Feb. 29. 2015

CIMAC Cascades

Visual combustion studies for Dual Fuel and Gas Engines

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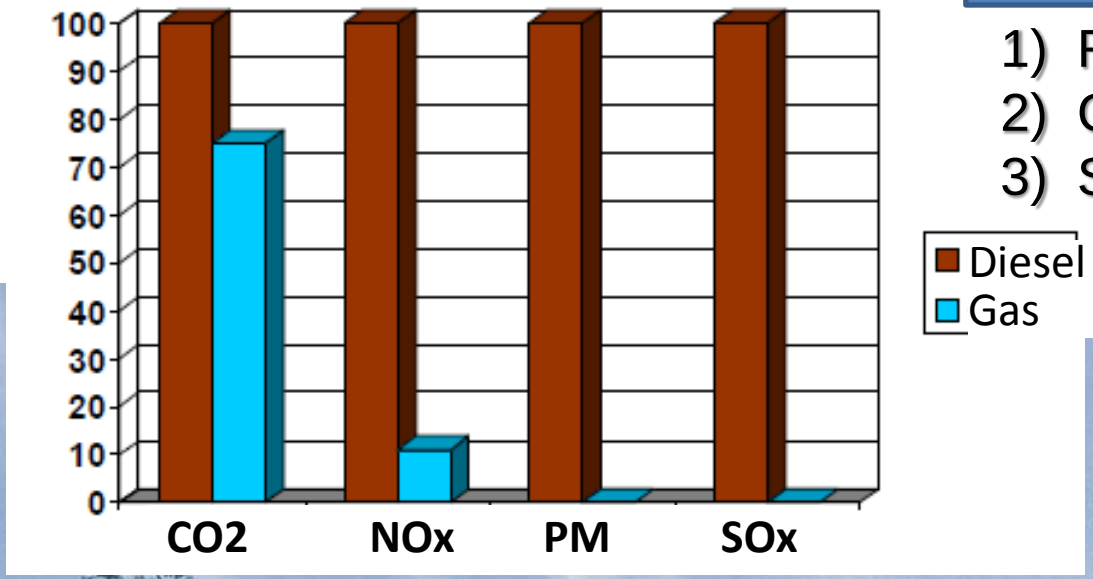
Contents

Marine diesel oil • • **C16H34 · · 16 CO2 +17 H2O + Q**

Natural gas • • **12 CH4 · · 12 CO2 +24 H2O + Q**

Effect on emissions reduction by changing marine fuel from diesel oil to natural gas



Issues to overcome for introducing LNG fueled ship

1) Regulation
2) Cost (initial and operation)
3) Supply Infrastructures

‘All-mighty’ effect of natural gas fuelled ship

Natural gas fueled ships in service

About 50 ships in North Europe driven by medium-speed 4-stroke lean-burn type gas engines (ferry, off-shore supply vessel, etc.).


Bergensfjord/ Fjord 1 (130m x 20m, DNV)

フェリー


Viking Energy/ Eidesvik (95m x 20m, DNV)

オフショア支援船


Bit Viking/ Tarbit Shipping (177m x 26m, GL)

ケミカルタンカー


Argonon/ Deen Shipping (110m x 16m, LR)

重油バンカー船 @オランダ・ロッテルダム港


Høydal/ Nordnorsk Shipping (70m x 16m, DNV)

貨物船（水産飼料運搬）


Viking Grace/ Viking Line (218m x 32m, LR)

Seagas/ Sirius Shipping (50m x 11m, DNV)

クルーズフェリー及び世界唯一のLNGバンカー船
@スウェーデン・ストックホルム港


EcoNuri/ Incheon Port Authority (36m x 8m, KR)

観光船 @韓国・仁川港


Barentshav/ Norwegian Coast Guard (93m x 17m, DNV)

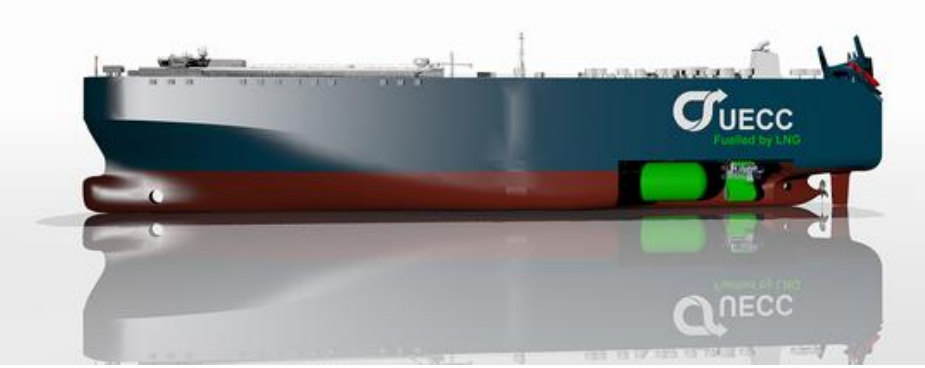
沿岸警備船


Francisco/ Buquebus (99m x 26m, DNV)

高速フェリー @豪州にて海上公試
（アルゼンチン⇔ウルグアイ航路）

Natural gas fueled ships from now

including large ships driven by low-speed 2-stroke natural gas engines.

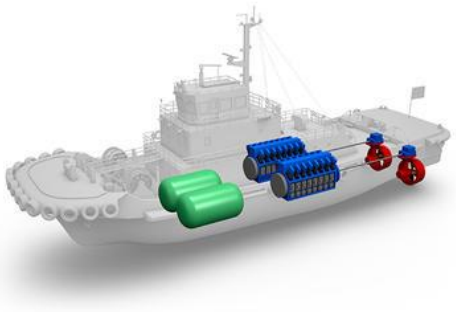


• United European Car Carriers (UECC) jointly owned by NYK and Wallenius Lines has ordered KHI two PCCs propelled by MAN low-speed ME-GI gas (DF) engine. (for voyage in European ECA)

• NYKとWallenius共同出資のUECC社が、MANの低速２ストGI（DF）エンジンを搭載した自動車運搬船を川崎重工に発注（欧州内ECAに投入予定）。

• TOTE Line has ordered 3,100TEU container ships propelled by MAN low-speed ME-GI gas (DF) engine. (Route: Florida⇔ Puerto Rico)

• 米国内航船社TOTE社が、MANの低速２ストGI（DF）エンジンを搭載した3,100TEUのコンテナ船を発注（フロリダ⇔プエトリコ航路に投入予定）



・Development of LNG-fuelled tug-boat by NYK Group・・ 2013～
（ClassNK is supporting development of not only vessel itself but also medium-speed DF engine）

• 負荷変動の激しいタグボートをLNG燃料化（NYKグループ）（政府と日本海事協会の支援）

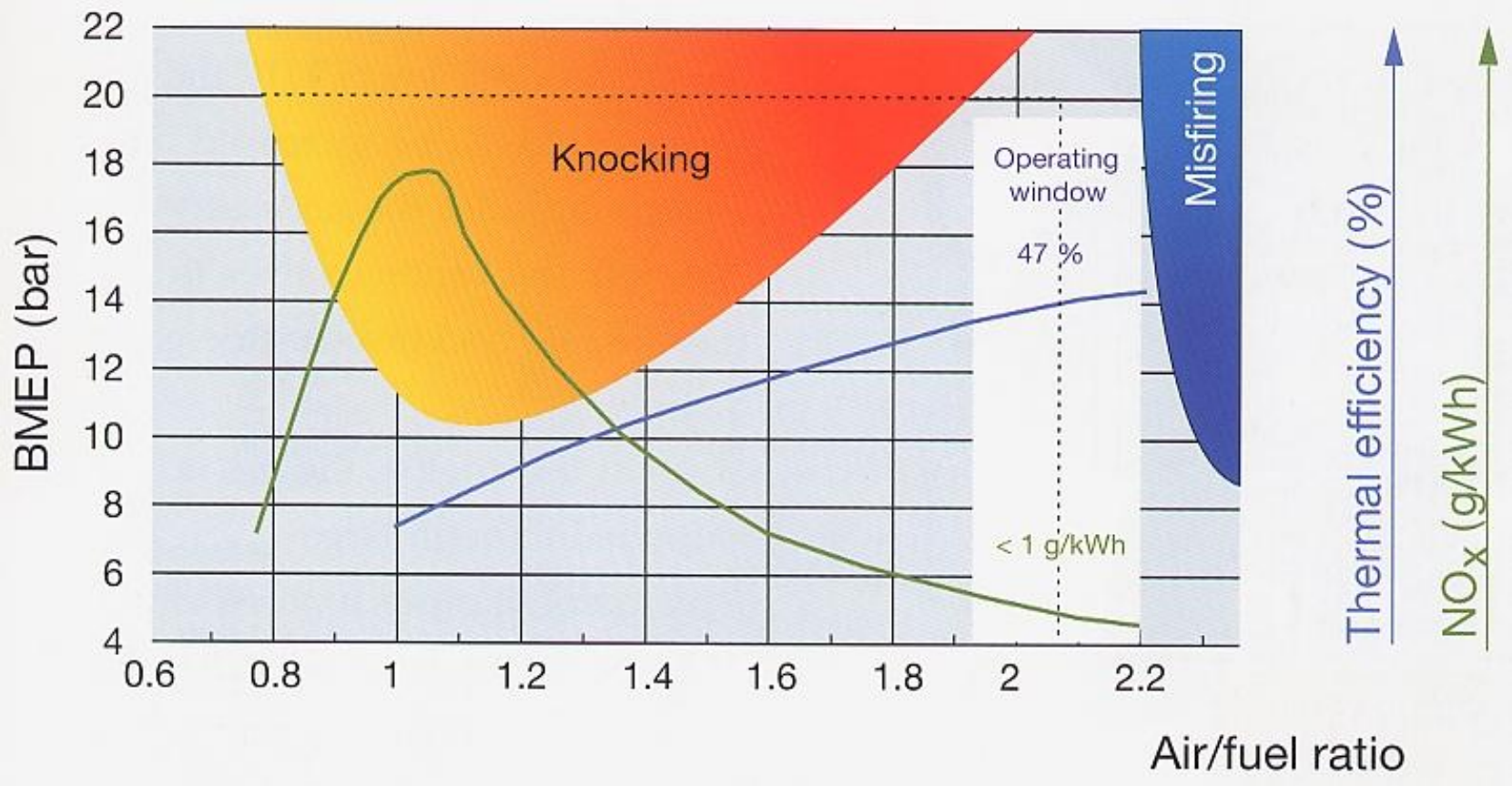
Table 1 Categorization of marine gas engines

	Direct coupling	Electric drive
Medium-speed 4-st.	Existing	Popular
Low-speed 2-st.	All	Nonexistent

	Mono-fuel	DF（Dual Fuel）
Medium-speed 4-st.	Existing	Popular
Low-speed 2-st.	Nonexistent	All

In case of **DF**, fuel can be switched instantly from gas to heavy fuel in an emergency like heavy knocking or gas-leak.

	Lean-burn (pre-mixed) (low-pressure gas supply)	**GI** (Gas Injection) (high press. gas injection)
Medium-speed 4-st.	Currently all	Possible but not yet applied
Low-speed 2-st.	Existing **Otto-cycle** type gas engine	Existing **Diesel-cycle** type gas engine



Possibility of abnormal combustion for lean burn gas engine

Wartsila company's data

Contents

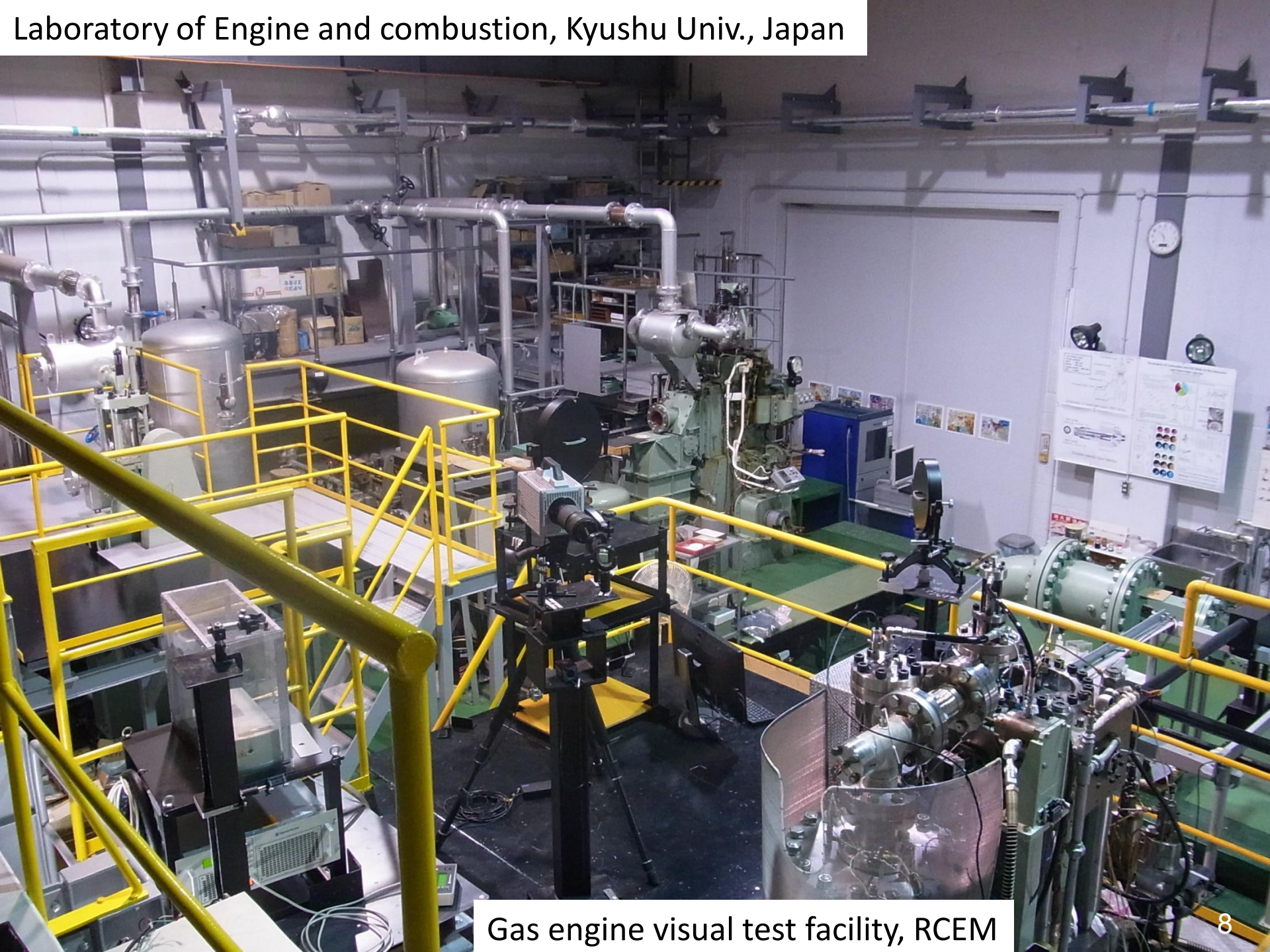
1. Real conditions of natural gas engines in marine use

2. Large sized RCEM: Rapid Compression and Expansion Machine

3. Image of lean-burn combustion (Otto-cycle type gas engine)

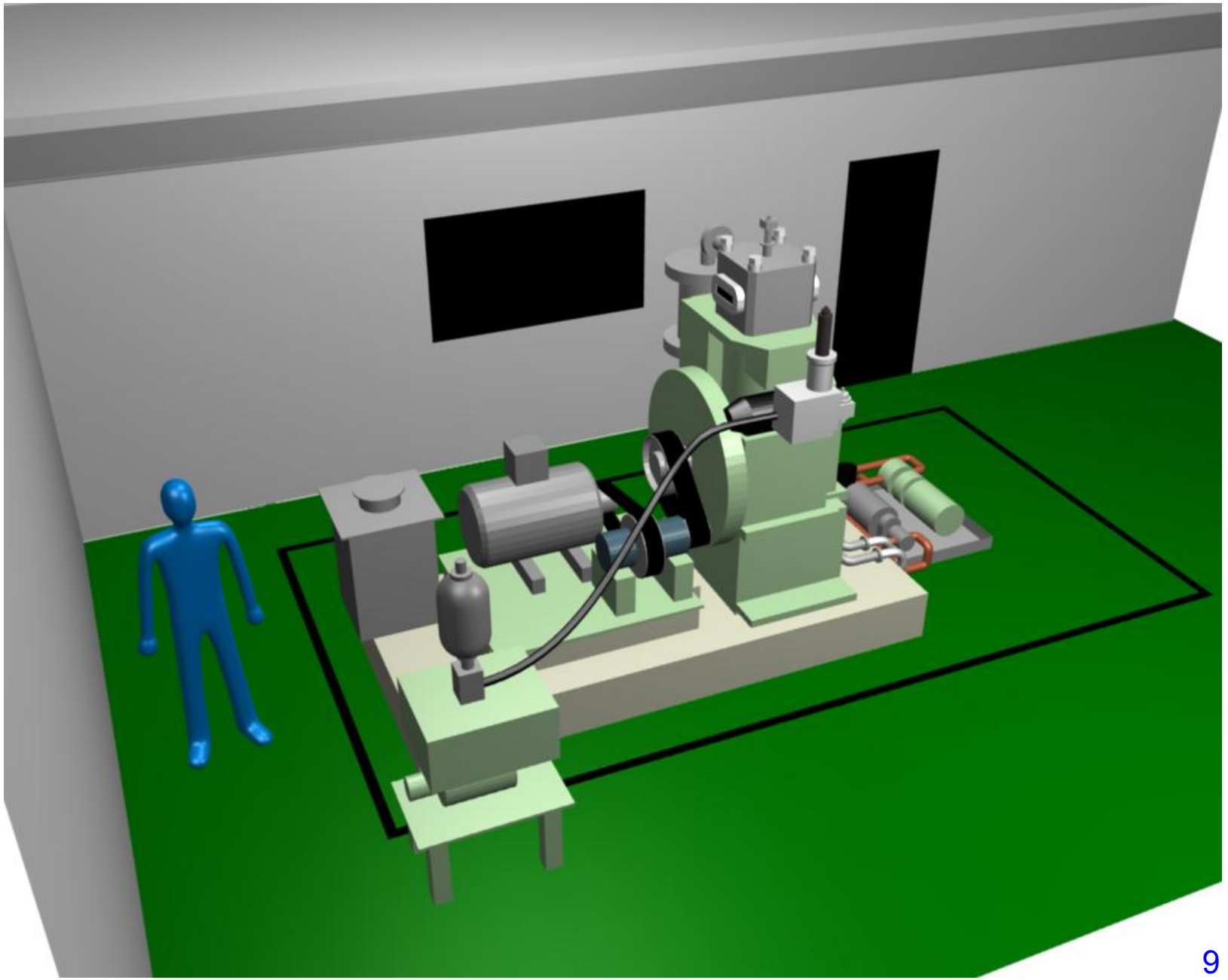
4. Image of GI (high pressure Gas Injection) combustion

Laboratory of Engine and combustion, Kyushu Univ., Japan



Gas engine visual test facility, RCEM

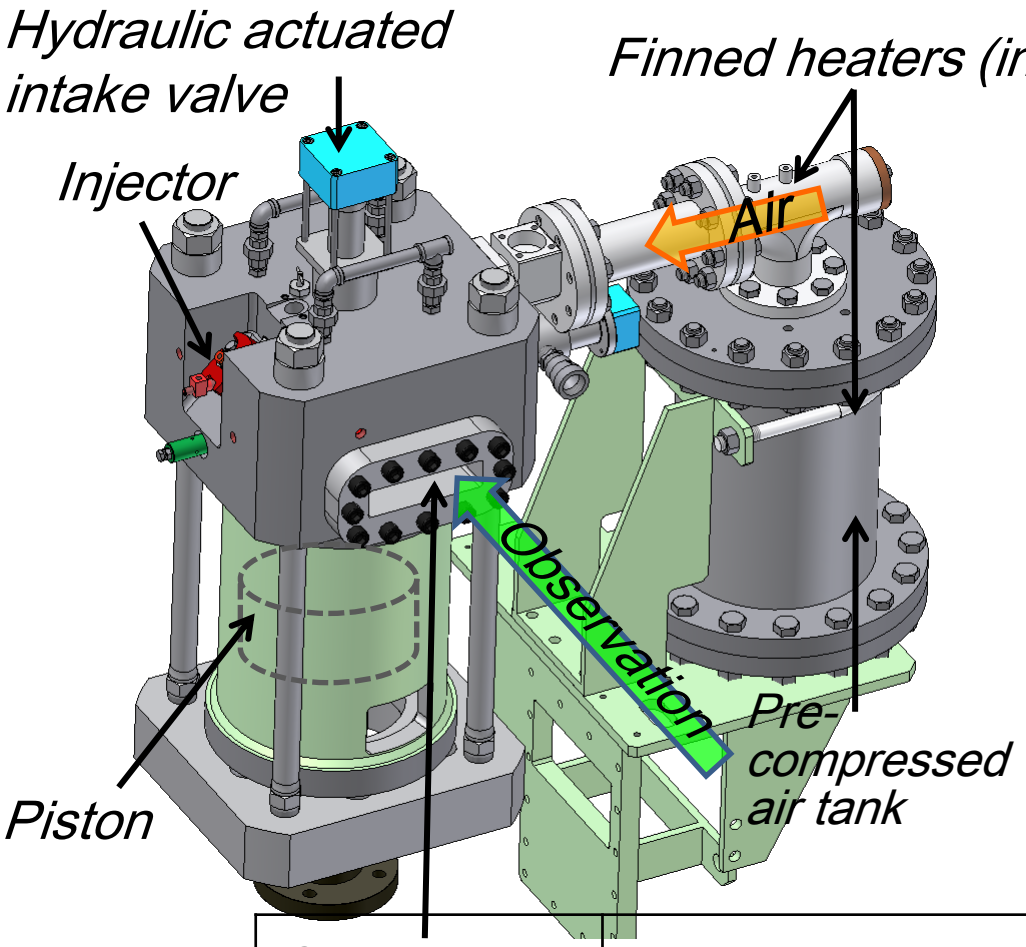
Construction and function of RCEM



RCEM *(**R**apid **C**ompression and **E**xpansion **M**achine)*

Supercharged condition is realized by **two-stage compression**.
Frequent experiments in a short time are possible by **single-shot function**.

Pmax limit: **20 MPa**, Speed: **300 rpm**, Glass window: 200 mm wide or 240 mm dia.

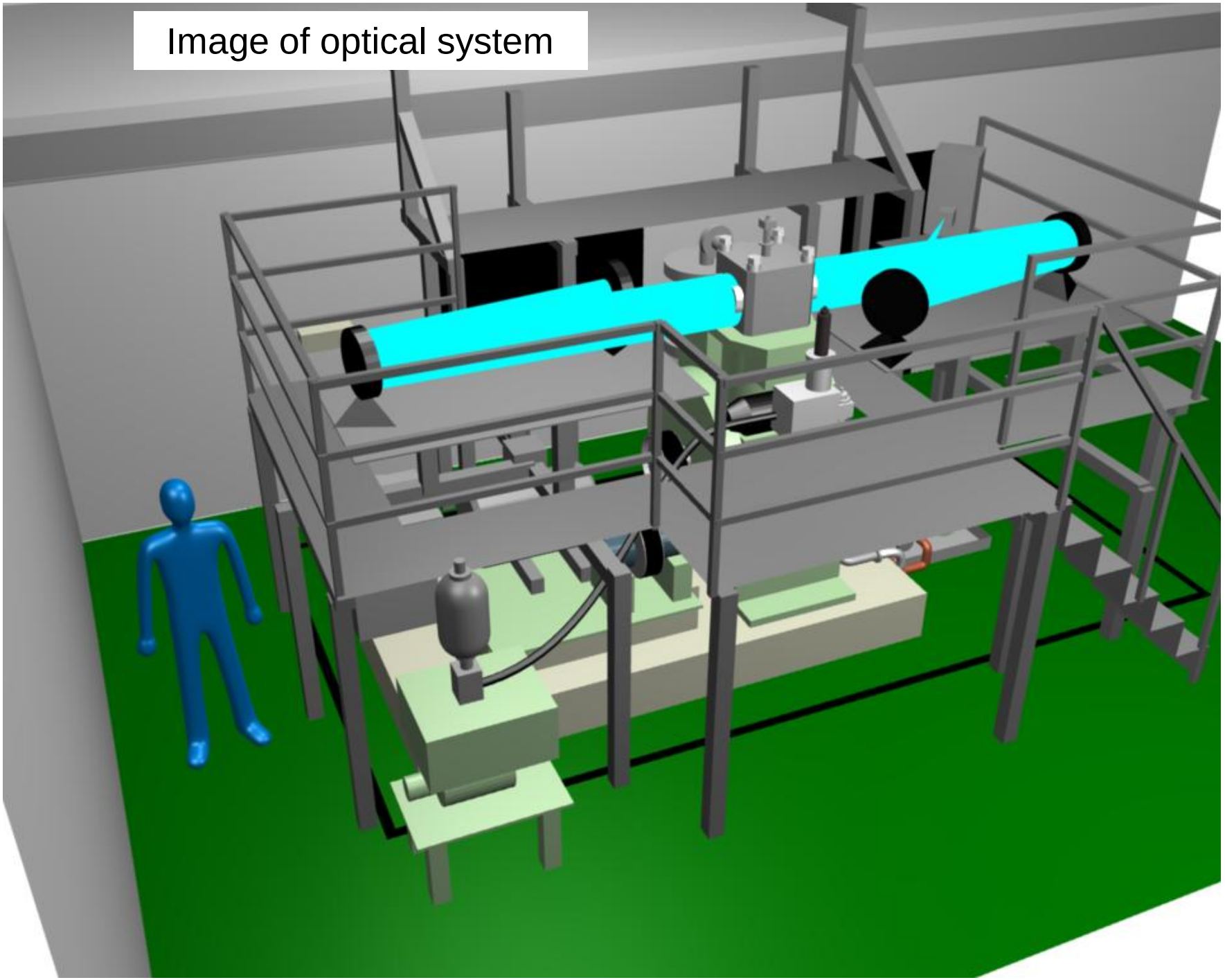


Main specifications of RCEM	
Stroke	260 mm
Clearance volume	$200 \times 66 \times 80$ mm^3
Compression ratio	z.B. 10.0
Engine speed	300 rpm
Initial charging conditions	
Press. P1	z.B. 0.9 MPa
Temp. T1	z.B. 150 deg. C

(15 MPa, 615℃) of (Pc, Tc) at compression end is possible by applying above (P1, T1) .

Quartz window	*200 (wide) × 50 × 100 (thick) mm*

Image of optical system



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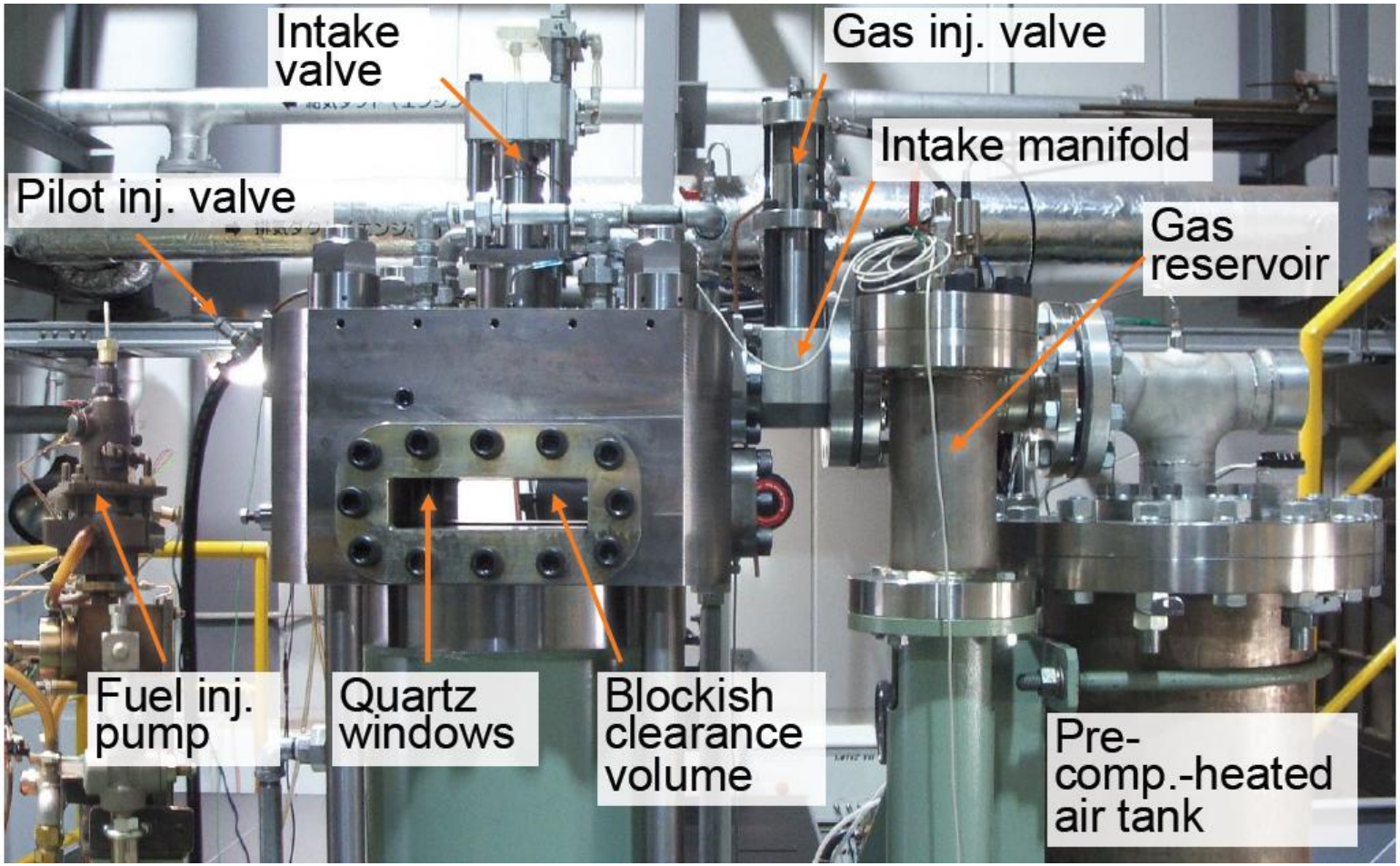
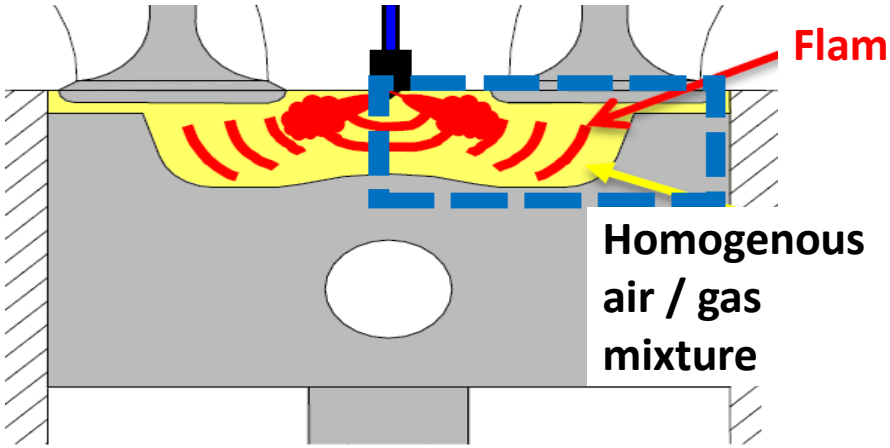




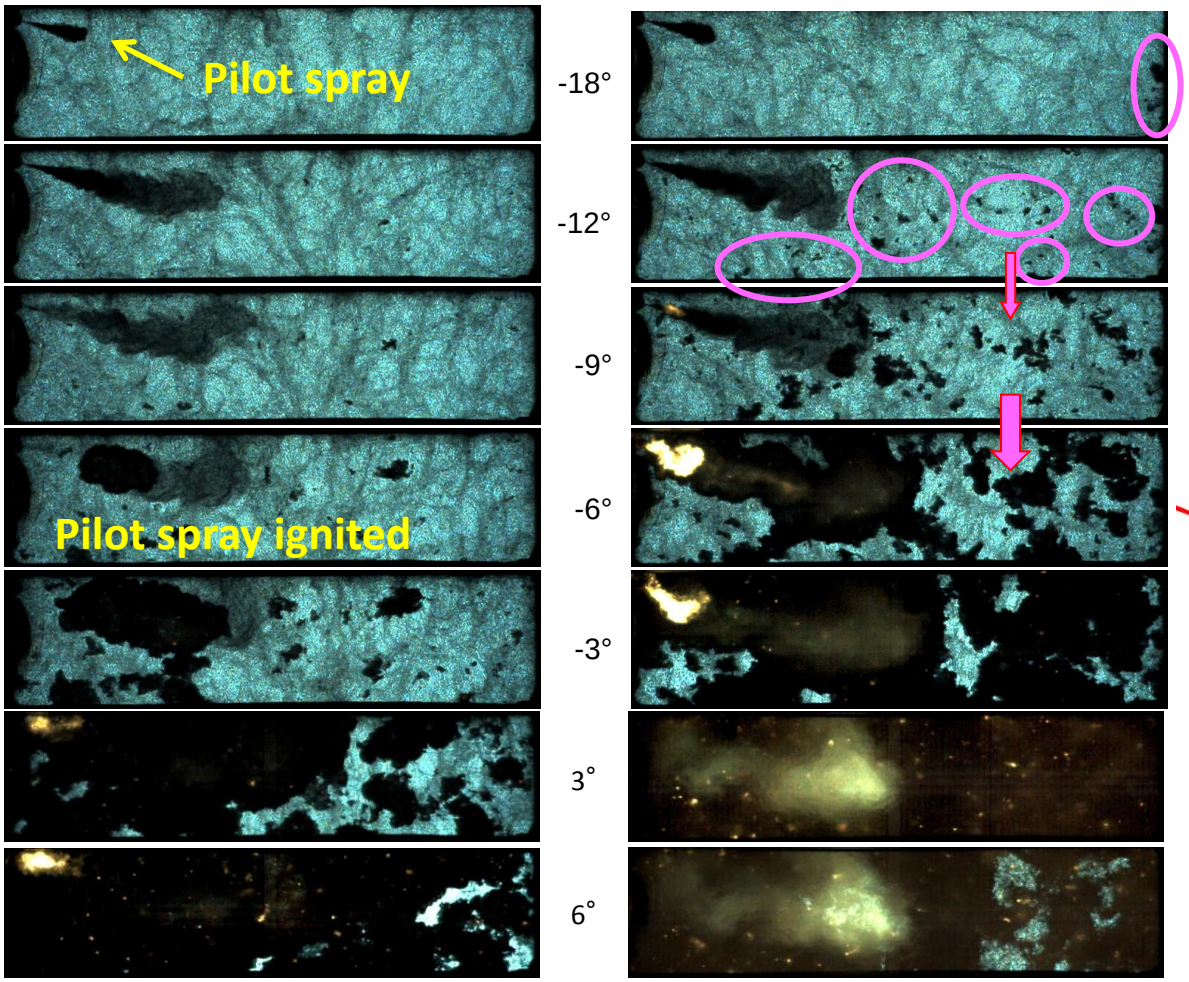
How is the flame propagation and abnormal combustion in lean-burn type gas engine?

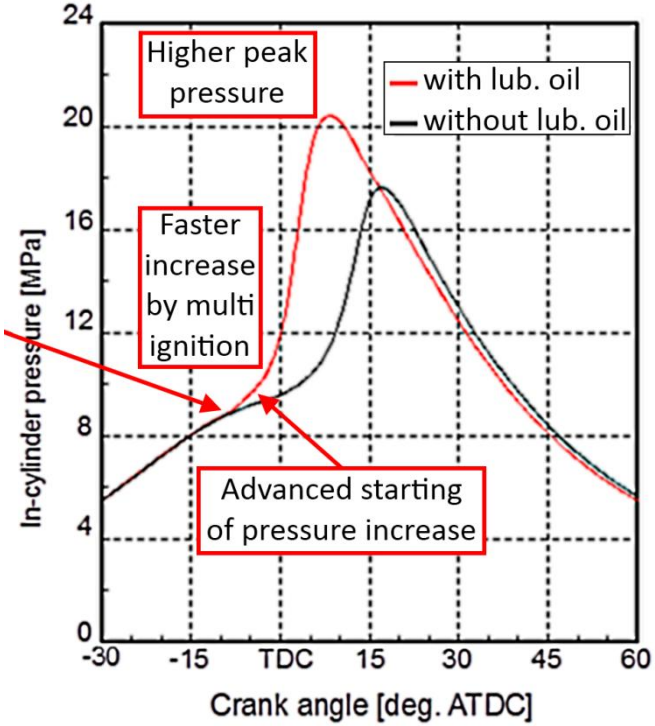
Abnormal combustion caused by lubricating oil

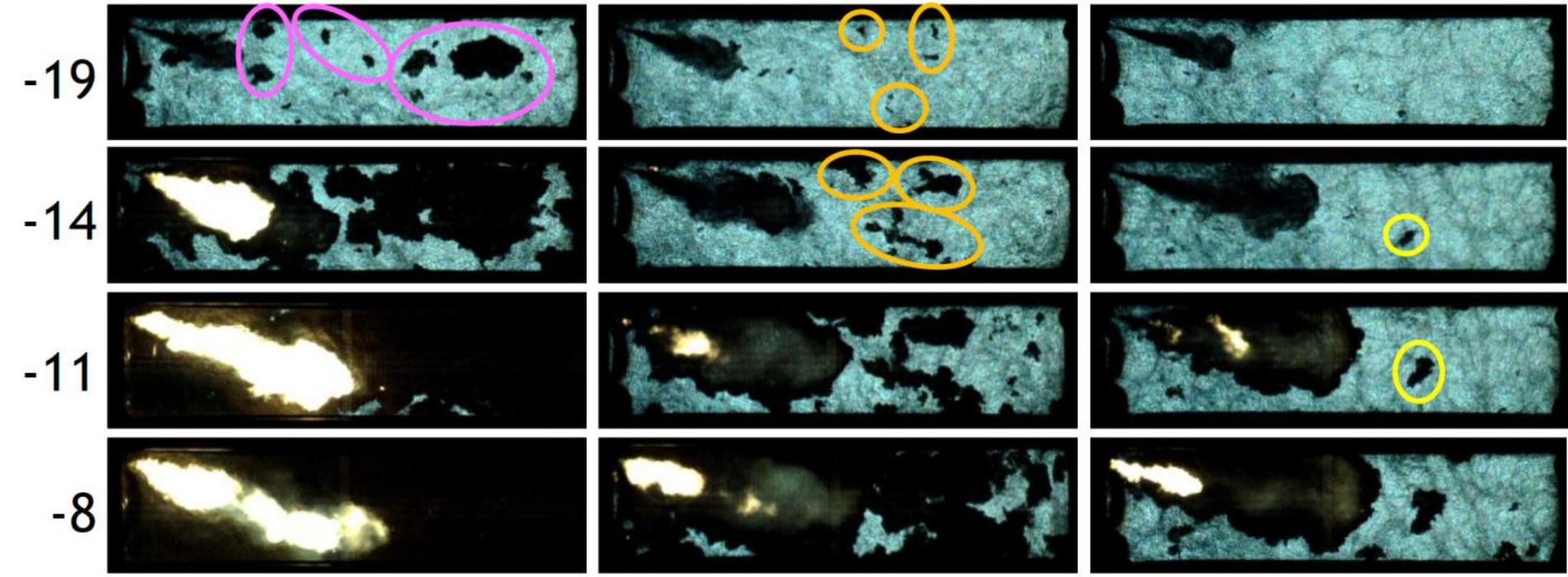
(Shadowgraph technique shows burning area black.)

Without lubricating oil

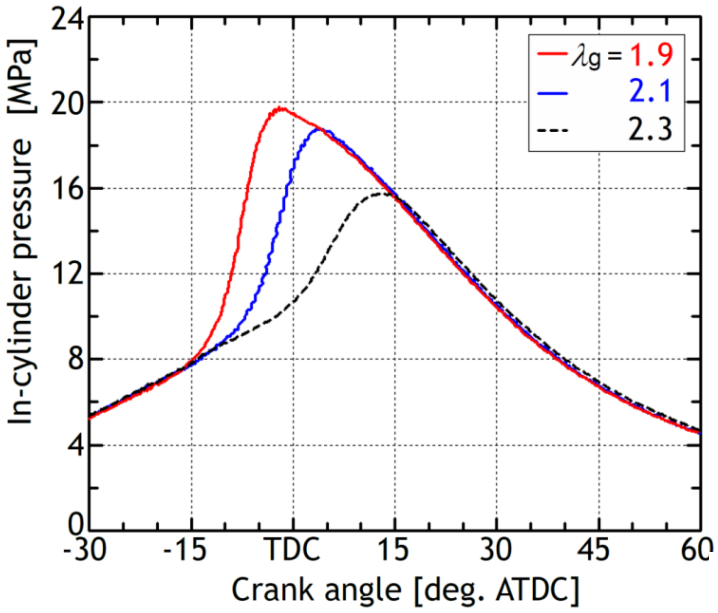
≈ 0.5 g/kWh
lubricating oil







Lub. oil particle could be an origin of self-ignition.
And it grows faster to be big flame in richer mixture.



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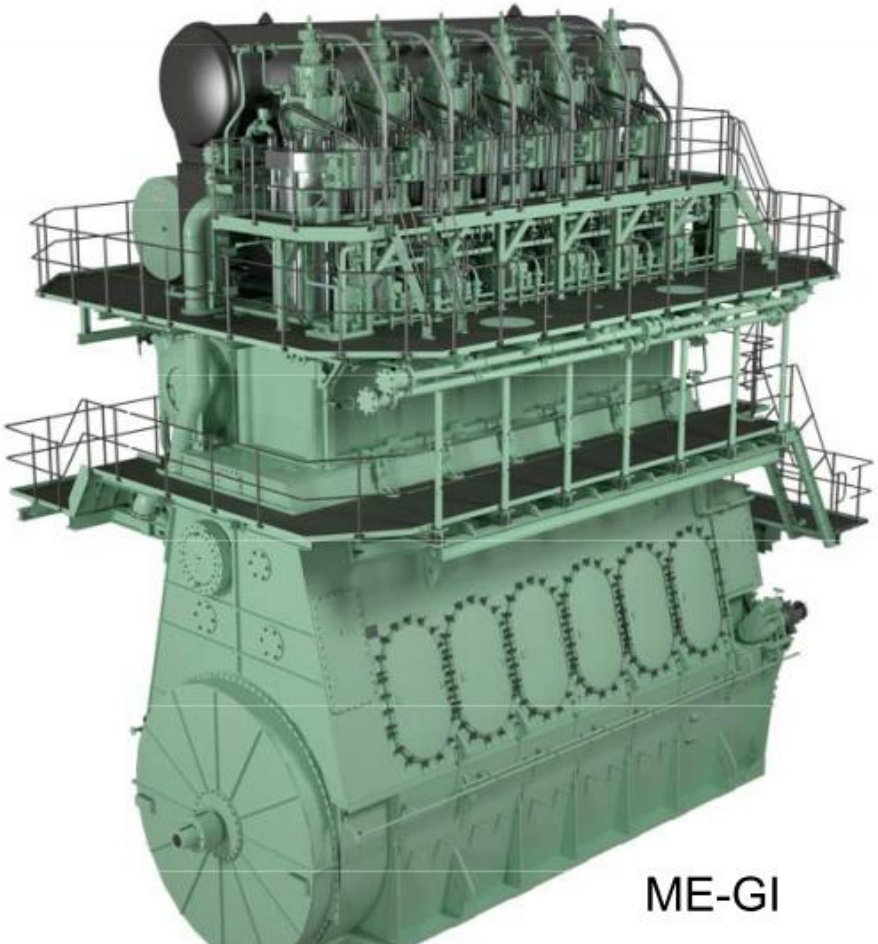
4. **Image of GI** (high pressure **G**as **I**njection) combustion

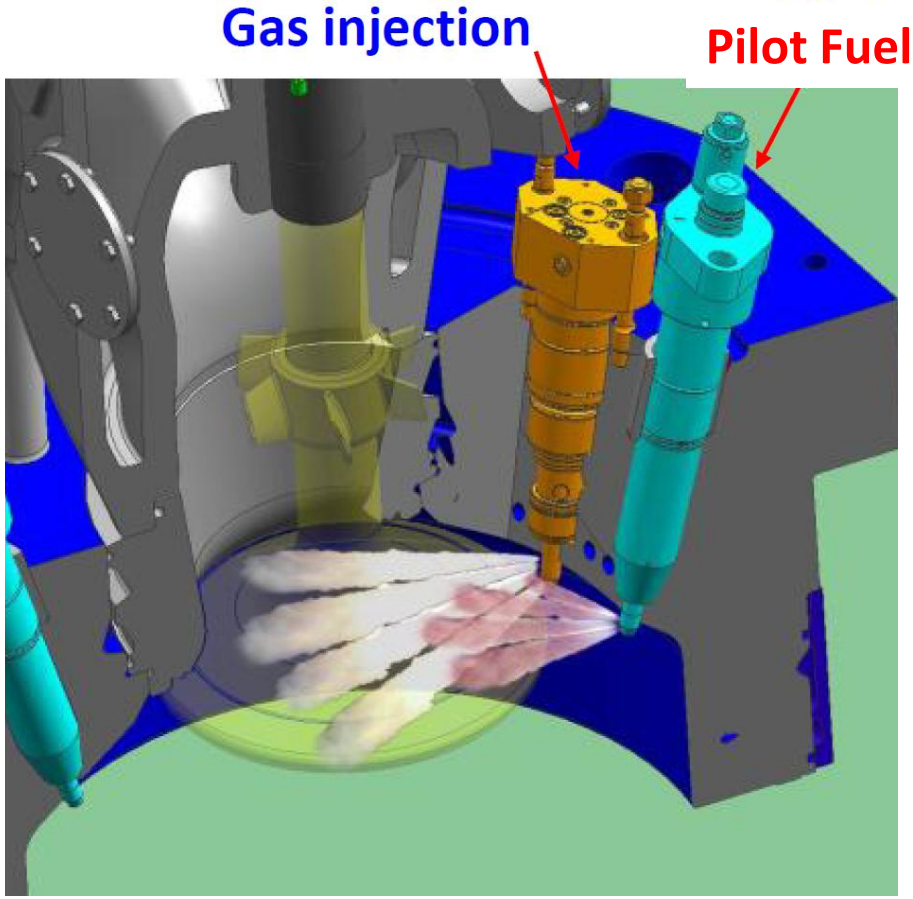
GI (**G**as **I**njection) type combustion • • named ‘Diesel cycle gas engine’

(Diffusive combustion of high pressure gas jet ignited by pilot fuel.)

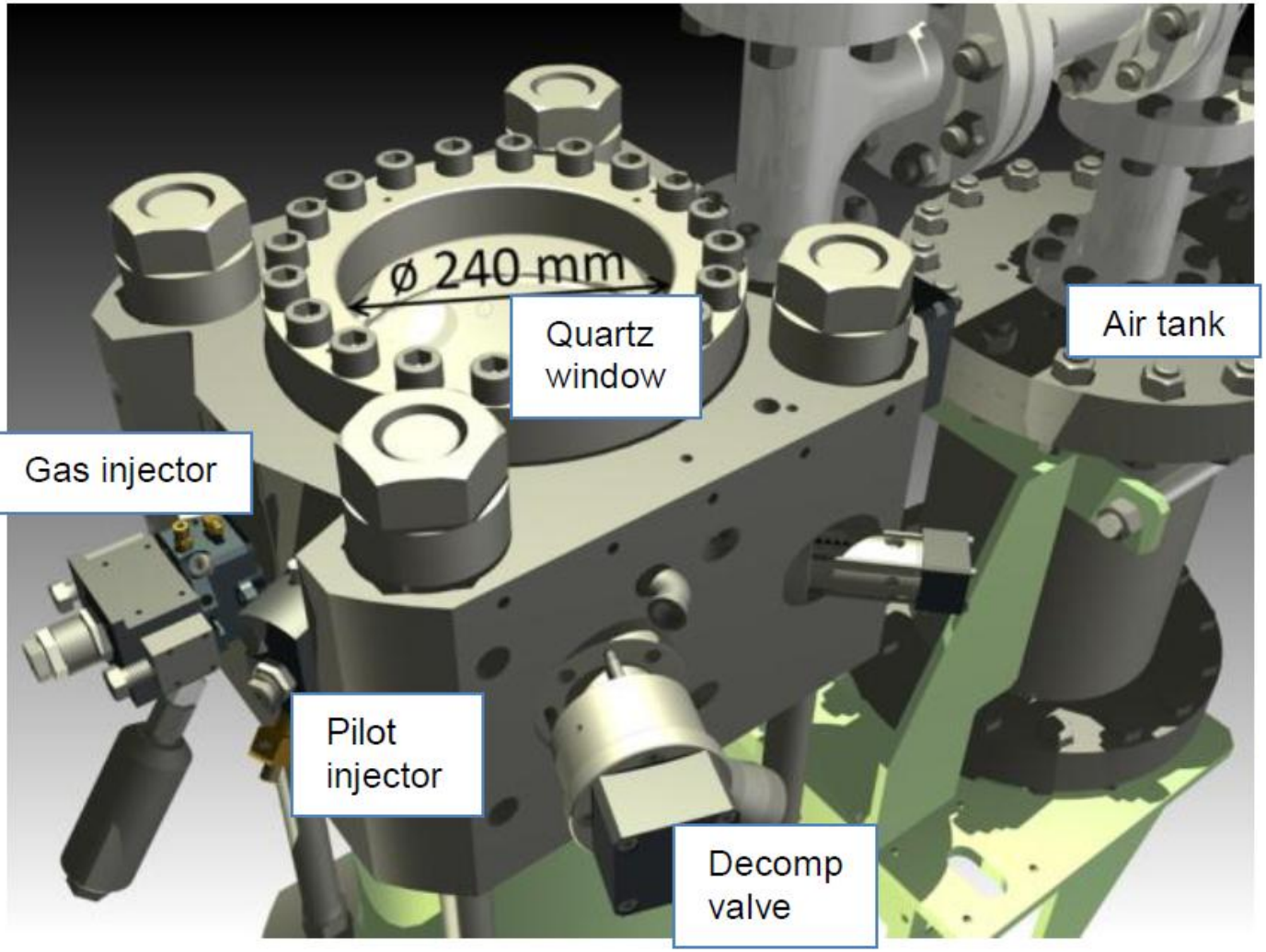
Merits • • Free from knocking & abnormal combustion (Any MN is allowable.)

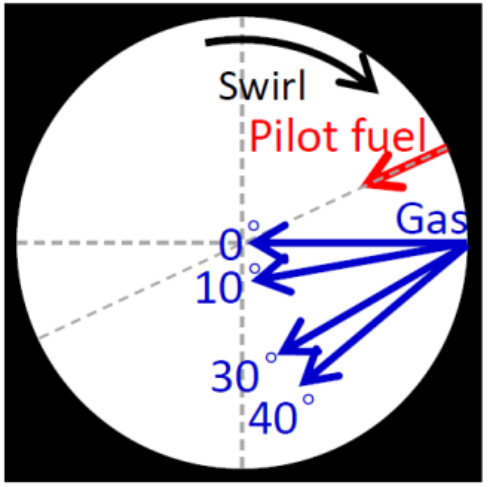
Lower methane slip



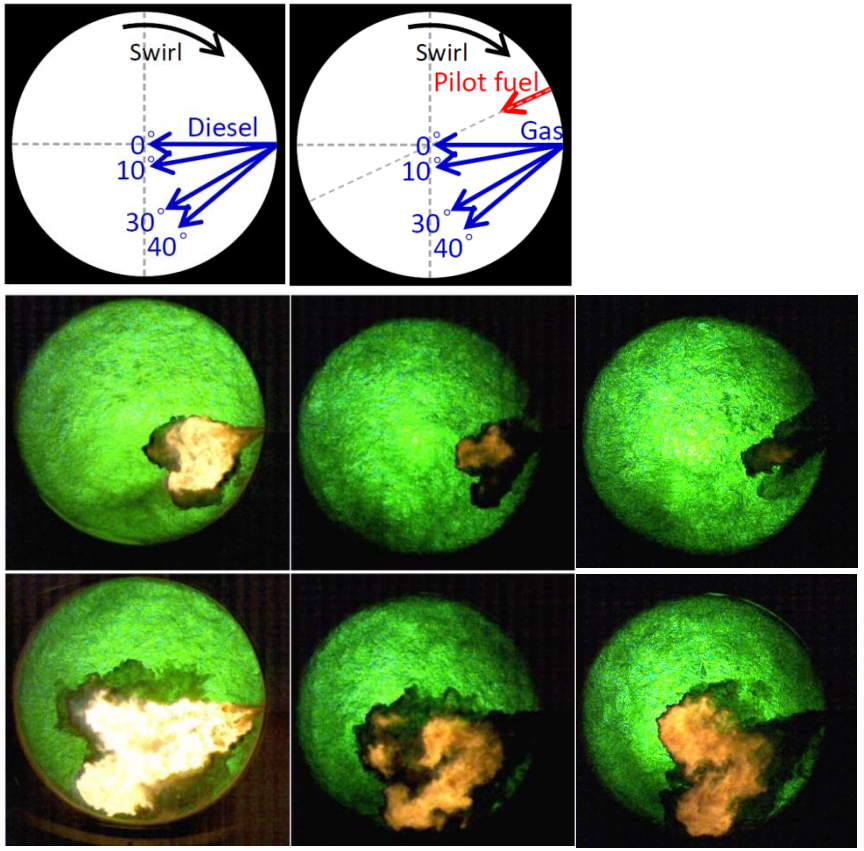


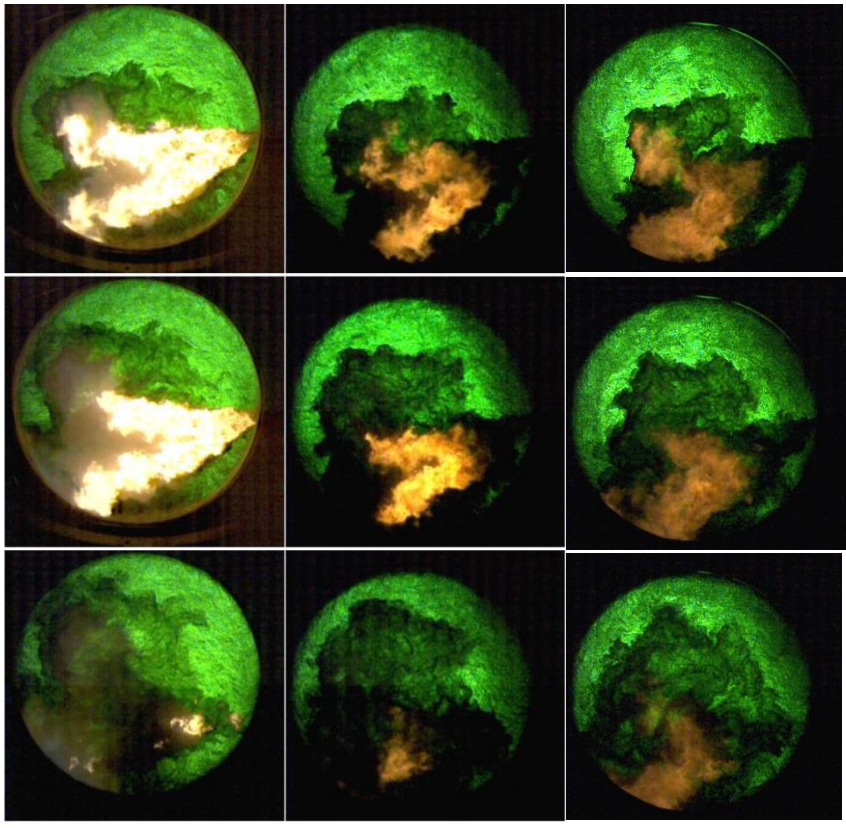
Combustion chamber for top view from 240 mm dia. full window





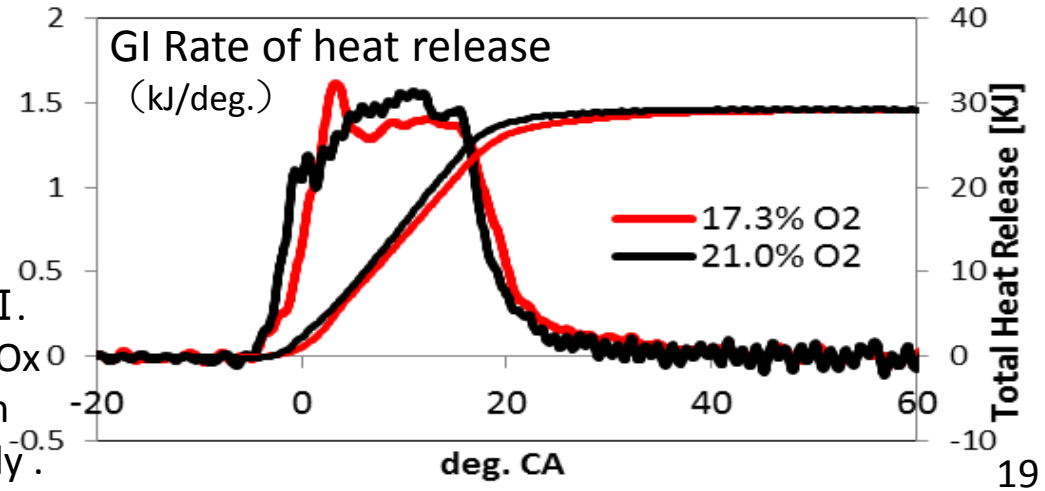
Mirror on top of piston for Schlieren technique





Emissions	Diesel	Std. GI	EGR GI
CO[ppm]	17	30	45
NOx[ppm]	499	300	44

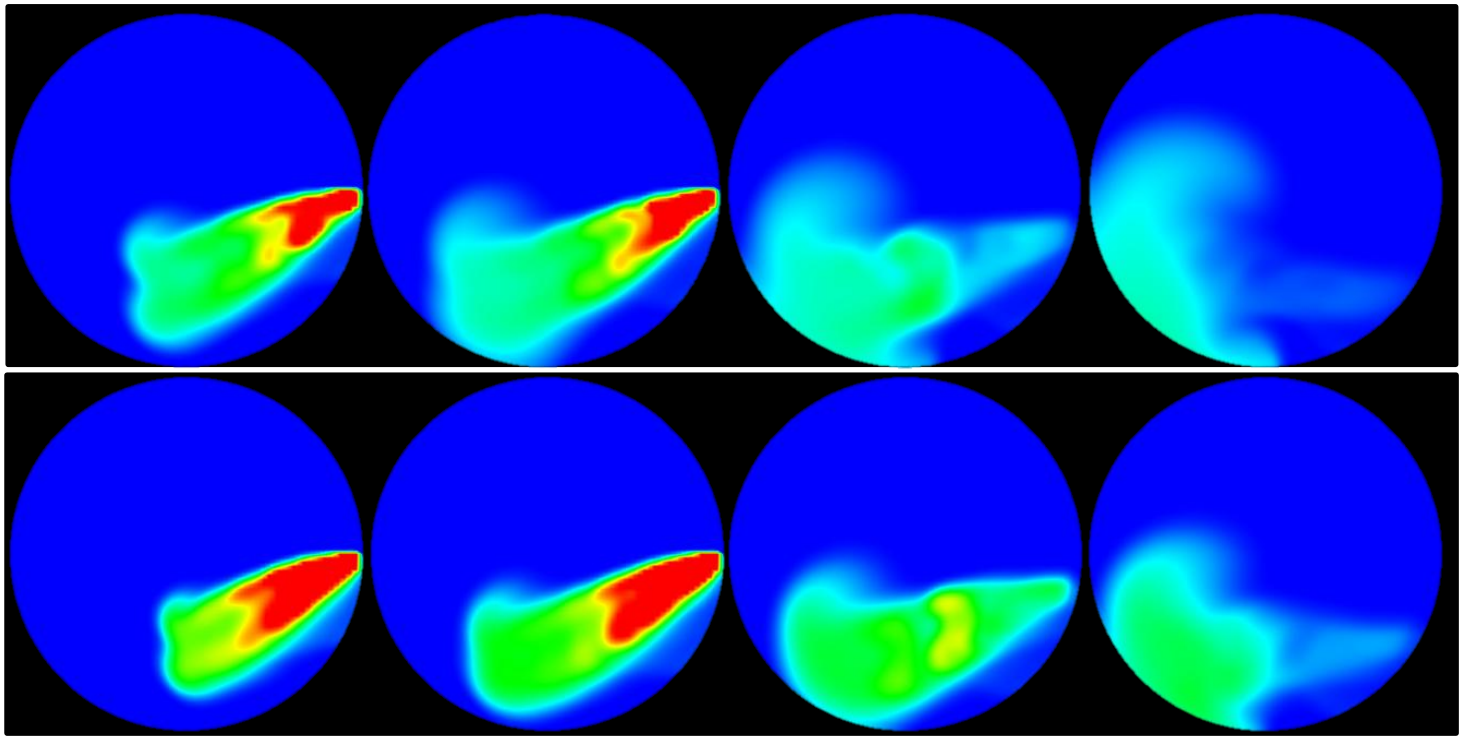
EGR（or SCR）is necessary for GI to clear TierⅢ.
EGR condition is simulated by 17% O2 air and NOx is reduced to 10% of diesel mode with minimum sacrifice of combustion in this fundamental study.

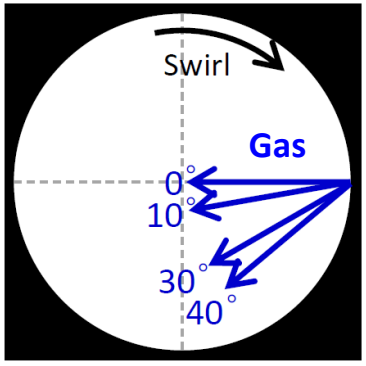


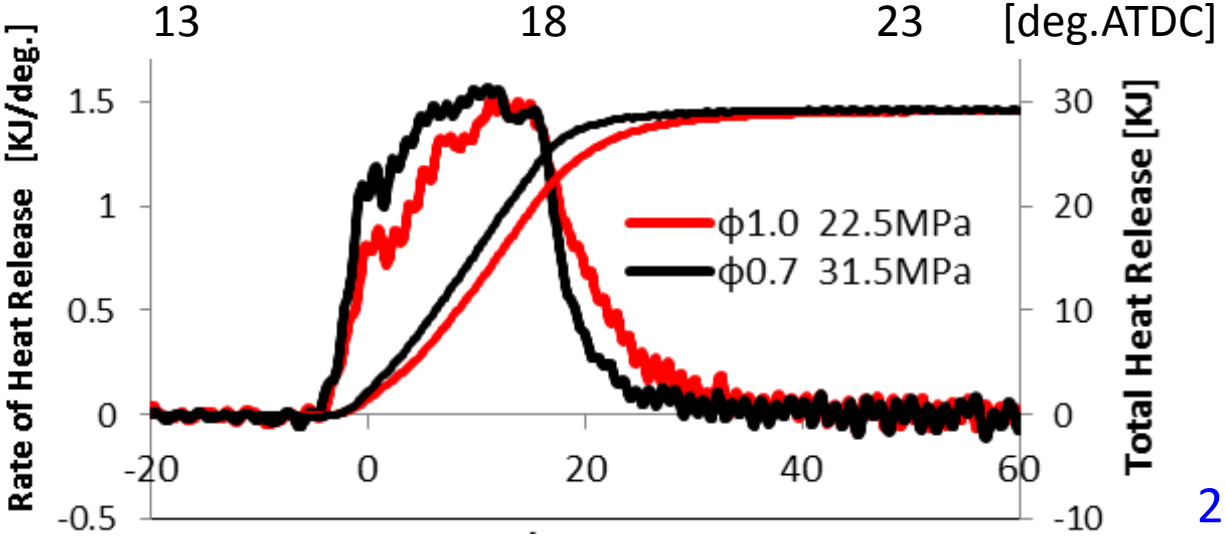
Visualization of fuel mass fraction in gas jet applying CFD

d: 4x **ϕ0.7**
31.5MPa

d: 4x **ϕ1.0**
22.5MPa



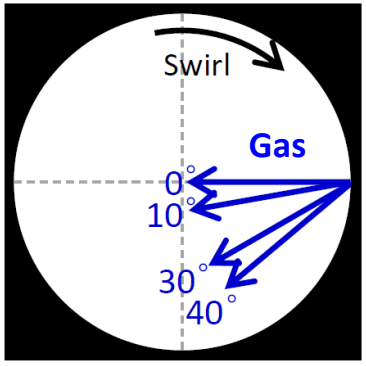




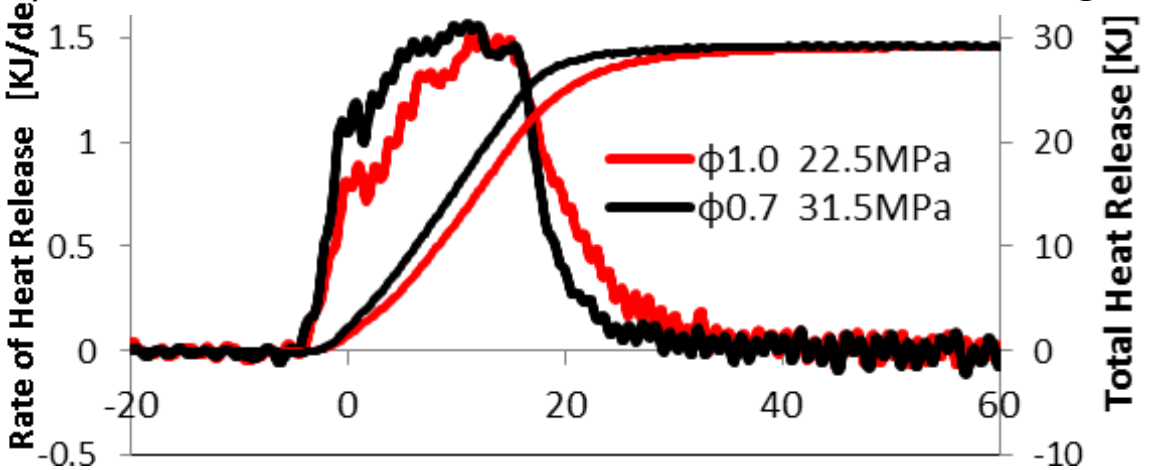
Lower gas pressure case shows longer burn-up length of flame.

d: 4x **ϕ0.7**
31.5MPa

d: 4x **ϕ1.0**
22.5MPa



8 12 16 20 [deg.ATDC]



Introduction of
new theme ‘Hydrogen-admixture to natural gas for gas engines’ sponsored by ClassNK

Direct

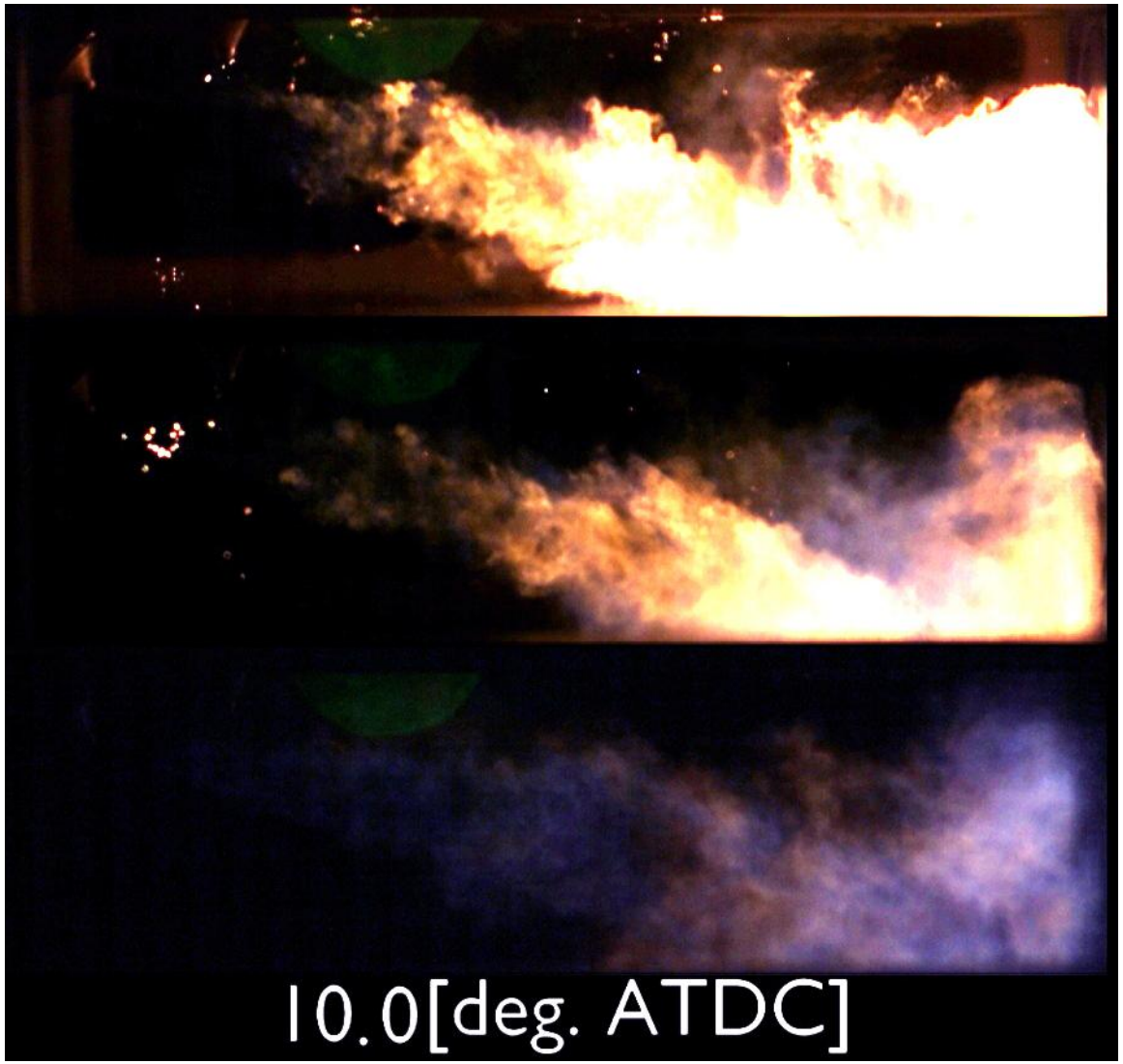
200 mm wide window

No.052 **80% CH_4 - 20% H_2 (F2)**
Inj. Hole Dia. 1.2 [mm]
Inj. Press. **26.4**[MPa]

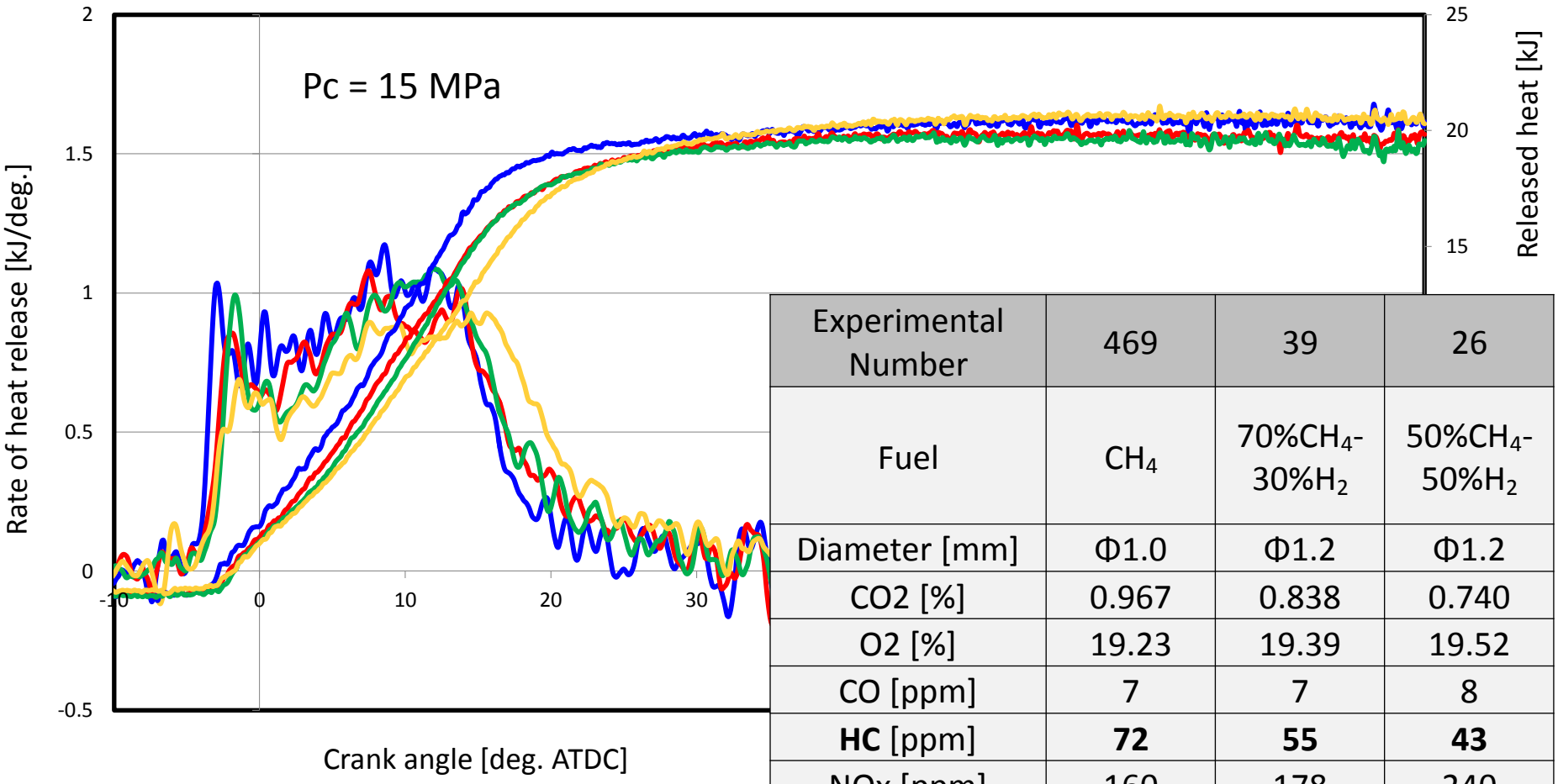
No.043 **70% CH_4 - 30% H_2 (F2)**
Inj. Hole Dia. 1.2 [mm]
Inj. Press. **27.6** [MPa]

No.021 **50% CH_4 - 50% H_2 (F2)**
Inj. Hole Dia. 1.2 [mm]
Inj. Press. **30.7**[MPa]

% = vol. %



Improvement of diffusive combustion by adding hydrogen to methane (Pc: 8 MPa)



Experimental Number	469	39	26
Fuel	CH_4	70%CH_4-30%H_2	50%CH_4-50%H_2
Diameter [mm]	Φ1.0	Φ1.2	Φ1.2
CO2 [%]	0.967	0.838	0.740
O2 [%]	19.23	19.39	19.52
CO [ppm]	7	7	8
HC [ppm]	**72**	**55**	**43**
NOx [ppm]	160	178	240

No.469 **CH_4**
Inj. Hole Dia. 1.0 [mm]
Inj. Press. **30.1** [MPa]

No.050 **80% CH_4 - 20% H_2**
Inj. Hole Dia. 1.2 [mm]
Inj. Press. **26.5** [MPa]

No.039 **70% CH_4 - 30% H_2**
Inj. Hole Dia. 1.2 [mm]
Inj. Press. **28** [MPa]

No.026 **50% CH_4 - 50% H_2**
Inj. Hole Dia. 1.2 [mm]
Inj. Press. **31.2** [MPa]

Further research theme ‘Hydrogen-admixture to natural gas for gas engines’

Today,

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4. Image of GI (high pressure Gas Injection) combustion

have been introduced as

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by Kyushu Univ. Japan

Thank you for your kind attention