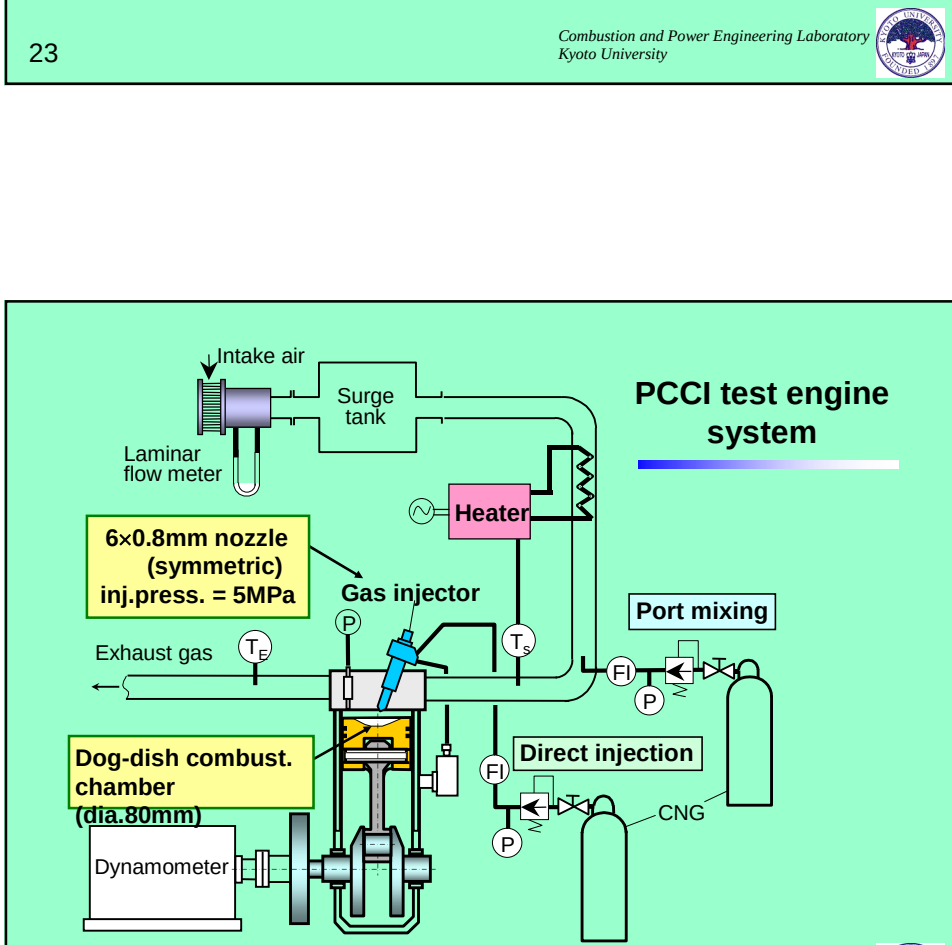
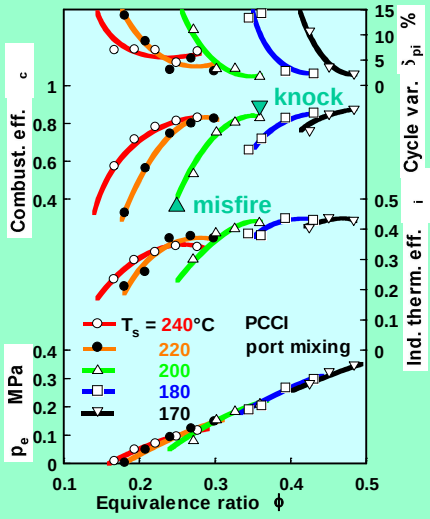
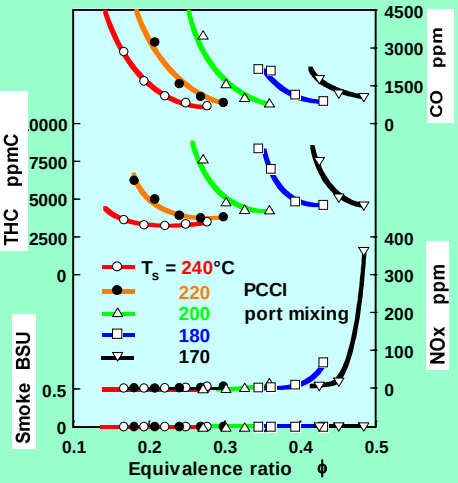
4. Premixed Charge Compression Ignition Engine



PCCI test engine system

Performance and emissions (premixed charge)





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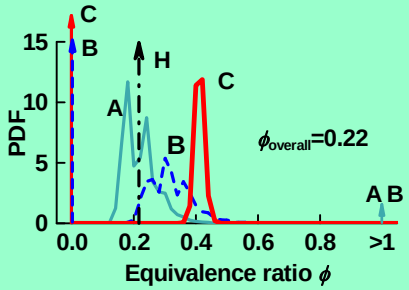
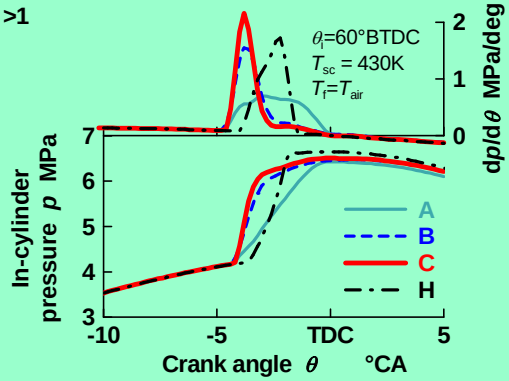


Effect of mixture heterogeneity (Stochastic CFD)

> PDF of equivalence ratio affects the rate of pressure rise
→ control of mixture formation can be a means to stabilize ignition at lean conditions and to suppress knock at rich conditions



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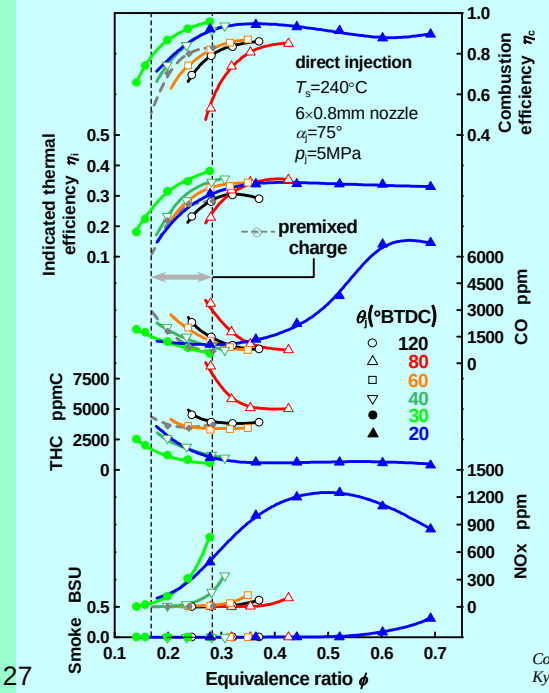

Effect of injection timing (direct injection)

> Possibility of extending operating range

> Lower unburned species, but higher NOx emission

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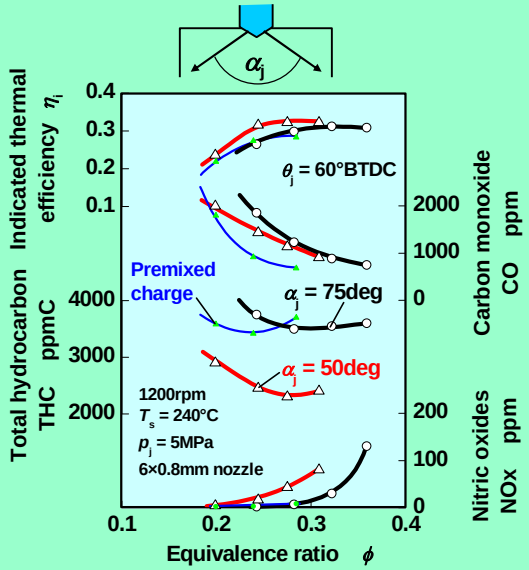

Effect of injection parameters (injection angle)

> Higher thermal efficiency and lower unburned species emissions than premixed charge operation

Suppression of cooling of mixture on cylinder wall
Suppression of formation of excessively lean mixture

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Summary (1)

Dual-Fuel engine:

> Diesel-equivalent thermal efficiency with almost no smoke emission at high loads

> Low thermal efficiency at middle and low loads
← control of throttle and pilot fuel injection

> Conversion of diesel to natural gas engines
← minor modifications

Summary (2)

Glow-plug ignition engine:

> Diesel-equivalent thermal efficiency with almost no smoke emission at high loads

> NOx emission at higher loads
← EGR

> Low thermal efficiency at lower loads
← increased jet momentum, glow-plug shield

> For heavy duty engines (dedicated)

Summary (3)

PCCI engine:

> (possible) high efficiency low NOx, PM

> High compression temperature and pressure
← supercharging

> Restricted output range
← direct injection, EGR, variable compression ratio

> Combination with SI or other combustion techniques?

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