Capri, September 14-18, 2008

30th IEA / Collaborative Task – HCCI

Two-stage combustion – multipoint autoignition of end gas region of natural gas and air mixture without knock

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(1)Early injection of High cetane number fuel

→multipoint ignition

→ flame development of high octane number fuel

- SAE Paper No.2002-01-2723
- 1st HCCI symposium (at Berkeley) in 2004

(2) Flame development → autoignition, but not knock

→ another flame development

- KONES2008 (in Poland)

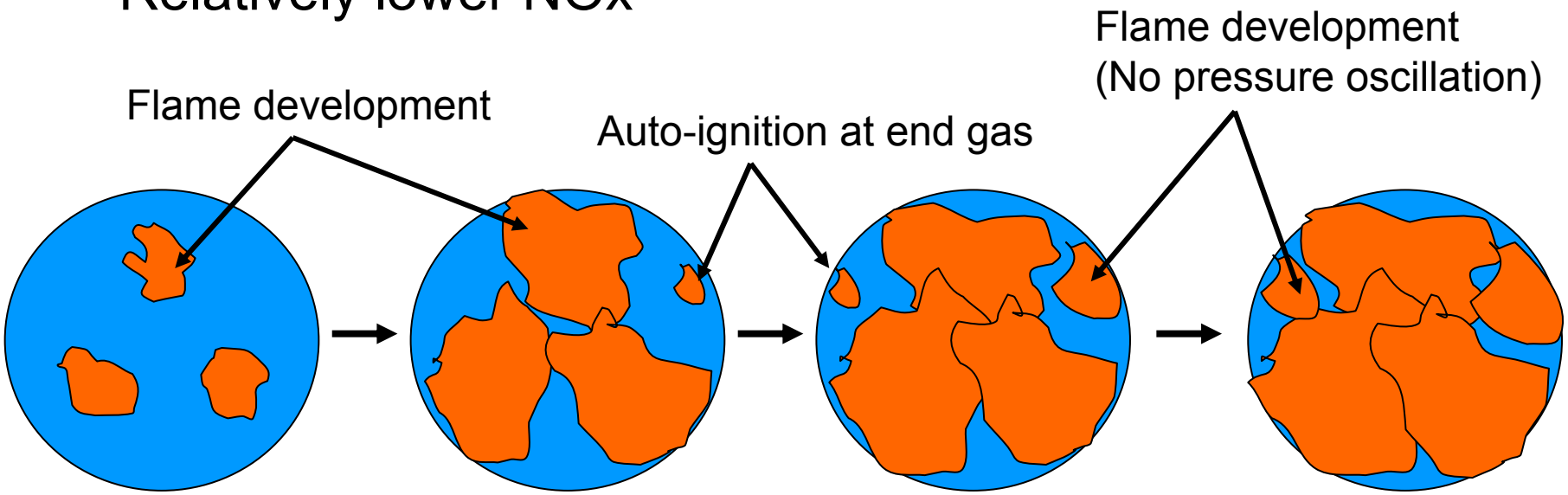
Dual fuel engine: natural gas (high octane number fuel)
+ diesel fuel (High cetane number fuel)

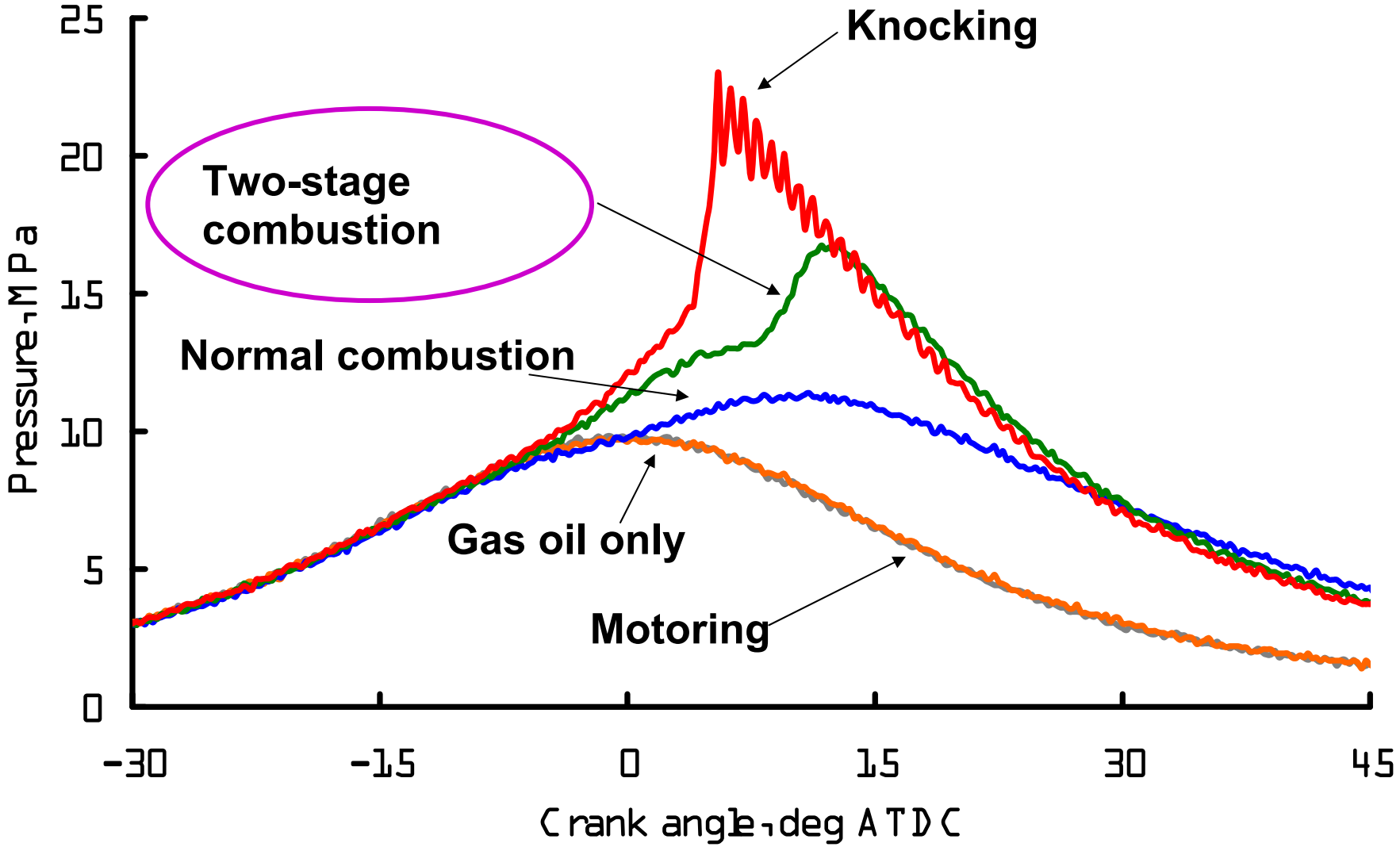
(2) Flame development → autoignition, but not knock → flame development (Two-stage combustion)

Engine: Lean burn natural gas engine ignited with diesel fuel (Gas oil)

Features

- Higher thermal efficiency
- Lower HC
- Relatively lower NOx





Engine speed=1000rpm, ϕ_t=0.6, m_{go}=2.0mg/cycle, P_{in}=200kPa

Natural gas engine ignited with pilot diesel fuel

Development of natural gas engine for co-generation

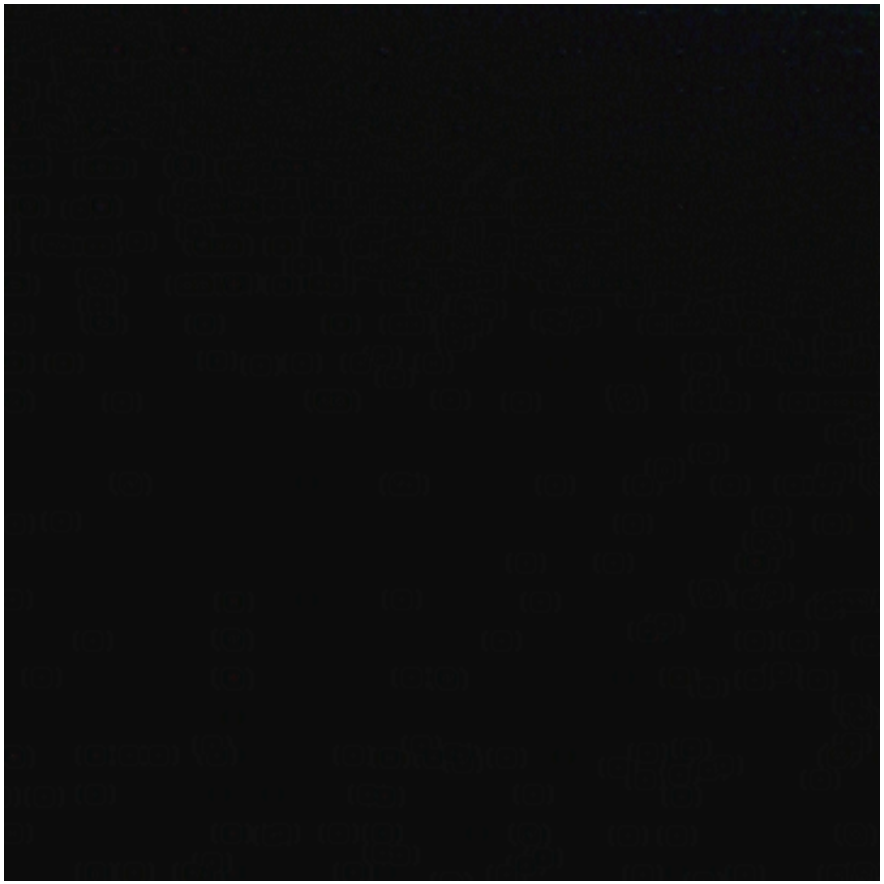
Clean, rich amount,
high ignition temperature

Selecting ignition method

- Spark
- HCCI
- Dual fuel system

Dual fuel system

Natural gas-air mixture is ignited by a small amount of diesel fuel injected into cylinder.

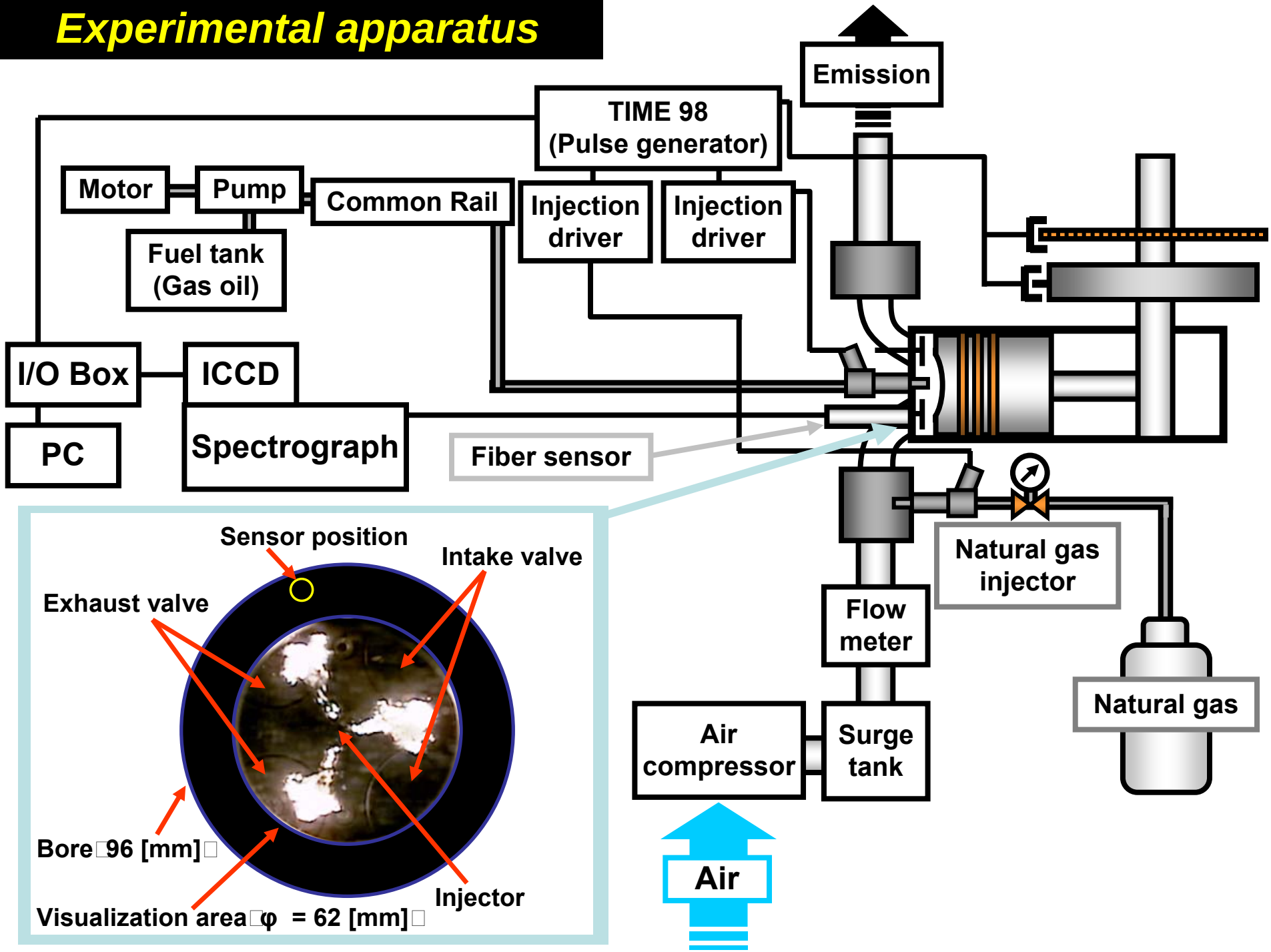


Pilot injection (4hole)
Fuel (diesel fuel+pyrolysis gas)
Biomass gas made of wood tip

High ignition energy

Background

Experimental apparatus

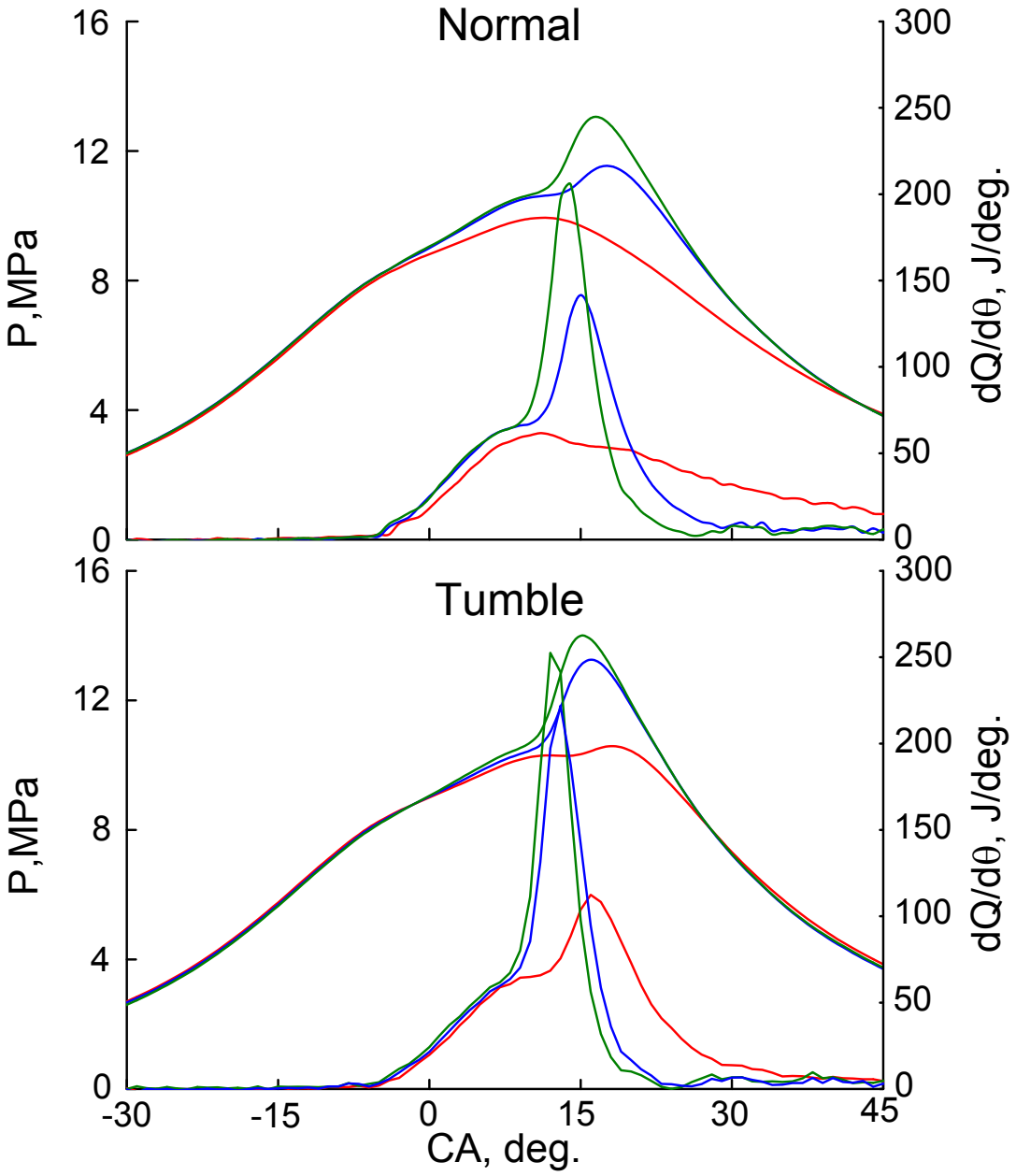


Bore × Stroke : 96 × 108 [mm]
Compression ratio : 16.0
Combustion chamber : Shallow dish

Cylinder head:
Normal and Tumble

Engine speed	n=1000rpm
Gas oil injection timing	θ_{inj}=6°□11°BTDC
Gas oil injection pressure	P_{inj}=40MPa
Gas oil injection quantity	m_{inj}=2 mg/cycle (φ=0.016)
Nozzle	3holes (φ0.10mm)
Boost pressure	P_{in}=200kPa(abs.)
Equivalence ratio	φ_t=0.59, 0.61, 0.62

Operating conditions



ϕ_t=0.61

θ_{inj}= 8 deg.BTDC

8.5°

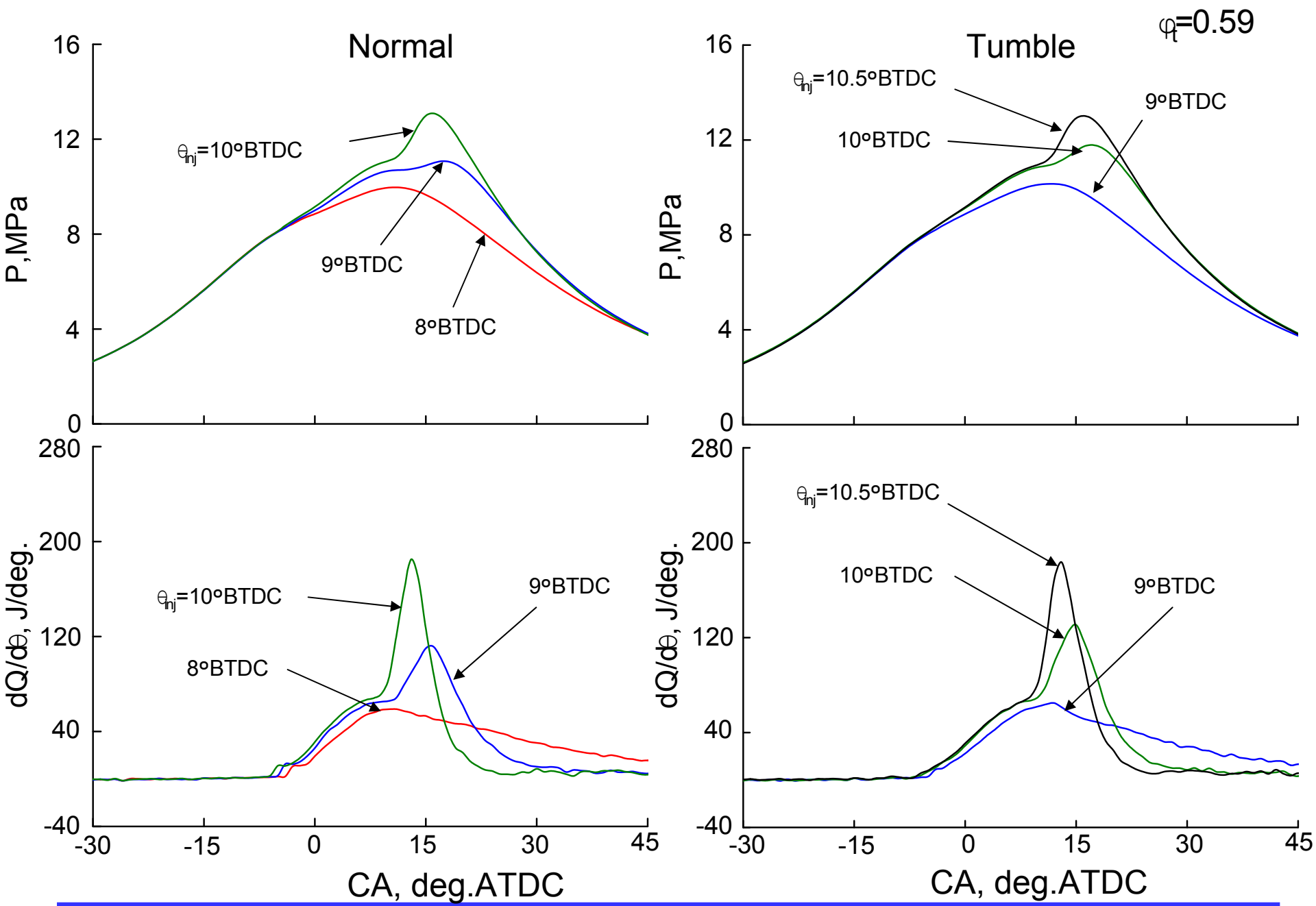
9°

At θ_{inj}=8°BTDC, two stage combustion could be seen in tumble head, while two stage combustion could not seen in normal head.

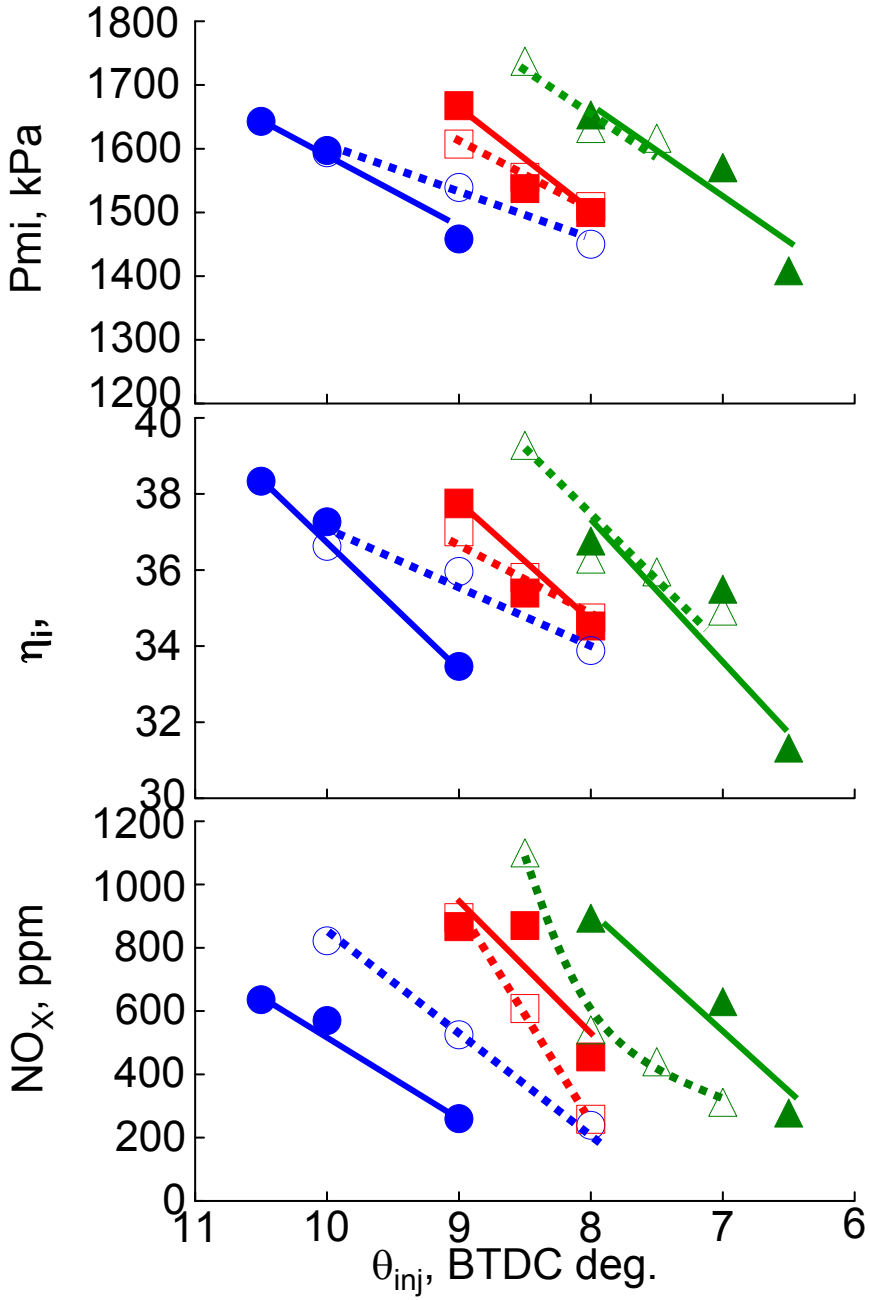
When injection timing of diesel oil is advanced, two-stage combustion was seen under the condition of both cylinder head.

Strong two stage combustion leads to short combustion period

Pressure and rate of heat release



Effect of gas flow on combustion



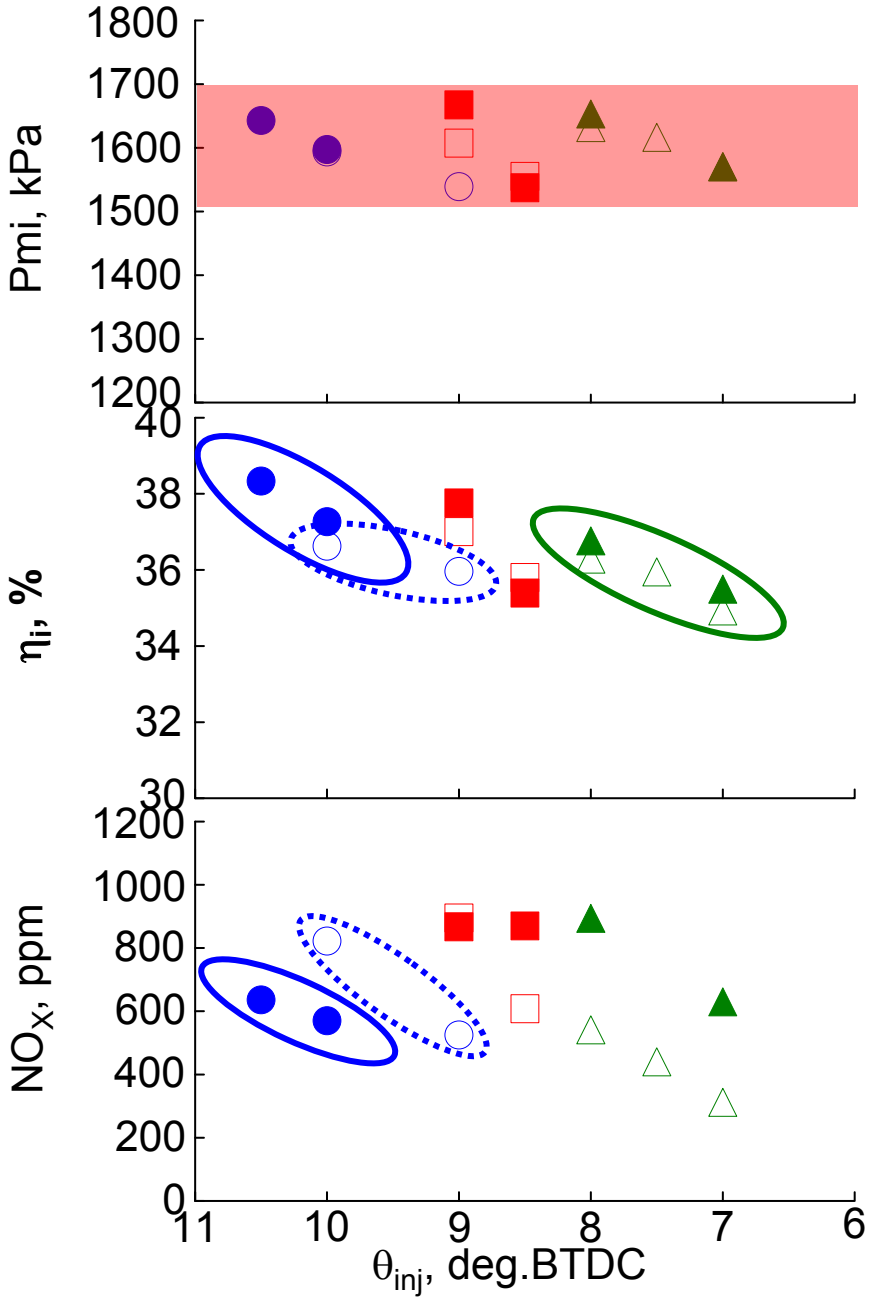
ϕ_t	0.59	0.61	0.62
Tumble	●	■	▲
Normal	○	□	△

Advance of injection timing of diesel fuel leads to higher engine output, higher thermal efficiency and higher NOx.

In two stage combustion, higher output and higher thermal efficiency was performed even in smaller equivalence ratio.

In leaner case, tumble is better for lower NOx emissions in higher thermal efficiency.

Combustion and exhaust performance



ϕ_t	0.59	0.61	0.62
Tumble	●	■	▲
Normal	○	□	△

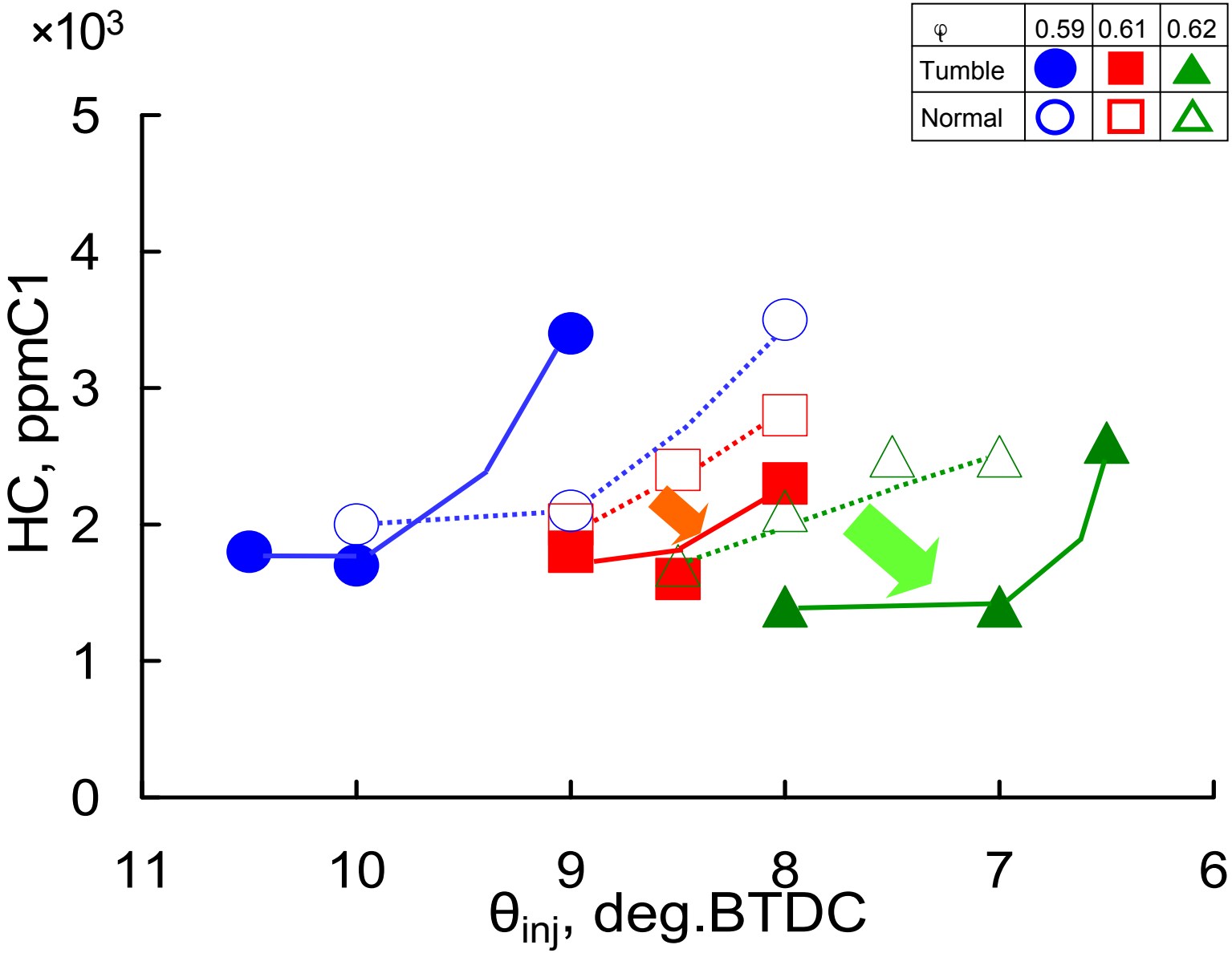
Two-stage combustion

-Higher output (Pmi)

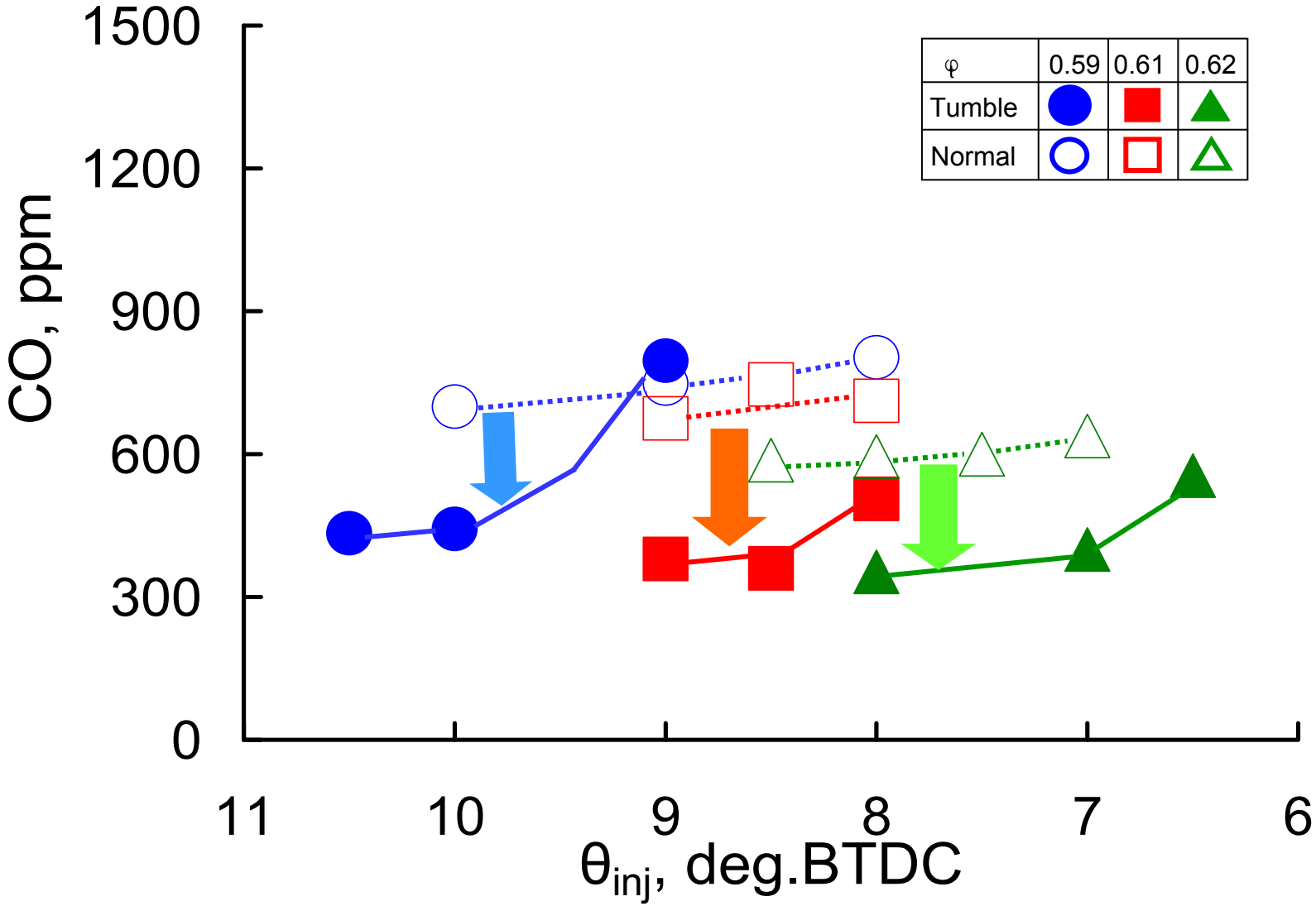
-Higher thermal efficiency

For ϕ_t=0.59 (leaner condition), Lower NOx and Higher thermal efficiency were achieved.

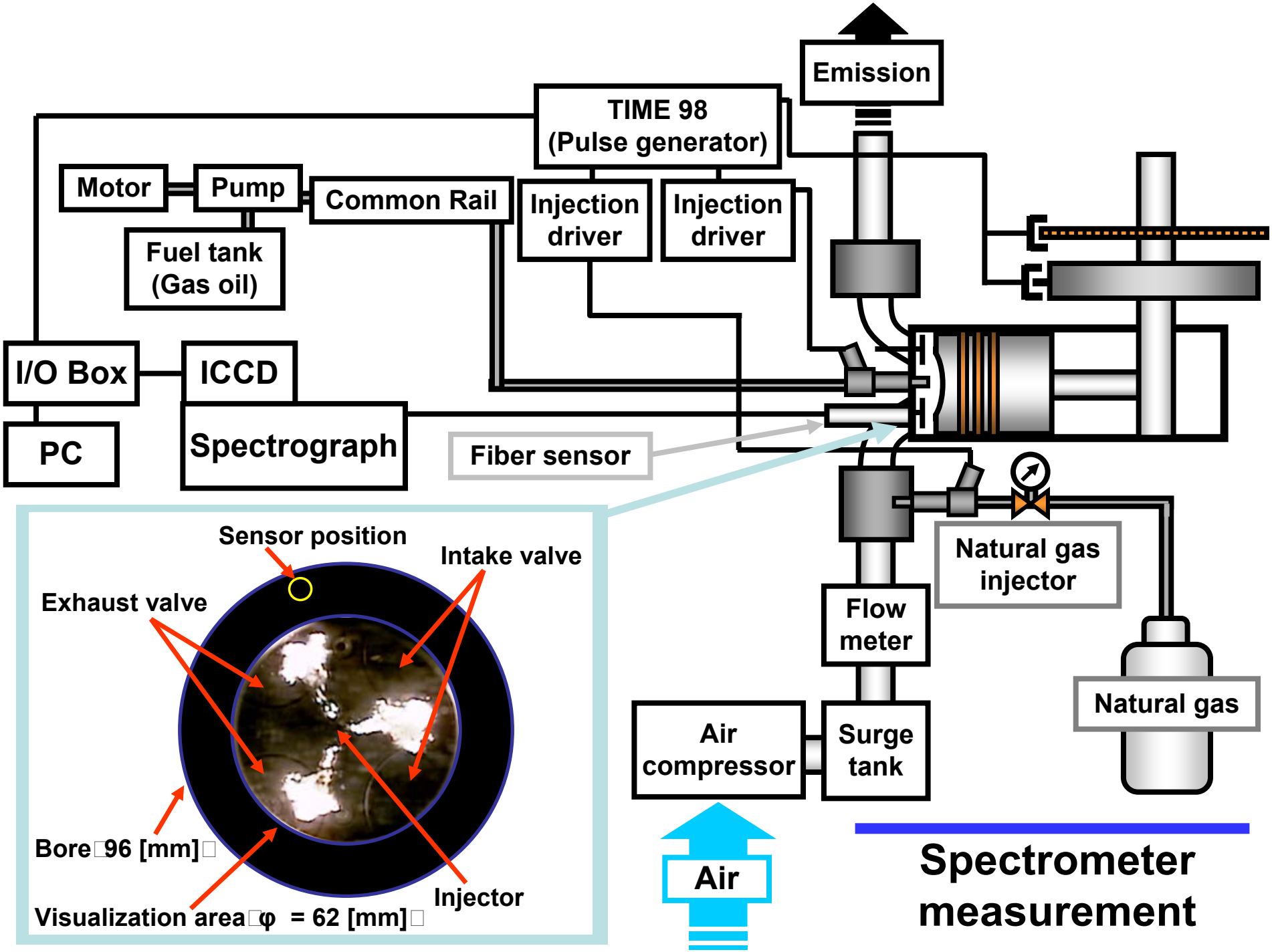
Combustion and exhaust performance

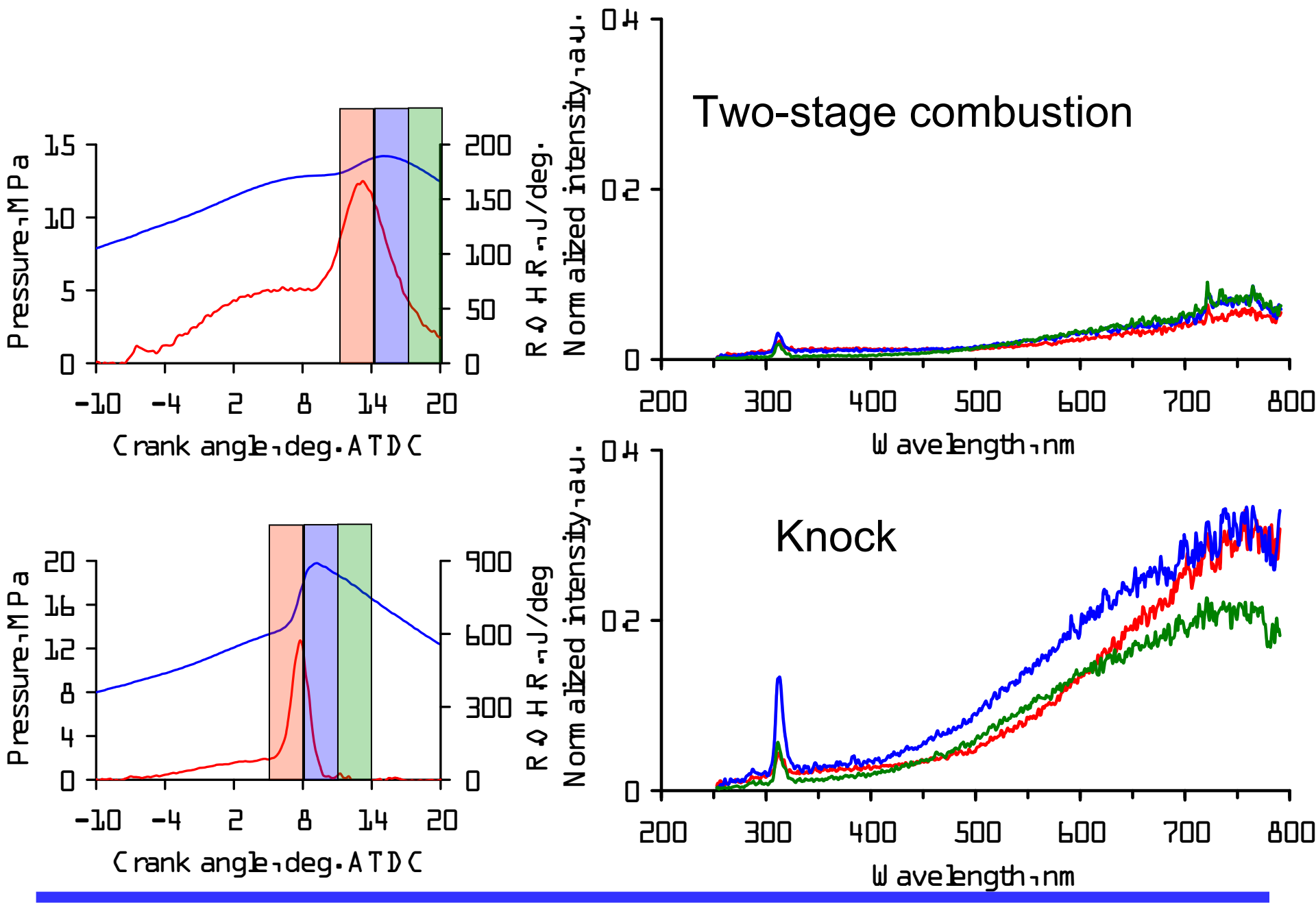


HC emissions



Emission of carbon monoxide


Emission
TIME 98
(Pulse generator)
Motor
Pump
Common Rail
Injection driver
Injection driver
Fuel tank
(Gas oil)
I/O Box
ICCD
PC
Spectrograph
Fiber sensor
Natural gas injector
Flow meter
Natural gas
Air compressor
Surge tank
Air
Sensor position
Intake valve
Exhaust valve
Bore 96 [mm]
Injector
Visualization area φ = 62 [mm]
Spectrometer measurement



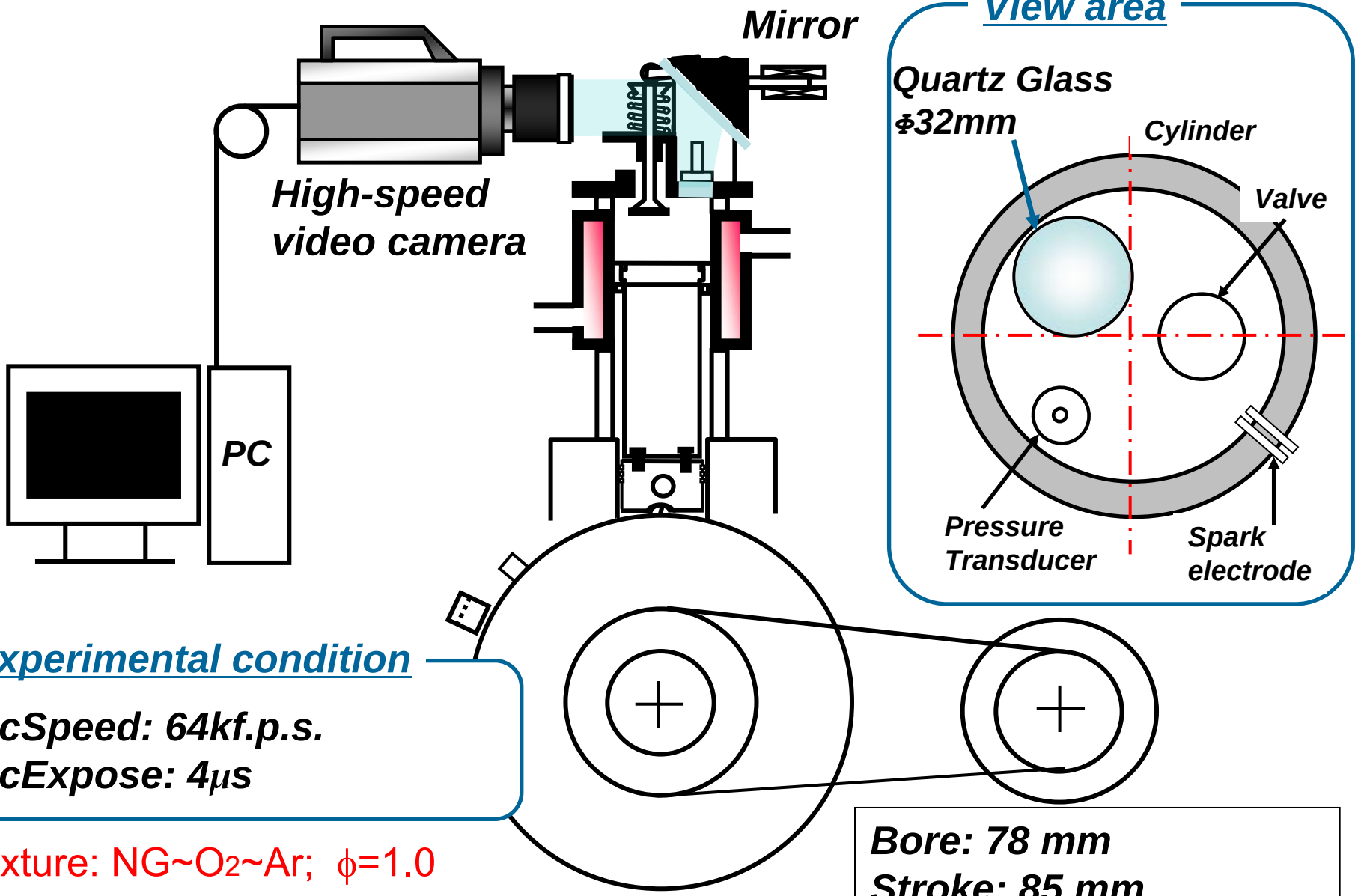
Chemiluminescence emitted from combustion

Two-stage combustion

Knock occurs at some operating conditions even in lean burn natural gas engines. But, a very attractive combustion can be achieved at some operating conditions between normal combustion and knock. At first, natural gas and air mixture is ignited with diesel fuel. Thereafter, flame develops in the premixed mixture with turbulence. The end gas reaction proceeds during the flame development. And sometimes auto-ignition occurs in the end gas regions. This is the initiation of the knock with pressure oscillation in the cylinder.

But in rare case, the knock does not occur and flame development starts from the auto-ignition regions. The rate of heat release increases larger than normal combustion from the middle of the combustion stage and the combustion completes very early timing. Under this operating condition, thermal efficiency increases and HC emissions decreases although NOx emissions increases a little. The research has started from this year. This study will be useful for increasing thermal efficiency in high load in natural gas engines.

Summary



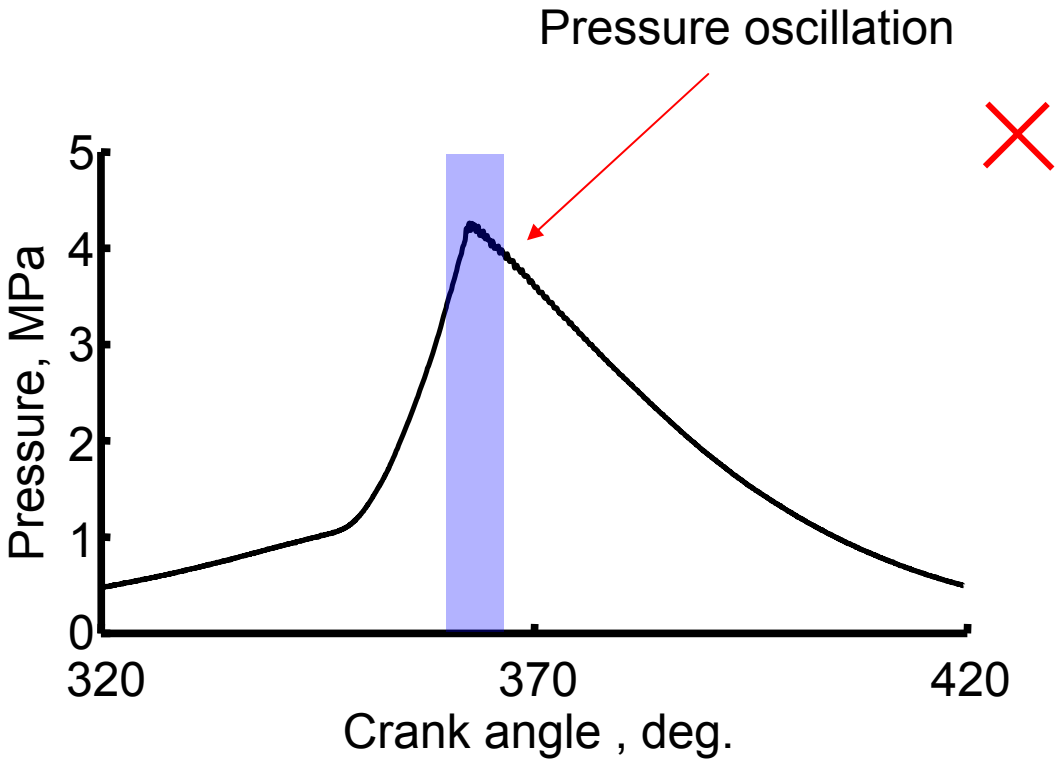
Experimental condition

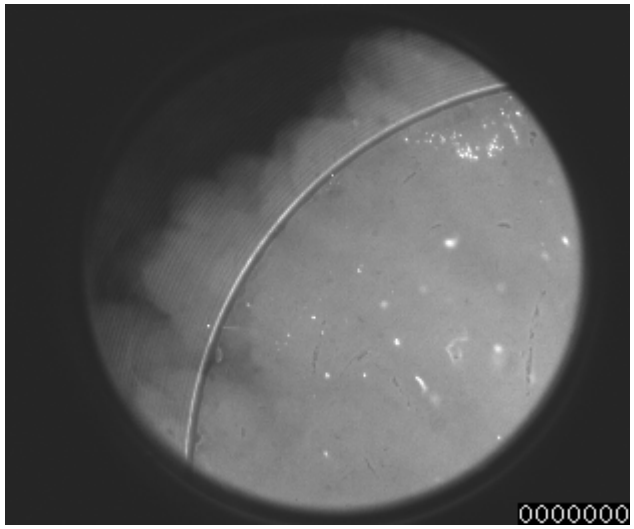
RecSpeed: 64kf.p.s.
RecExpose: 4μs

Mixture: NG~O_2~Ar; ϕ=1.0

Bore: 78 mm
Stroke: 85 mm
Compression ratio: 9.02
Engine speed: 600 rpm

Experimental apparatus





Auto-ignition

Knock (Pressure oscillation)

Fuel : Natural gas-O_2-Ar

Equivalence ratio : 1.0

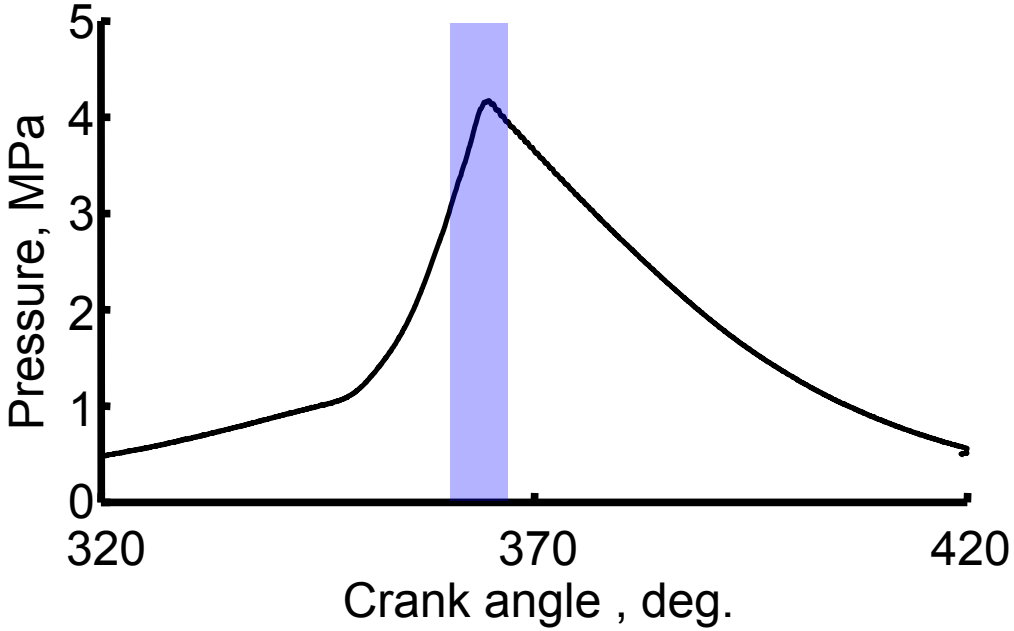
Initial pressure : 80kPa

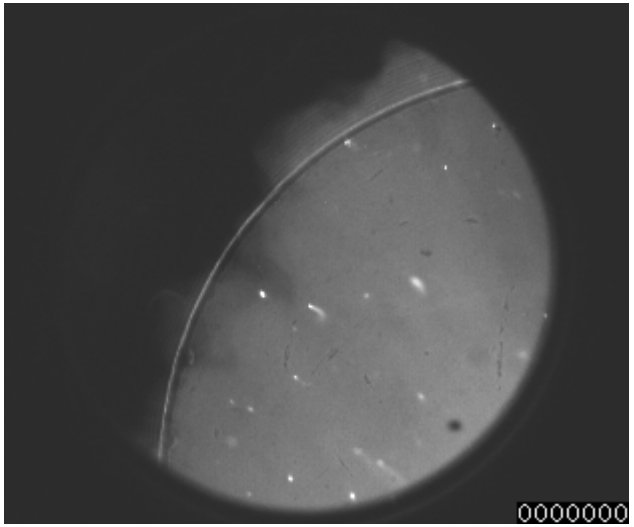
Initial temperature : 323K

Ignition timing : 345deg.

Rec.speed : 64kfps.

Knock intensity : 0.111MPa





Auto-ignition

↓

Flame development

(No pressure oscillation)

Fuel : Natural gas-O_2-Ar

Equivalence ratio : 1.0

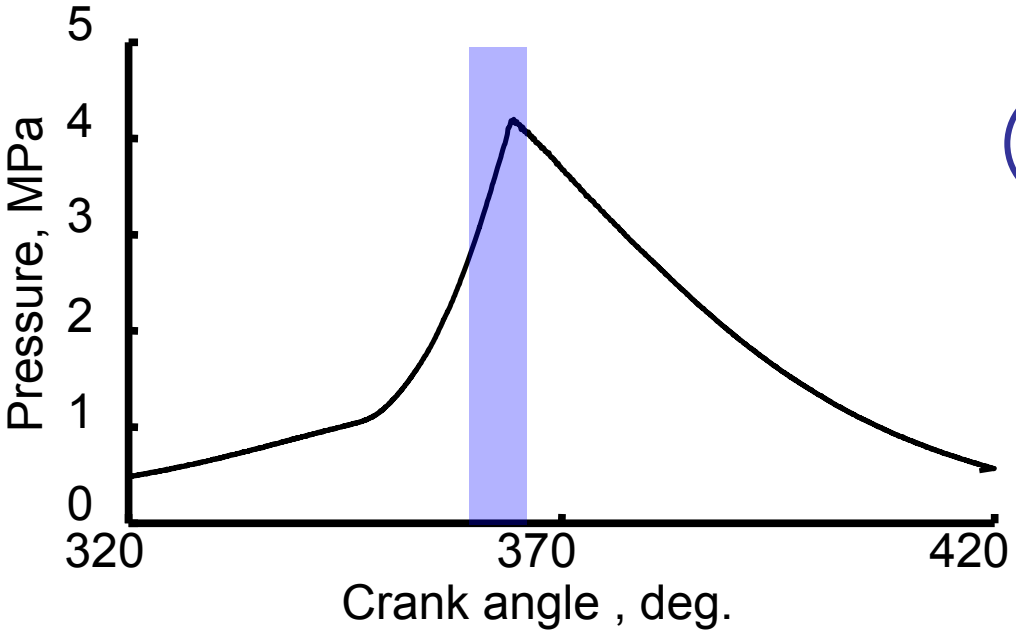
Initial pressure : 80kPa

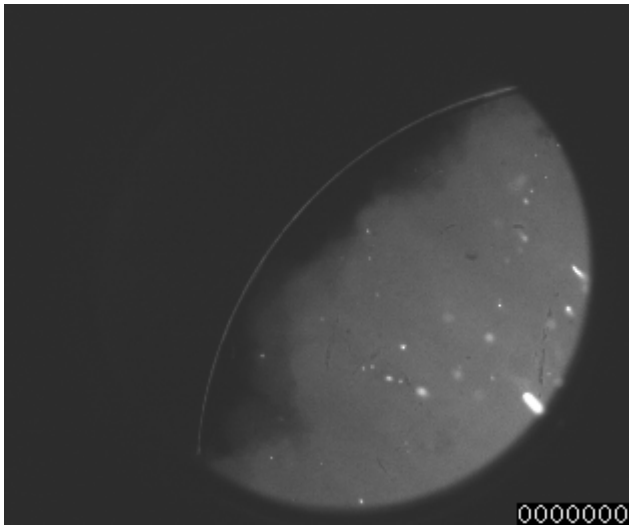
Initial temperature : 323K

Ignition timing : 345deg.

Rec.speed : 64kfps.

Knock intensity : 0.039MPa





Auto-ignition occurs in some part of the end gas regions.

↓

Flame development

↓

Knock (Pressure oscillation)

Fuel : Natural gas-O_2-Ar

Equivalence ratio : 1.0

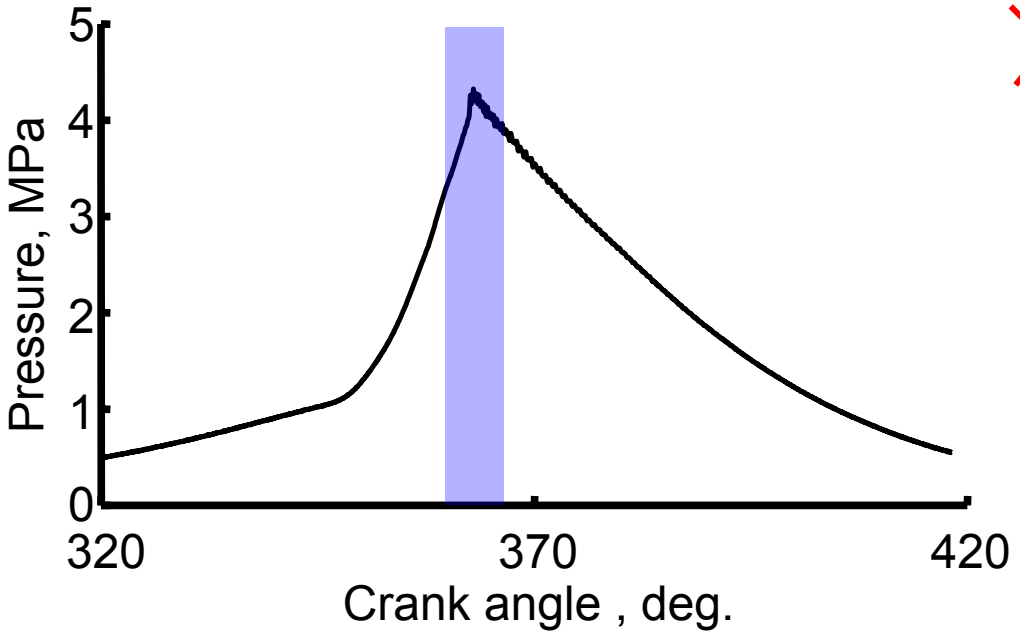
Initial pressure : 80kPa

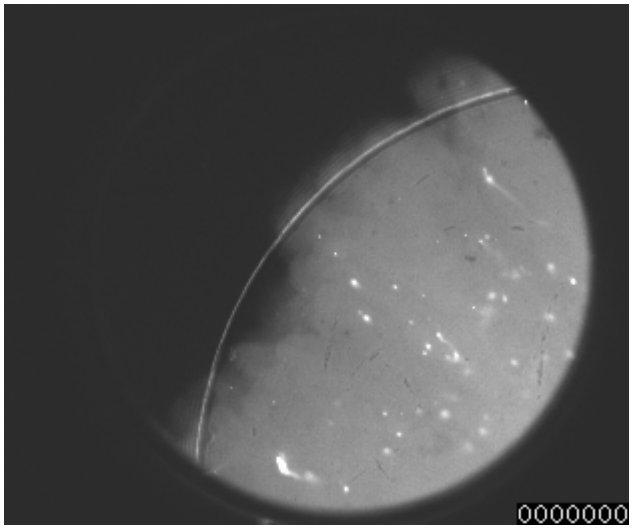
Initial temperature : 323K

Ignition timing : 345deg.

Rec.speed : 64kfps.

Knock intensity : 0.057MPa





Fuel : Natural gas-O_2-Ar

Equivalence ratio : 1.0

Initial pressure : 80kPa

Initial temperature : 323K

Ignition timing : 345deg.

Rec.speed : 64kfps.

Knock intensity : 0.154MPa