EFFECTS OF PRE-CHAMBER INTERNAL SHAPE ON CH4-H2 COMBUSTION CHARACTERISTICS USING RAPID-COMPRESSION EXPANSION MACHINE EXPERIMENTS AND 3D-CFD ANALYSIS

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1. Background

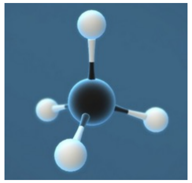
2. Methodology

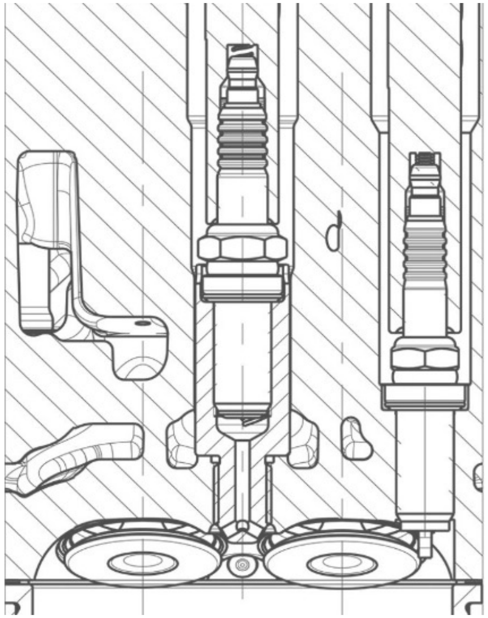
3. Result & Discussion

4. Conclusion

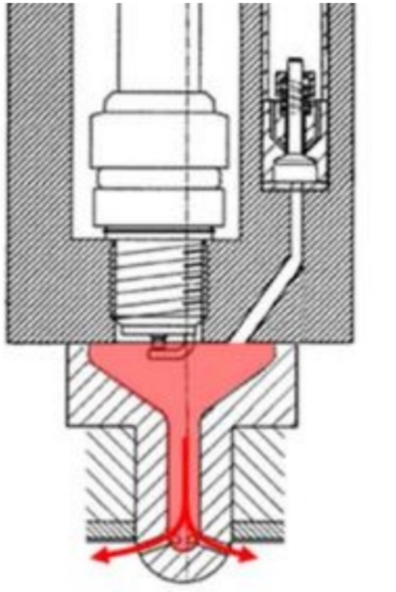
Background

Natural gas has a high calorific value per a carbon, but a low energy density per volume





Pre-chamber shape adopted by Maserati



Pre-chamber shape adopted by OEM

Improved by pre-chamber.

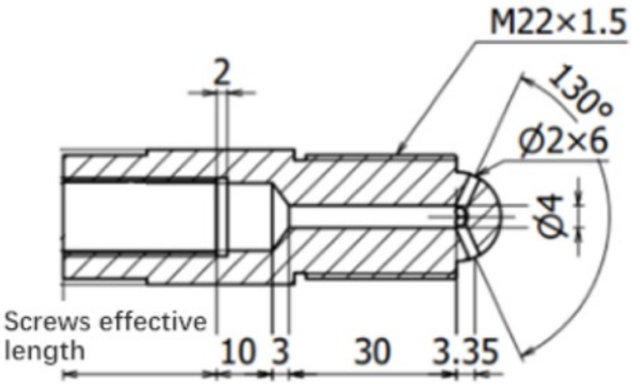
Hypothesis

Changing the internal shape of the pre-chamber can have an effect on combustion characteristics

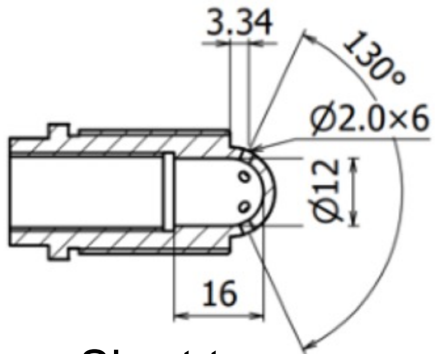
Research target

Investigation of the influence of internal shape of pre-chamber and H_2 addition

Preview experimental results in 2021



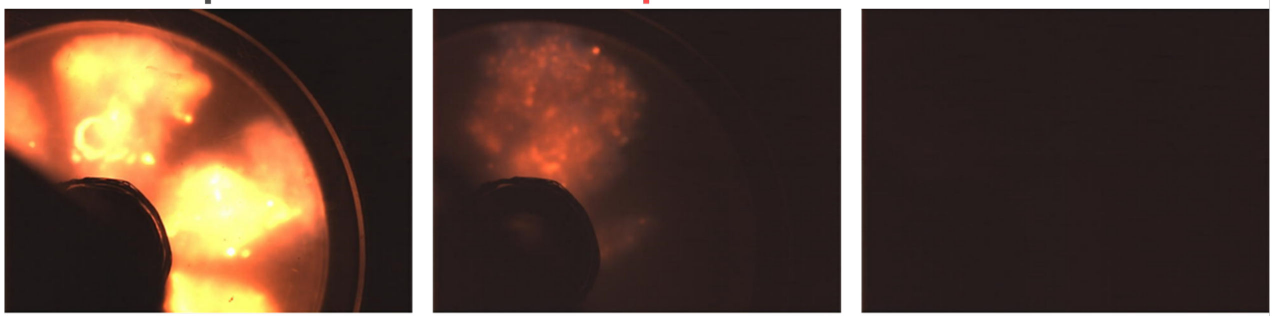
Maserati's pre-chamber



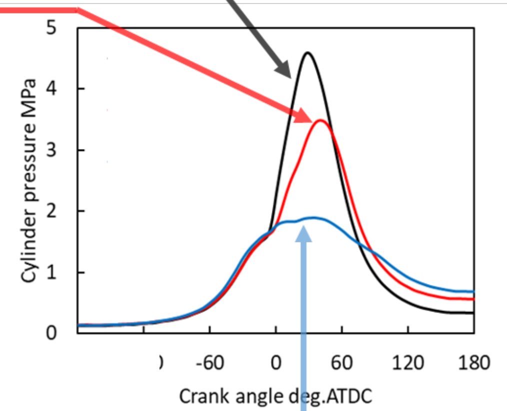
Short type

experiment using based on Maserati
➡ extinction phenomenon

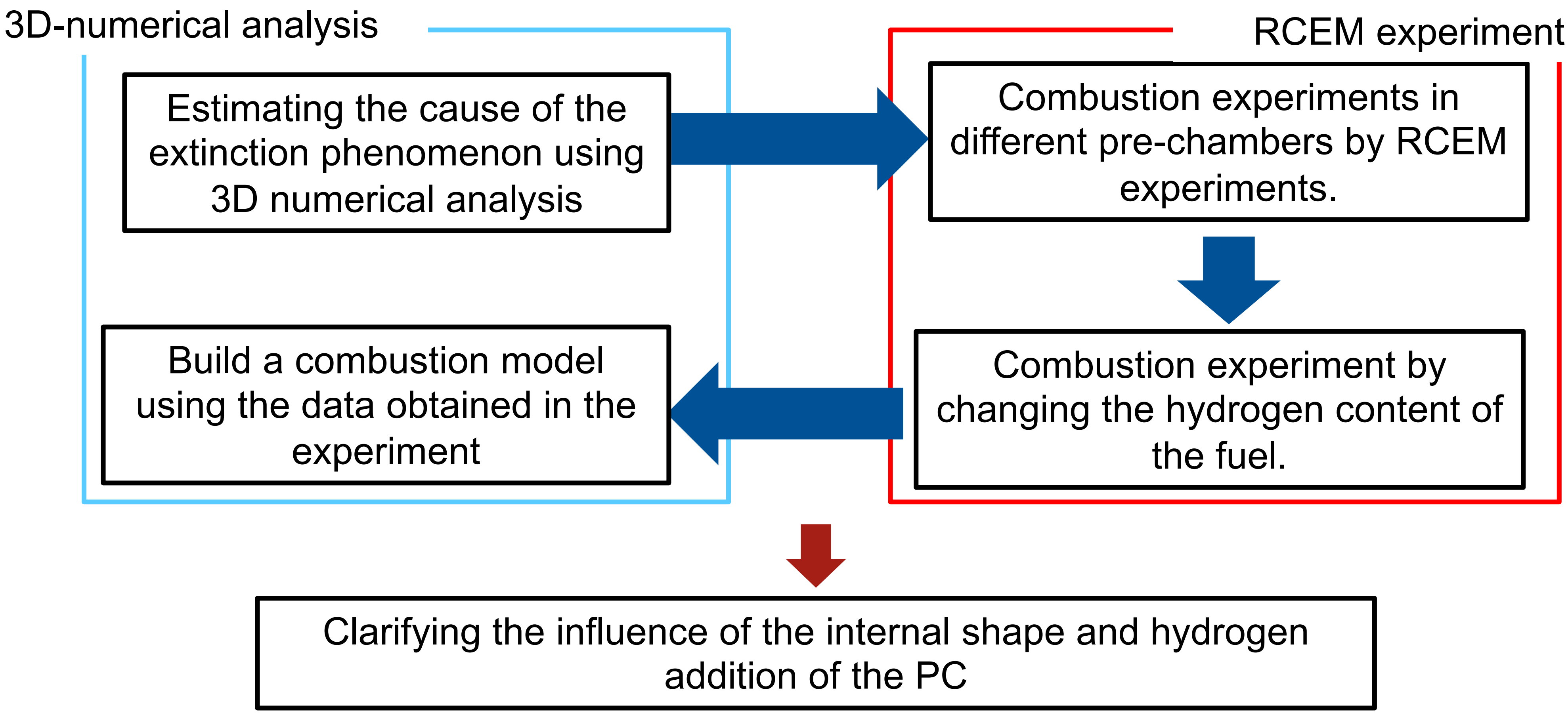
Intermediate channel can reduce combustion stability and lead to jet extinction.



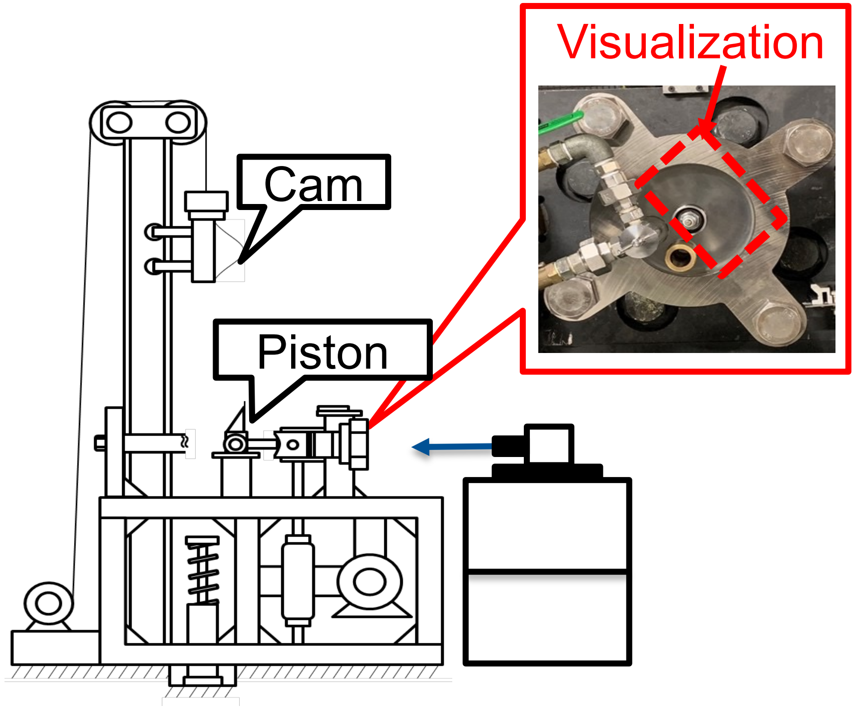
Normal combustion Delayed combustion Extinction



Research method



Experimental conditions



High speed camera specification

Fps 1/s	10000
Pixel setting	480 × 640

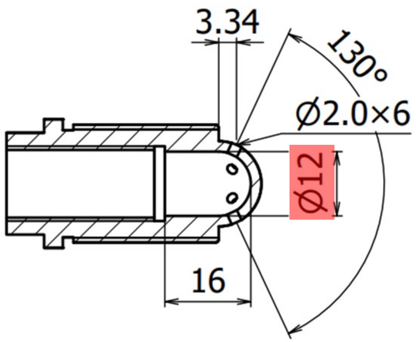
Common experiment conditions

Fuel	CNG(13A)
Mixing method	Premix
Ignition timing deg.	-16
Excess air ratio	1.0
Engine speed rpm	800
Premix gas temperature K	383
Initial pressure kPa abs	130

Machine specifications

Bore × Stroke mm	φ125 × 140
Displacement cc	1718
Compression ratio	8

Specification of pre-chamber



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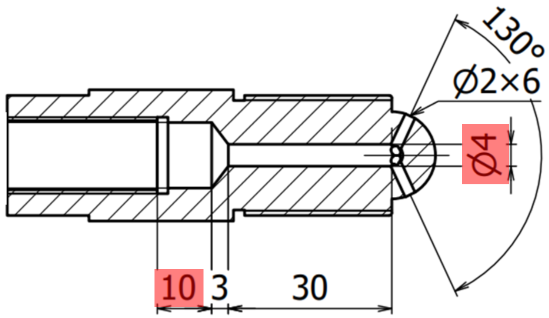
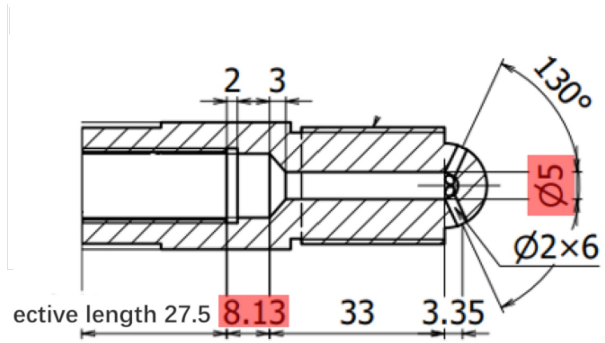
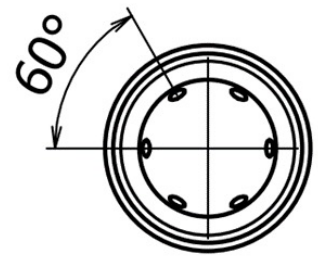


Long φ4.0 type



Long φ5.0 type



PC hole (common)

Short type PC common specifications

PC volume mm³	1718
PC hole diameter mm	Φ2.0
PC hole number	6

Long type PC common specifications

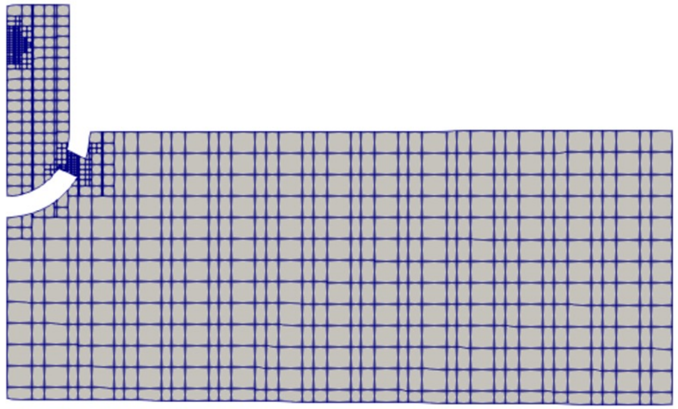
	Long φ4	Long φ5
Cross section area of minimum diameter mm²	12.57	19.63
Total cross section area of PC hole mm²	18.85	18.85

3D-numerical analysis setup

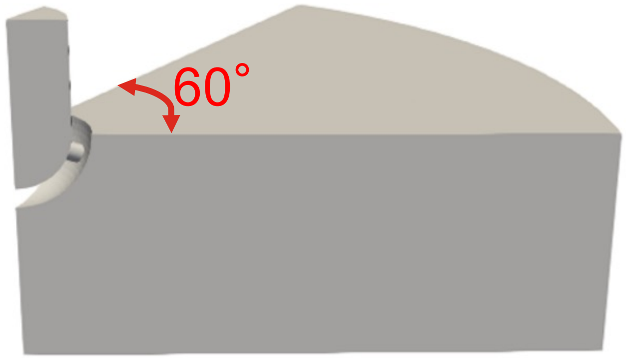
Base code	CONVERGE
Turbulence model	RNG k-epsilon
Chemical reaction scheme	GRI-Mech 3.0
Combustion model	G-equation
Wall model	Law-of-wall
Heat transfer model	O'Rourke and Amsden model
Grid control	Adaptive mesh refinement

3D-CFD modeling mesh size

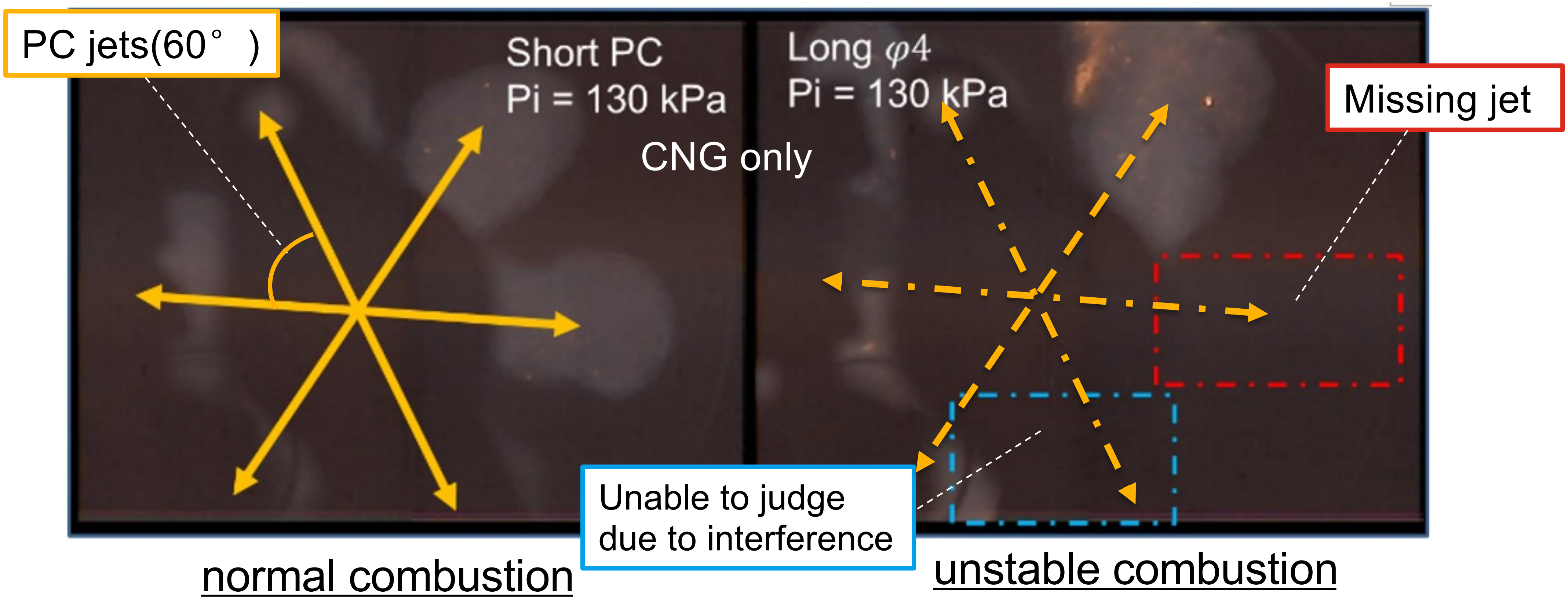
Base grid, mm	2.0
Near-spark mesh, mm	0.25
Hole mesh, mm	0.25



1/6 sector mesh (1 pre-chamber nozzle)



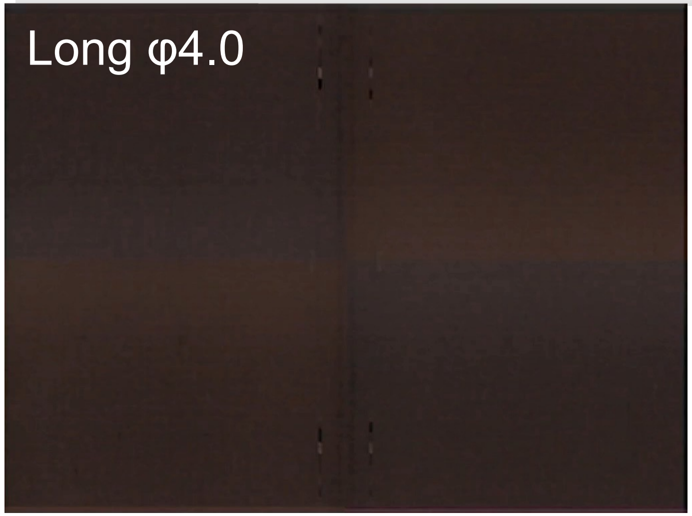
Extinction conditions

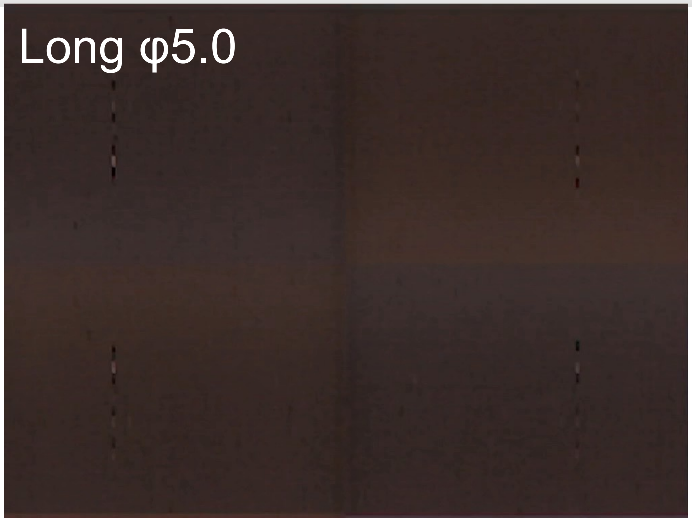


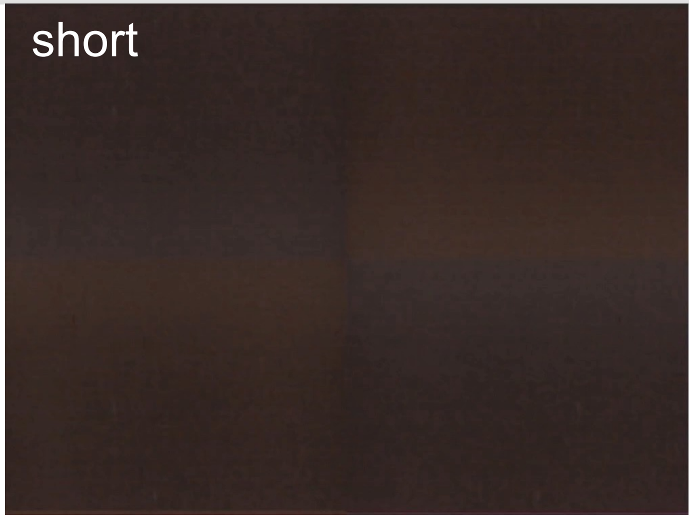
Experimental result for each pre-chamber

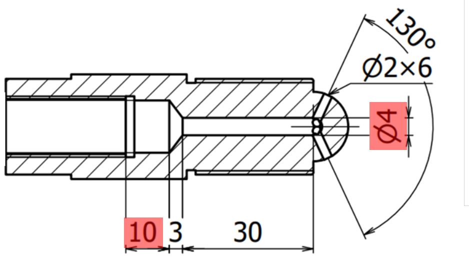
(λ=1.0, 800 rpm, P0 =130 kPa, CNG only)

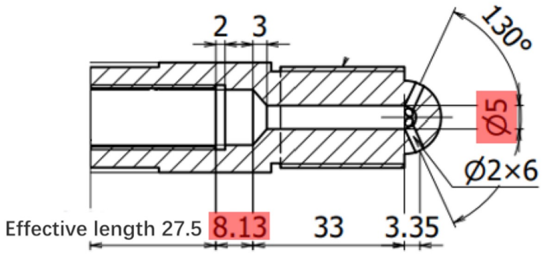
- ➡PC jet extinction did not occur in short and long φ5 types.
  ➡long φ4 type shows shortest combustion period.

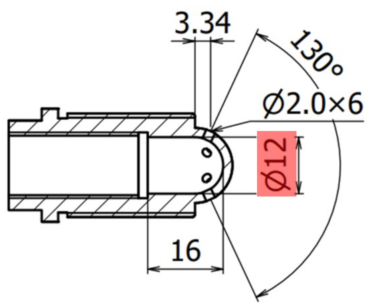












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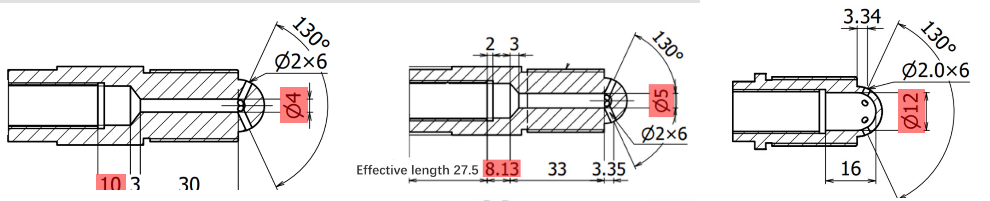
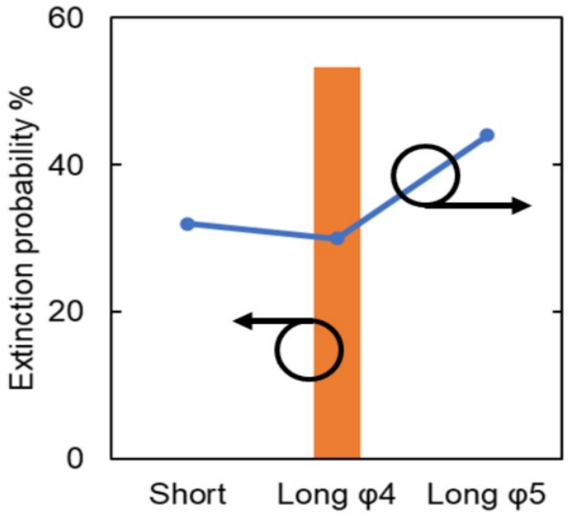
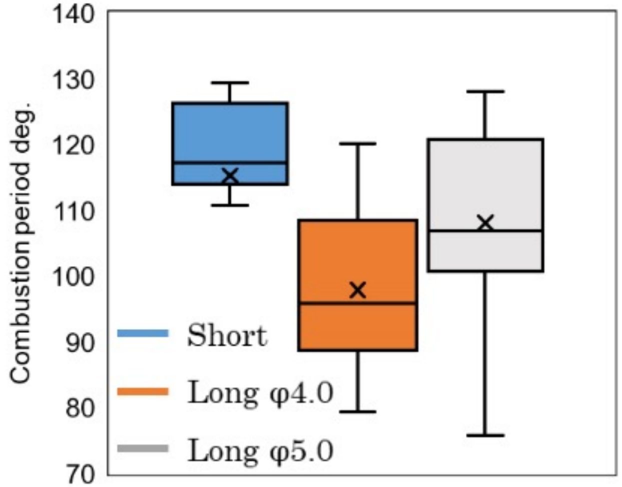
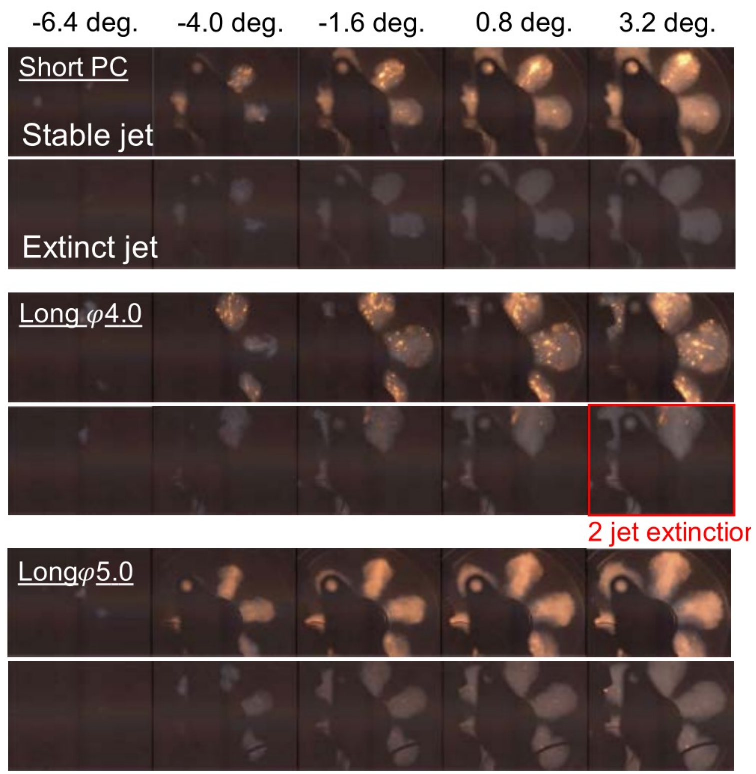




extinction probability



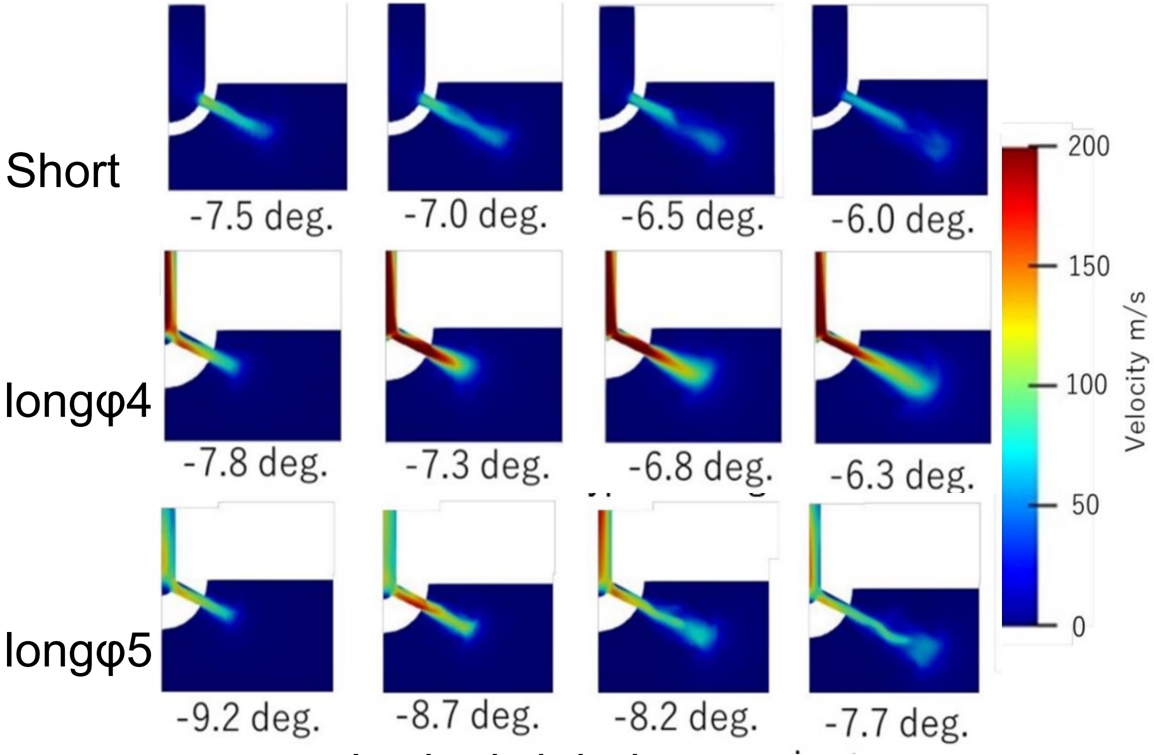
Combustion period



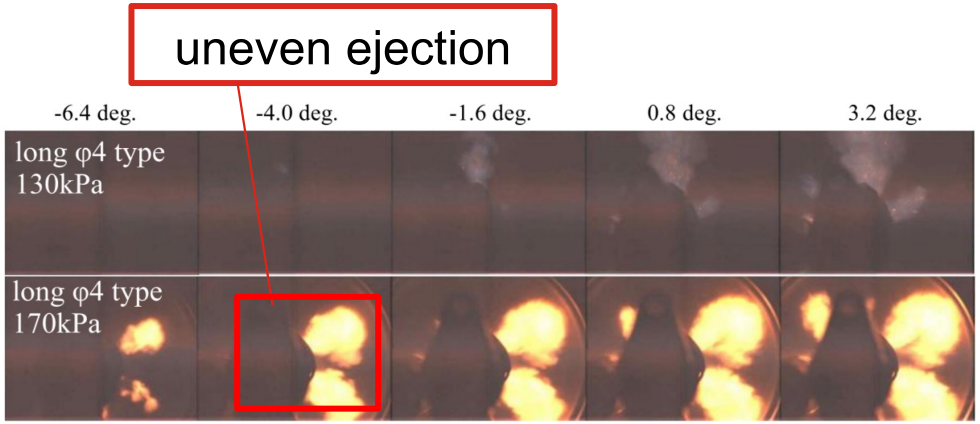
Combustion image

Effect of PC internal shape on combustion
(λ=1.0, 800 rpm, P_{ini} =130 kPa, CNG only)

- ➡The jet velocity decreases gradually in the order of longφ4, longφ5 and short.
  ➡longφ4 type has the most prolonged acceleration interval.



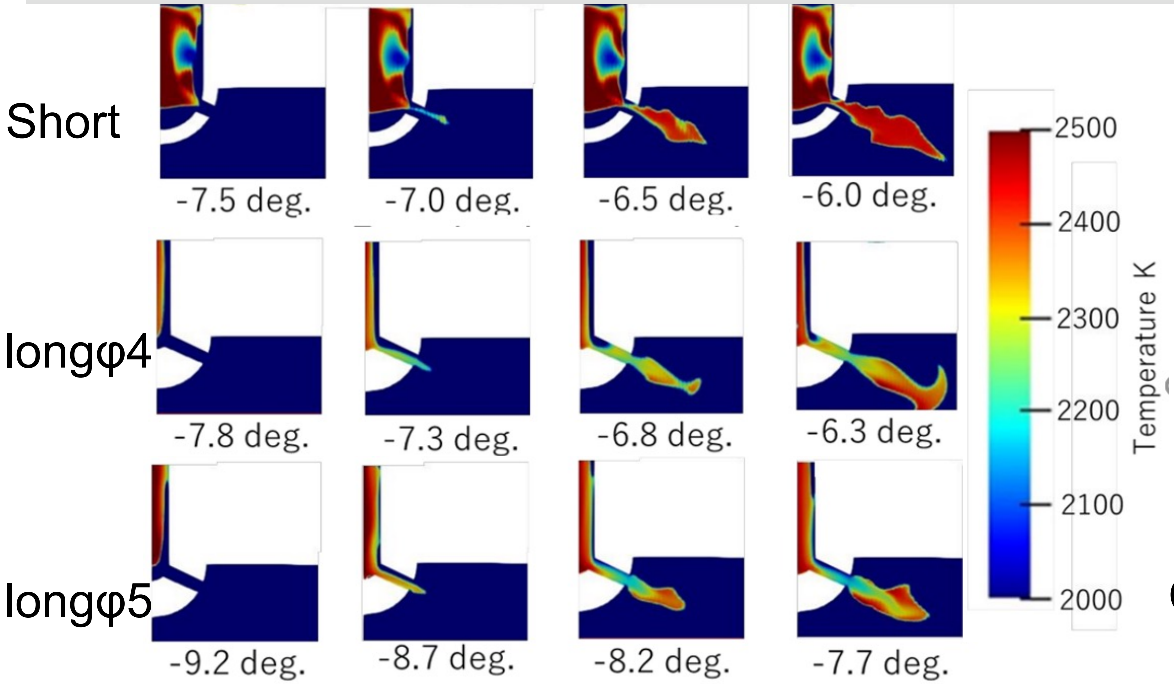
velocity distribution



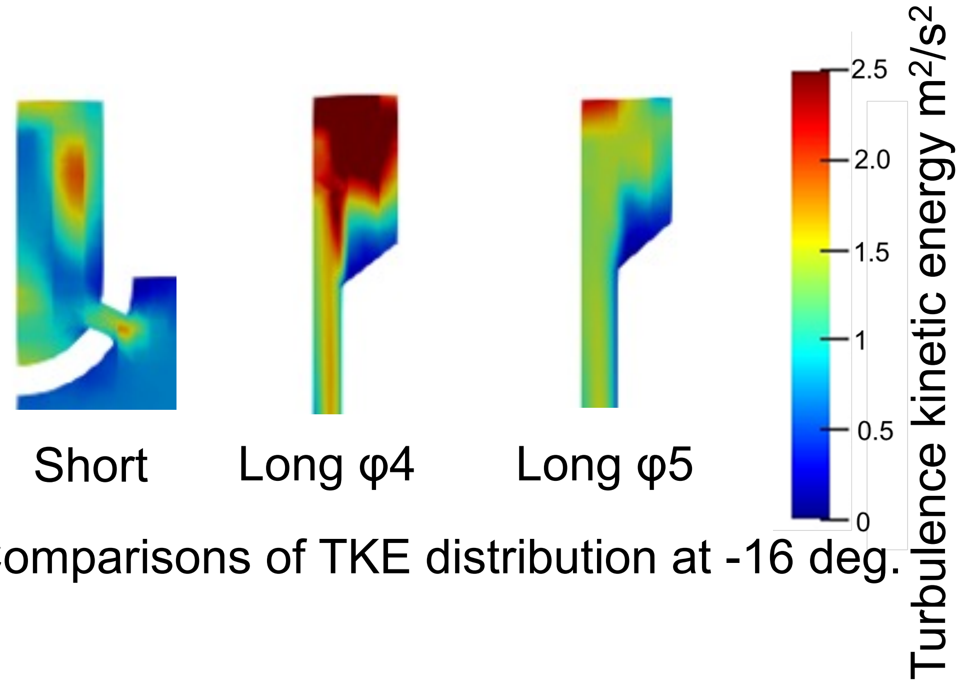
- spreading uniformly over the six nozzles
  ➡ normal jet flow
- uneven ejection phenomenon
  ➡ extinction phenomenon

Effect of PC type on temperature distribution and jet energy
(λ=1.0, 800 rpm, P_{ini}=130 kPa, CNG only)

- the lower the jet temperature, the higher the heat loss through the chamber.
- In long type pre-chambers, high temperature and high velocity jets cause more heat loss at the wall.



temperature distribution

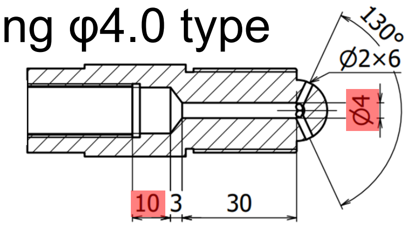


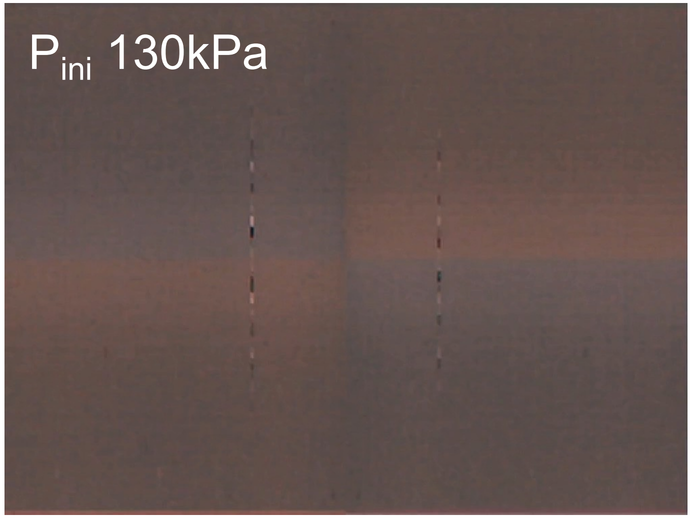
Comparisons of TKE distribution at -16 deg.

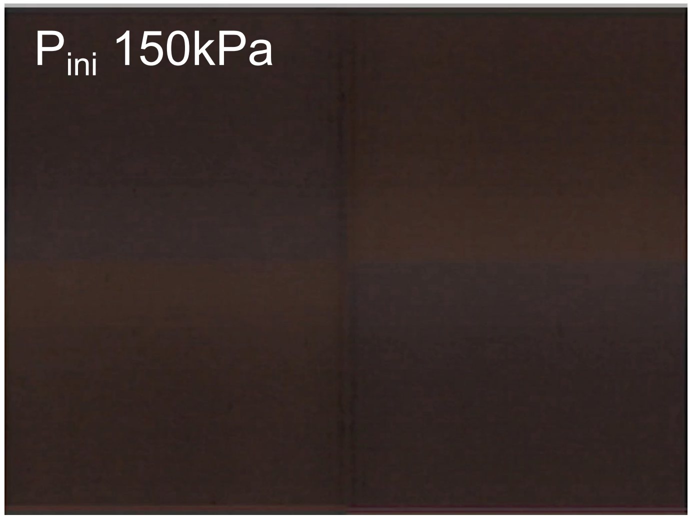
Effect of initial pressure on combustion
(λ=1.0, 800 rpm, CNG only, Long φ4.0 type, P0 = 130, 150, 170 kPa)

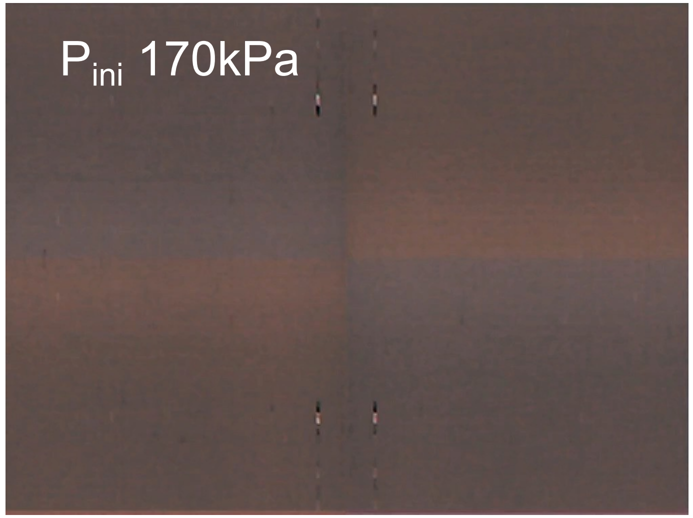
- ➡The jet extinction phenomenon varies with P_{ini}.
  ➡The combustion period also increased with the increase in P_{ini}.

Long φ4.0 type









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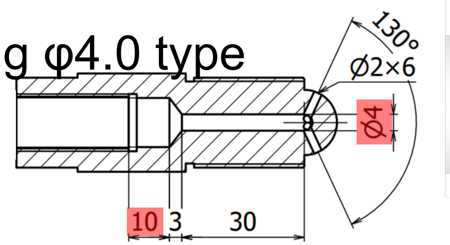
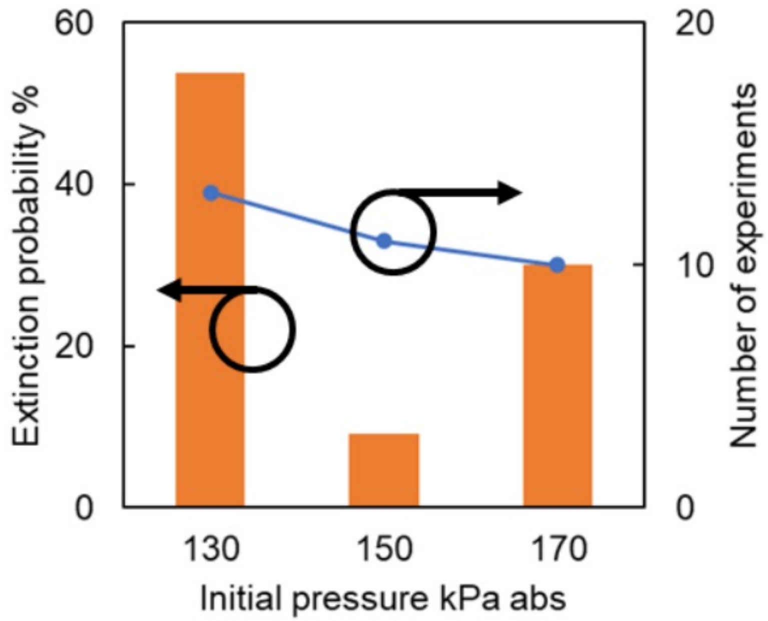
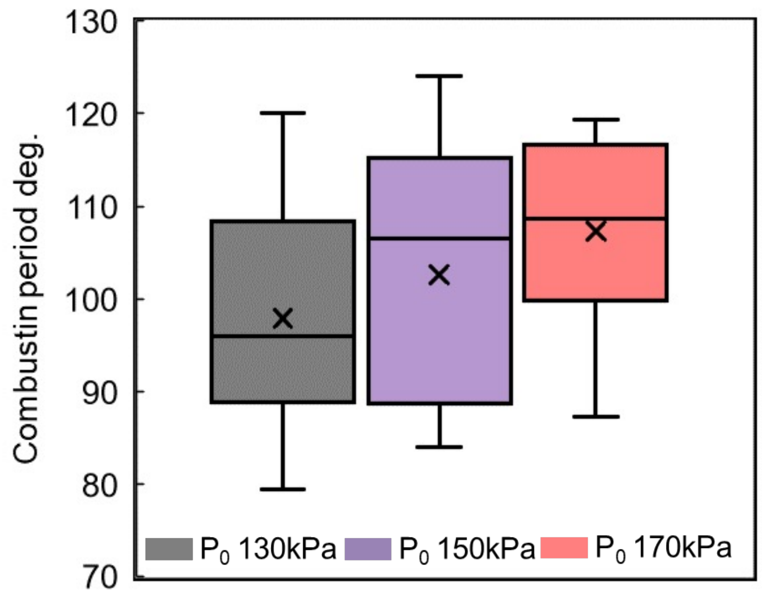




extinction probability

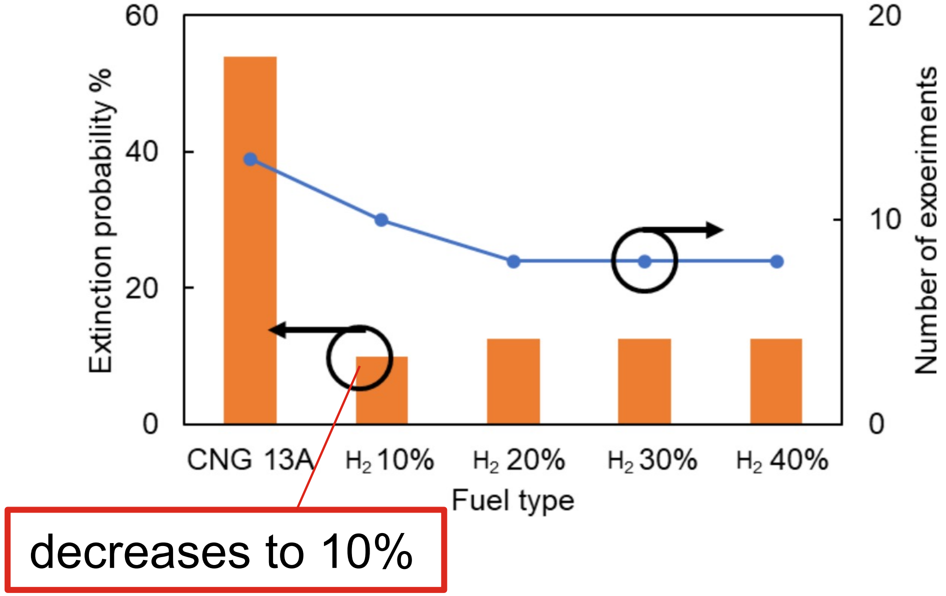


combustion period

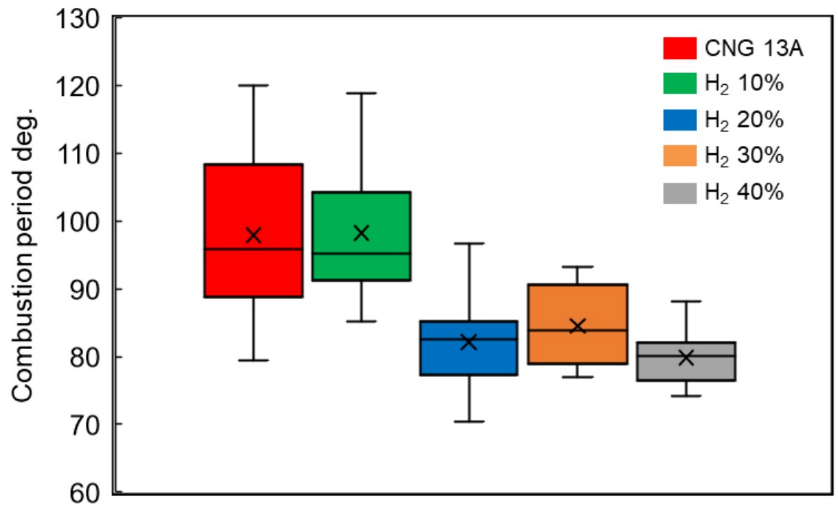
Effect of H_2 addition on combustion
(λ=1.0, 800 rpm, P_{ini}=130 kPa , Longφ4.0 type)

- more combustion experiments using a longφ4 for base CNG with 10%, 20%, 30%, and 40% H_2.
  ➡Jet extinction decreases but does not become 0%
  ➡The combustion of CH_4-H_2 is shorter than the baseline Japanese CNG13A fuel.

extinction probability



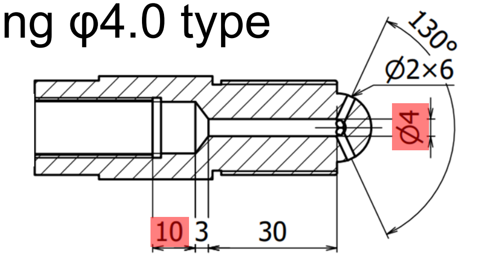
combustion period

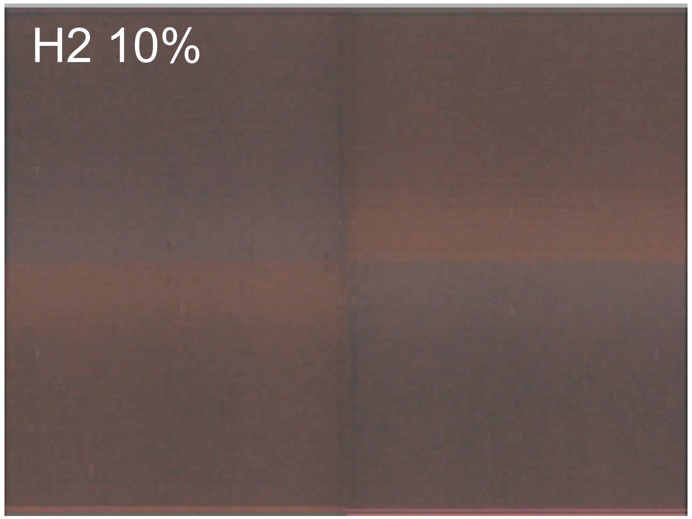


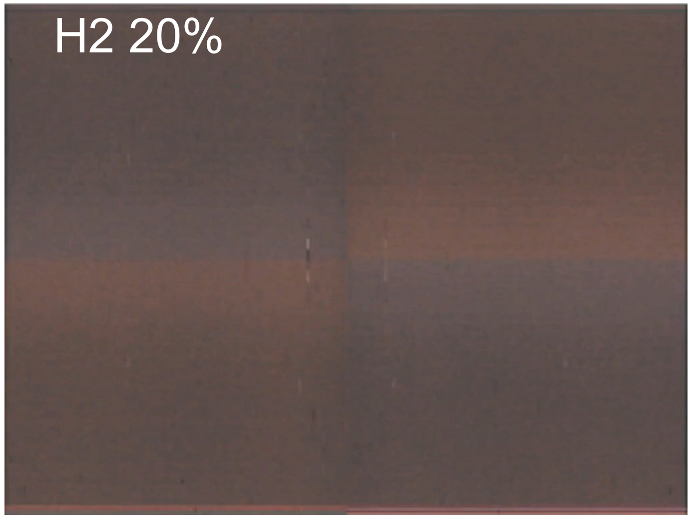
Effect of hydrogen addition on combustion
(λ=1.0, 800 rpm, P_{ini}=130 kPa, Longφ4)

- 3D-CFD simulations for CNG13A with hydrogen addition were performed.
- The difference in laminar flame speed affects the flame spread in the pre-chamber and the jet ejection time.

Long φ4.0 type







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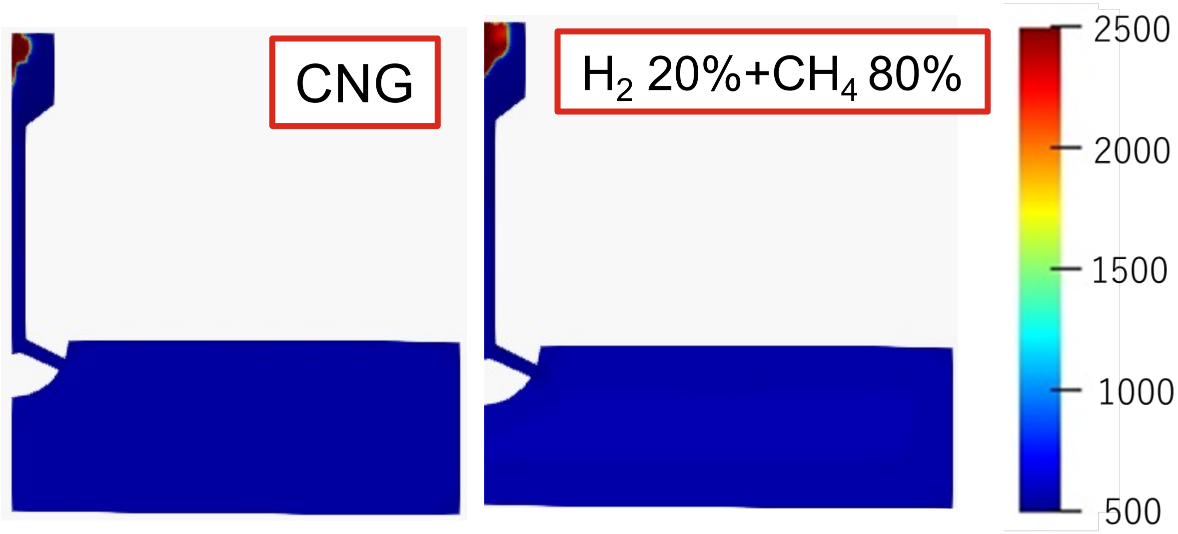
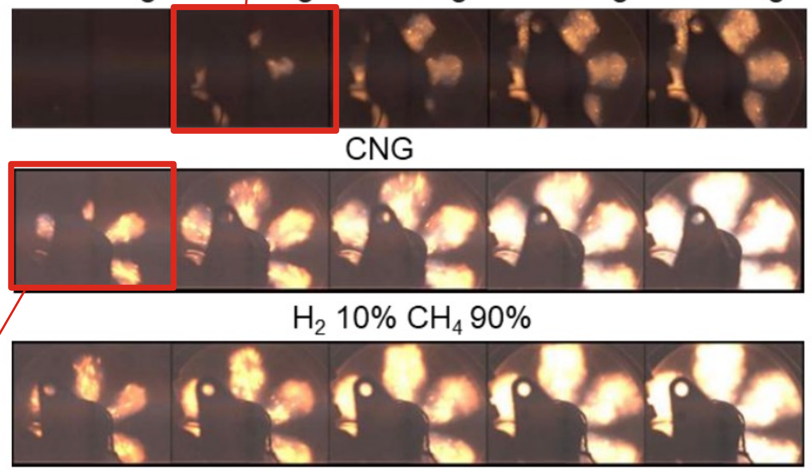


Temperature distribution



Conclusions

- Based on the experimental data from RCEM and the numerical simulation results from CONVERGE, the following conclusions were obtained:

  - The **funnel-shaped** long pre-chamber **accelerates the jet velocity and shortens the combustion period**.
  - The **size** of the flow path is the reason for the **occurrence** of extinction phenomena.
  - The **smallest diameter area** in the pre-chamber should be designed to be **larger** than the **total cross-sectional area** of the jets to **prevent jet extinction**.
  - **Thermal extinction** can be **prevented** by increasing the **initial pressure** and **changing the fuel type.**
  - **Hydrogen addition** increases the laminar flame speed and jet jetting time, **shortening the combustion period** under the 20% hydrogen addition condition.