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Performance of Ammonia/Natural Gas Co-Fired Gas Turbine with Two-Stage Combustor

IHI

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Advantages of ammonia as an energy carrier

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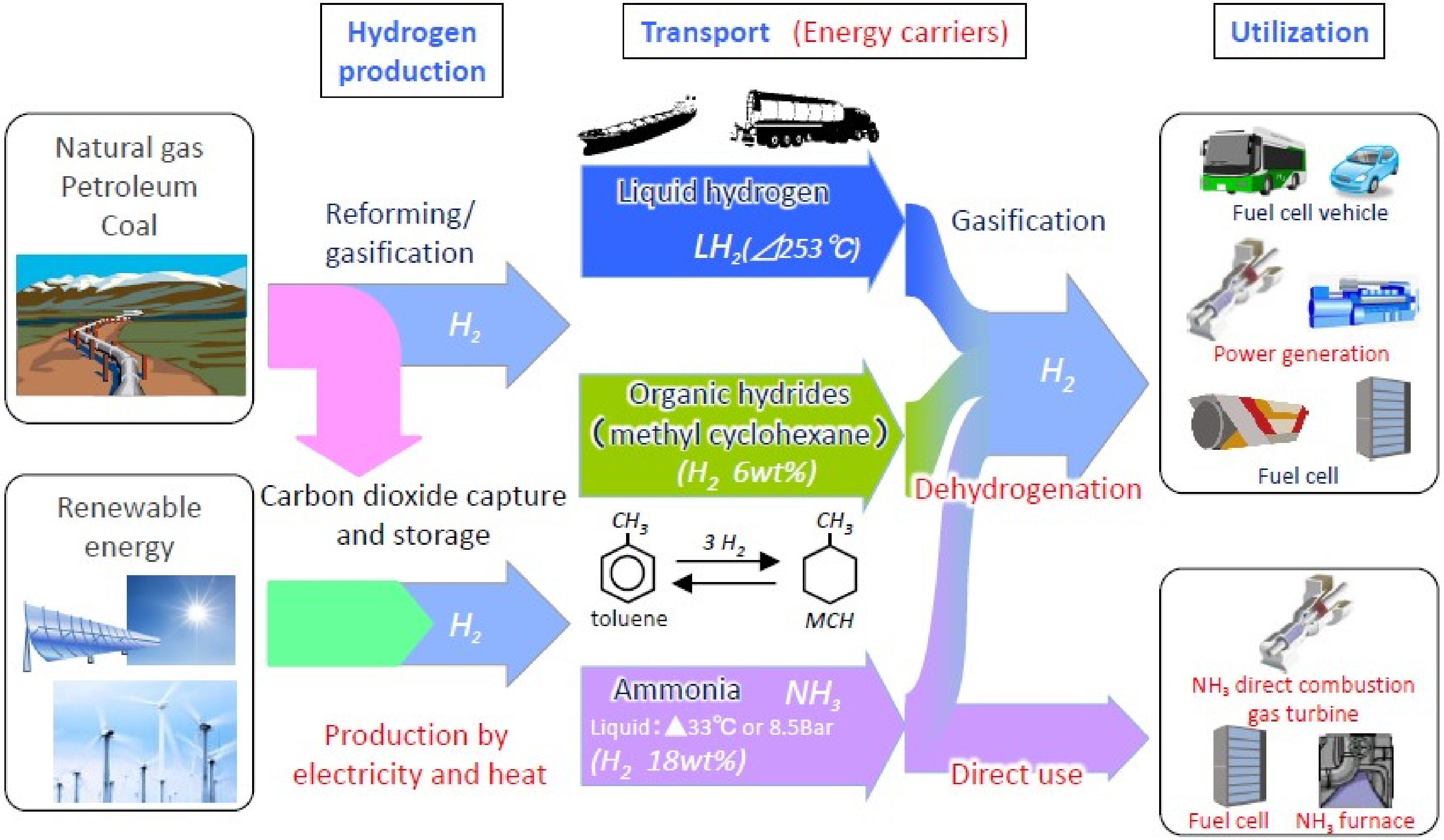
Advantages of ammonia as an energy carrier

(1) Highest hydrogen content per unit volume

(2) Easy to liquefy (-33°C at 1bar, similar to LPG)

(3) Infrastructures for production and transportation are already existing

(4) Can be used directly as a fuel for power plant



Energy carriers considered in 'SIP Energy Carriers' project

Problems to overcome

Problems to overcome

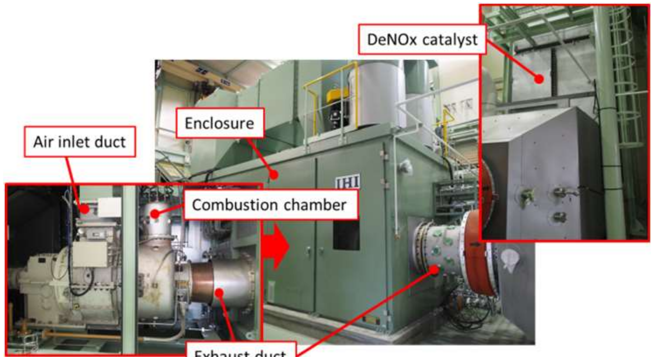
- **(1) Optimized combustor design for stable flame and reduction of fuel-NOx**
- (2) Evaluation of performance of the power plant
- (3) Safety measures
- (4) Cost (Feasibility studies)

IHI joined Cross-ministerial Strategic Innovation Promotion Program (SIP) for the development of Ammonia Direct Combustion technology for gas turbine and coal fired boiler and also Ammonia Fuel Cell.

Coal fired boiler

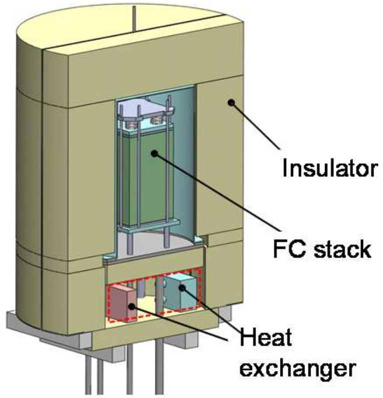
※CFT(Coal Firing Test Furnace)

Gas turbine



※IM270 Gas turbine

SOFC



Target power plant of 'SIP Energy Carriers' project in IHI

Ammonia co-firing gas turbine

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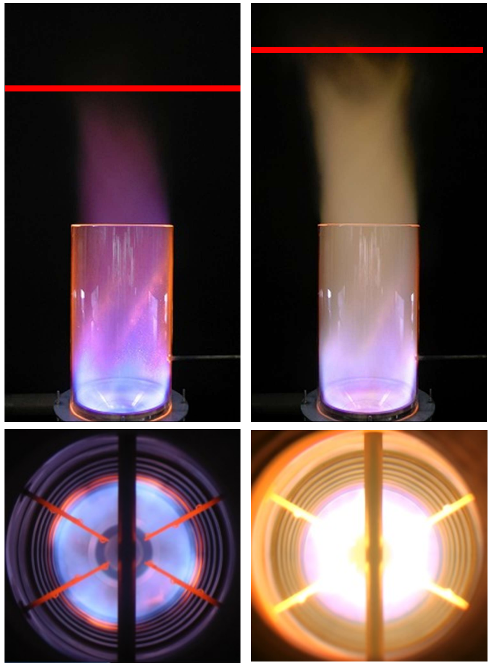
Task :
Optimization of combustor design to reduce NOx
Demonstration using 2MW scale commercial gas turbine



City gas   Ammonia co-firing

Comparison of swirl flame

Feature of NH_3 combustion (compared with CH_4)

- **Low flame speed (approx. 1/5)**
- Low heating value (approx. 1/2)
- Low flame temperature(approx. 200℃)
- **Emission of fuel-NOx** (Thermal NOx)

Problems to be solved

- **Burner design to achieve stable flame**
- **Reduction of fuel-NOx**
- **Reduction of unburned NH_3**

Engine test condition

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Item	Value
Engine	IM270 manufactured by IHI Corporation
Power generation output	2MWe
Cycle	Simple cycle
NH_3 mixing ratio	Maximum 20-25%LHV

NH_3 mixing ratio（based on LHV）

$$r_{NH_3}[\%LHV] = 100 \times \frac{\text{Energy input of NH}_3[\text{kW}]}{\text{Energy input of Natural gas}[\text{kW}] + \text{Energy input ofNH}_3[\text{kW}]}$$

Demonstration using commercial 2MW class GT

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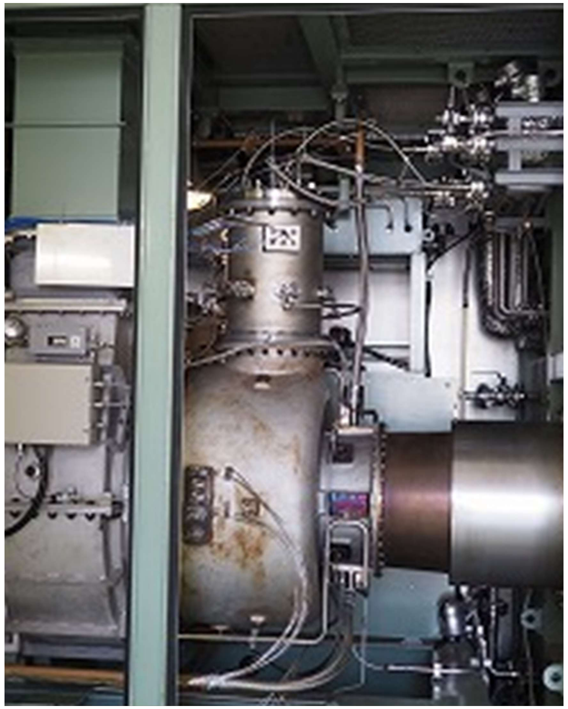
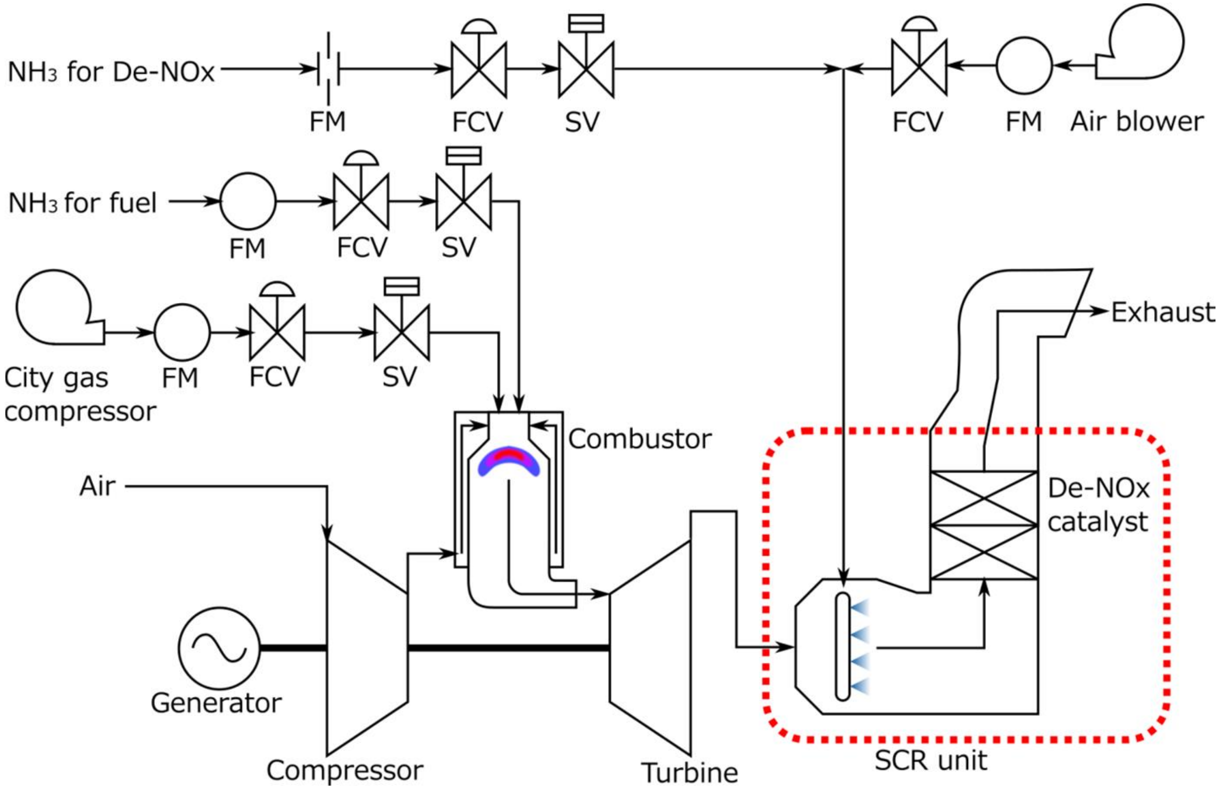
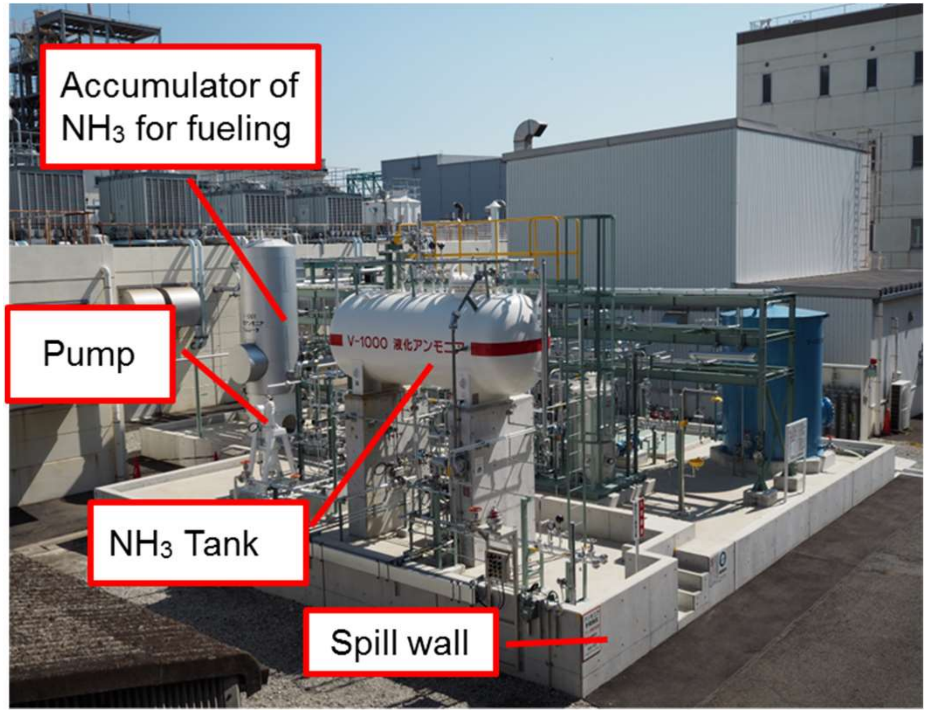


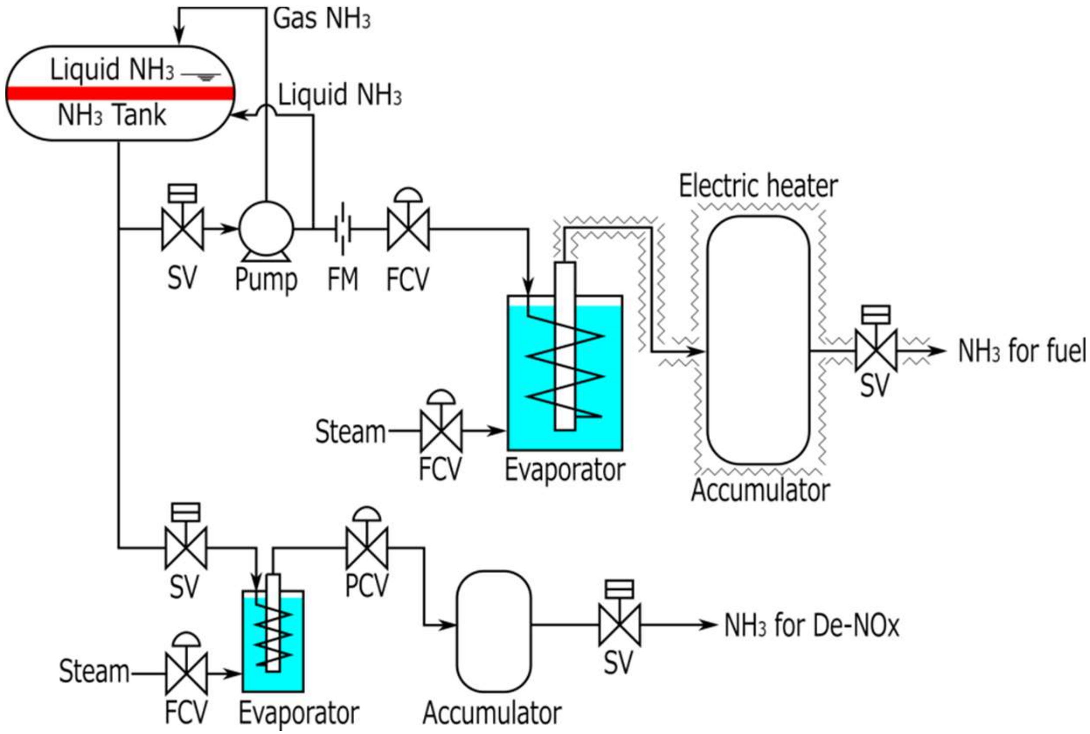
IM270 gas turbine



- Only the combustor was modified to co-fire NH_3 / Natural gas
- Selective Catalytic Reduction (SCR) unit for NOx reduction in exhaust gas
- Pressurized gasified NH_3 provided by NH_3 supply system

High pressure, gasified NH_3 Supply System





- Liquid NH_3 is pressurized by pump, then vaporized by hot water bath evaporator
- Feed lines and accumulator is heated to prevent re-liquefaction of gasified NH_3
- NH_3 for NOx reduction at SCR unit fed from separate low-pressure supply line

Previous results with Lean Premixed Combustor

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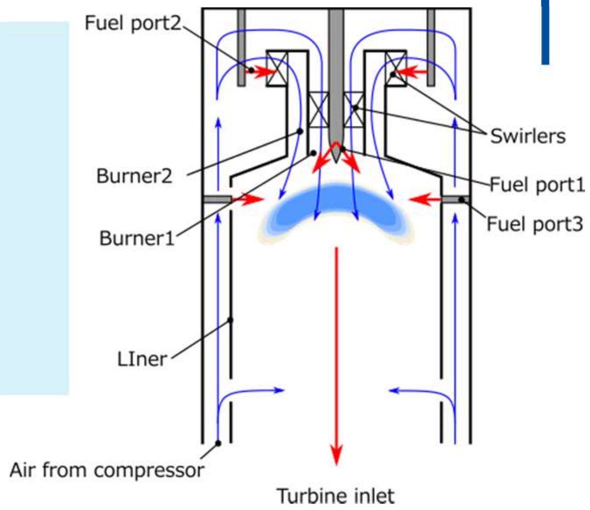
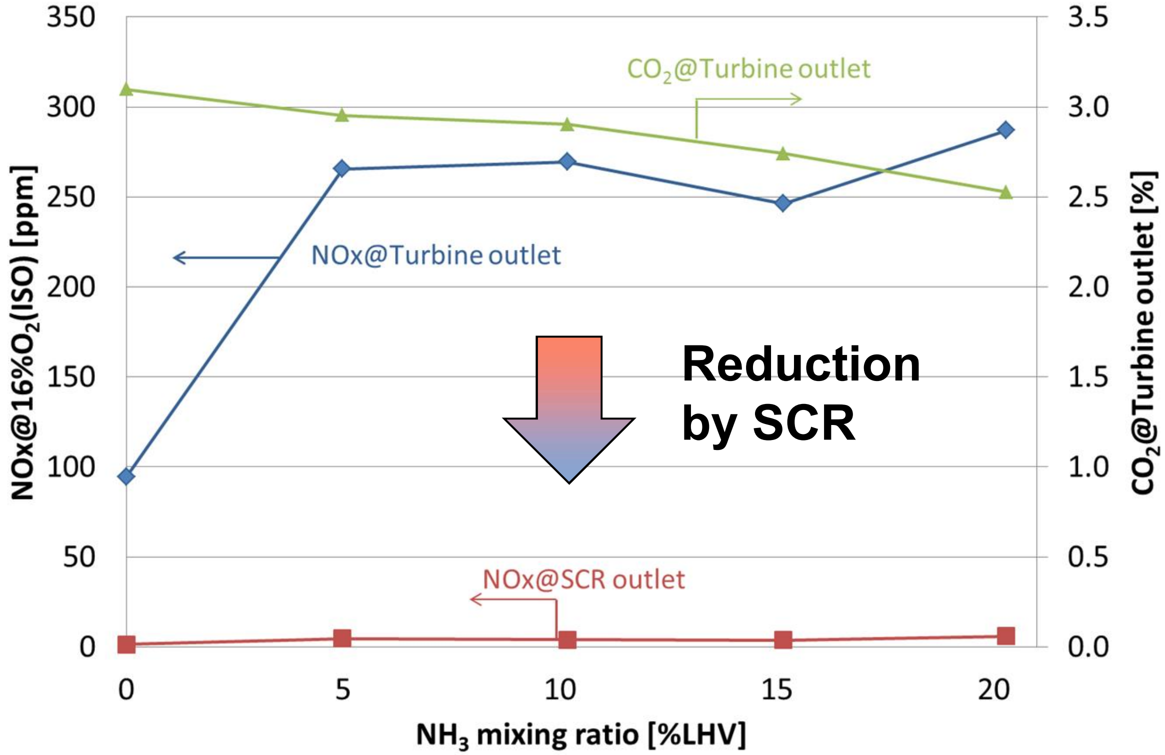
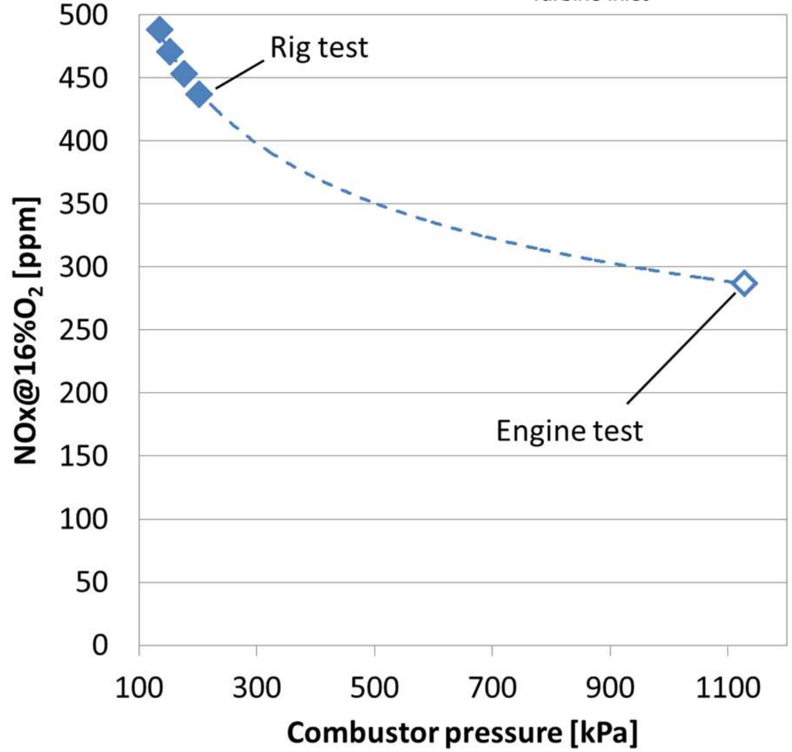
- Results with Lean Premixed Combustor with Secondary Port
- NOx emission increases with increasing NH3 mixing ratio

  290ppm @ NH3 mixing ratio = 20%
- NOx emission decreases with increasing test pressure





Effect of co-firing ratio on NOx emission



Effect of pressure on NOx emission

Low NOx combustion with Two-Stage Combustor

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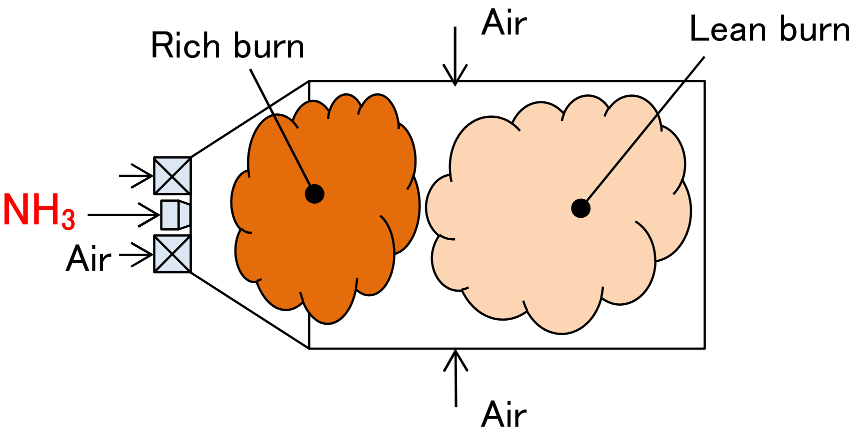
- To further decrease NOx emission, Rich-lean (or Two-stage) combustor is effective

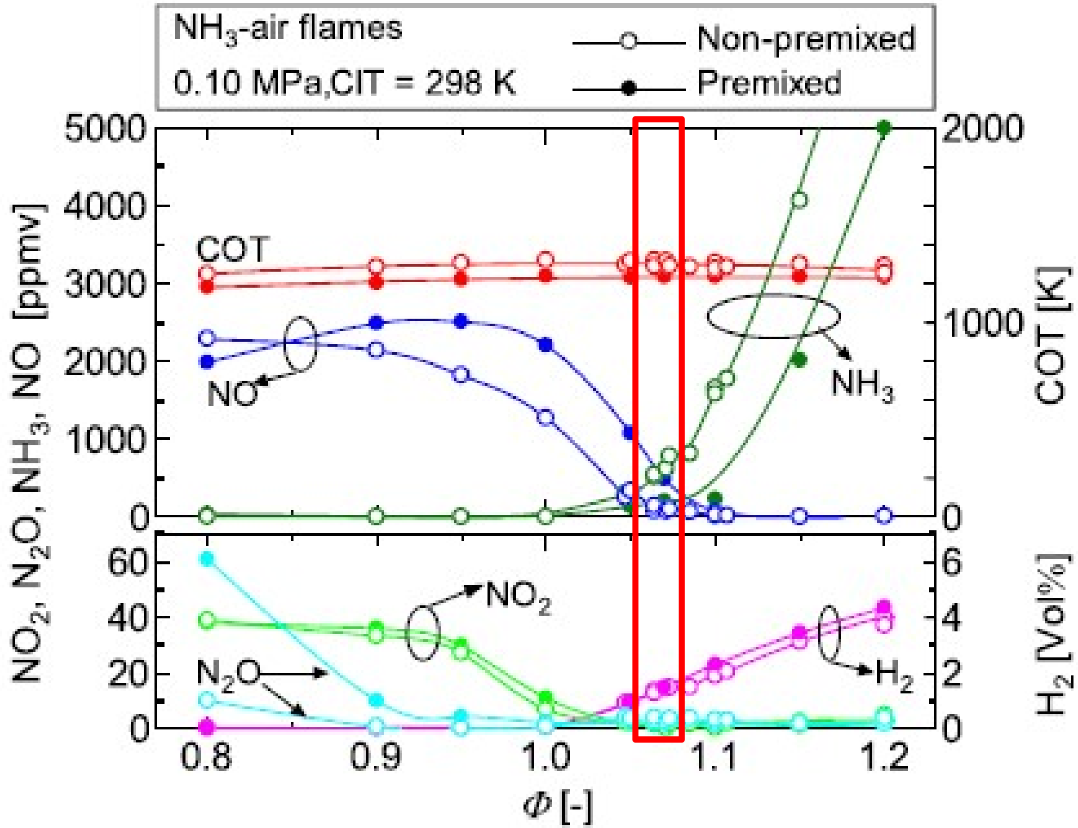
  Hayakawa et al.(2017), Kurata et al.(2017), Okafor et al.(2019)

- Minimum NOx condition around equivalence ratio of 1.07 for pure NH_3 combustion

=> Examine the effect of two-stage combustor in rig and engine tests



Concept of Two-stage combustor

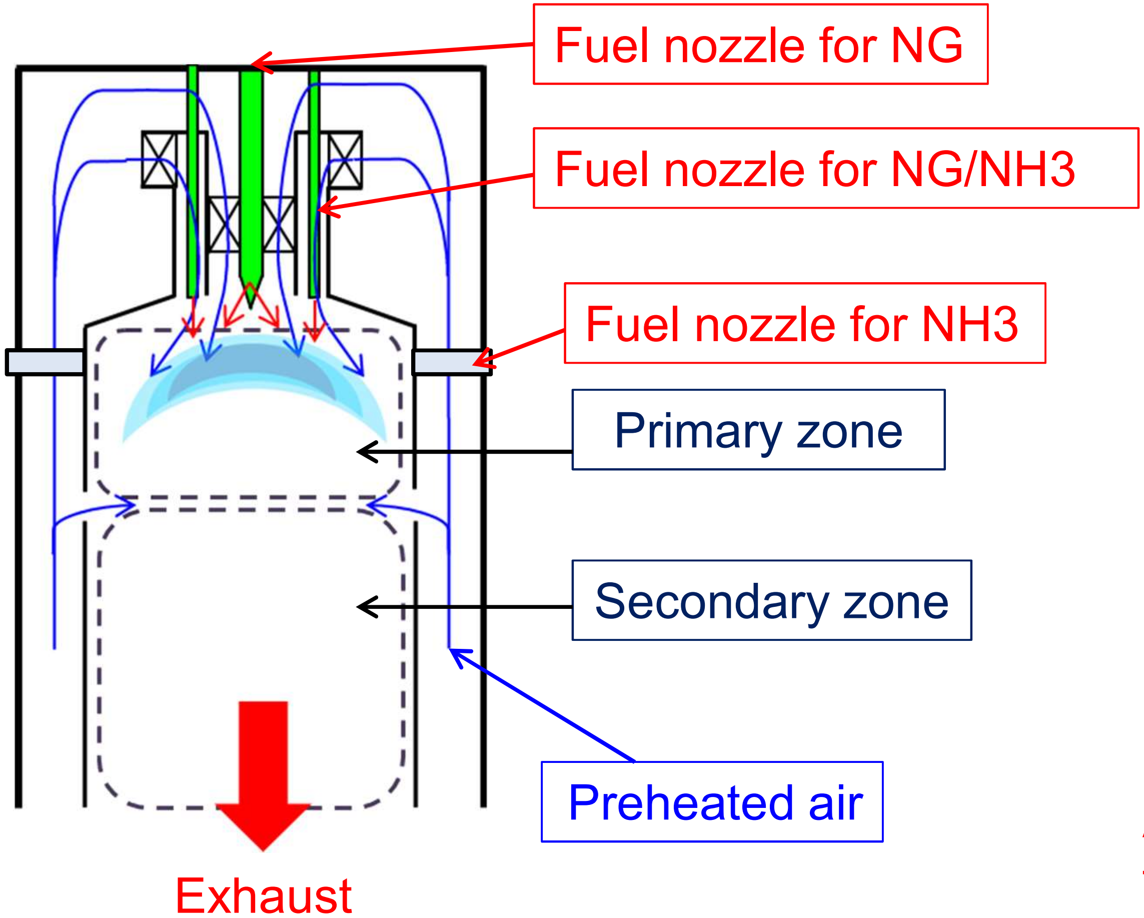


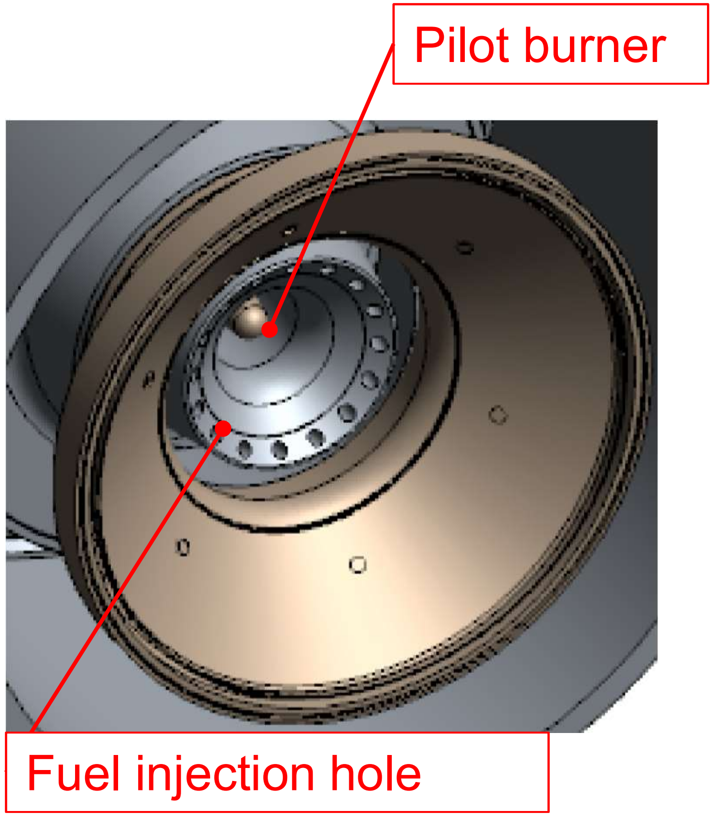
Effect of primary zone equivalence ratio on emission
(Hayakawa et al., J. Hydrogen Energy, 2017)

Diffusion burner for two-stage combustor

Two-stage Combustor with Secondary Burner

- Risk of flashback ⇒ diffusion flame burner
- Two injection port for NH_3: ①Main fuel nozzles, ②Secondary port
- Primary equivalence ratio: 0.85, 1.1, 1.4





Alternately arranged holes for NH3 and NG

Results of rig tests (1)

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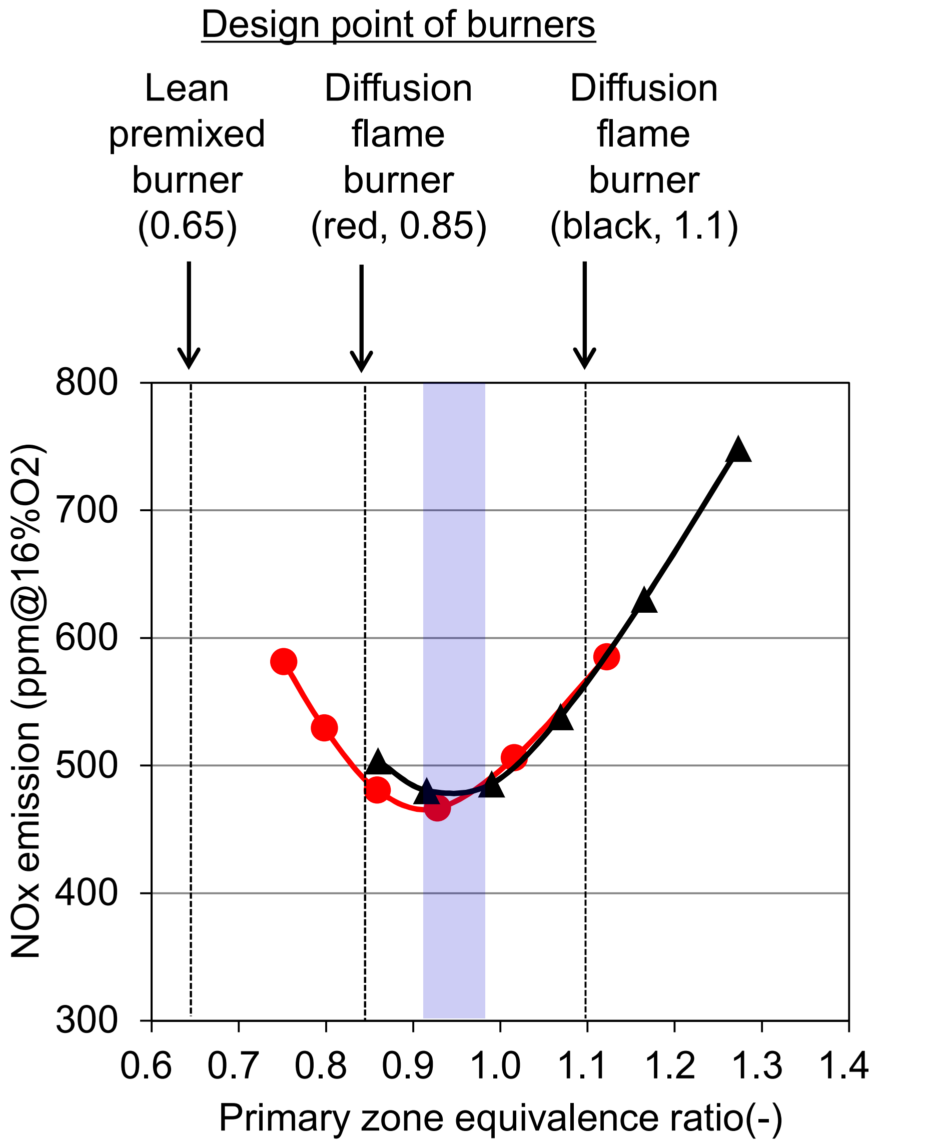
Result of rig tests at atmospheric condition

NH3 mixing ratio = 20%

- Air flow rate was changed to vary primary zone equivalence ratio
- NOx is evaluated by converted into 16% O2 condition to elucidate the effect of dilution
- Minimum NOx around primary zone equivalence ratio of 0.95
- Same results for two burners
  : effect of residence time is small
- Results not consistent with calculations
- Burner with primary equivalence ratio of 0.85 is expected to be most low NOx

NH3 injection from secondary burner



Results of rig tests (2)

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Result of rig tests at atmospheric condition

NH3 injection from main burner

NH3 mixing ratio = 20%

- Minimum NOx around primary zone equivalence ratio of 1.2
- NOx emission is much higher than secondary NH_3 injection case

⇓

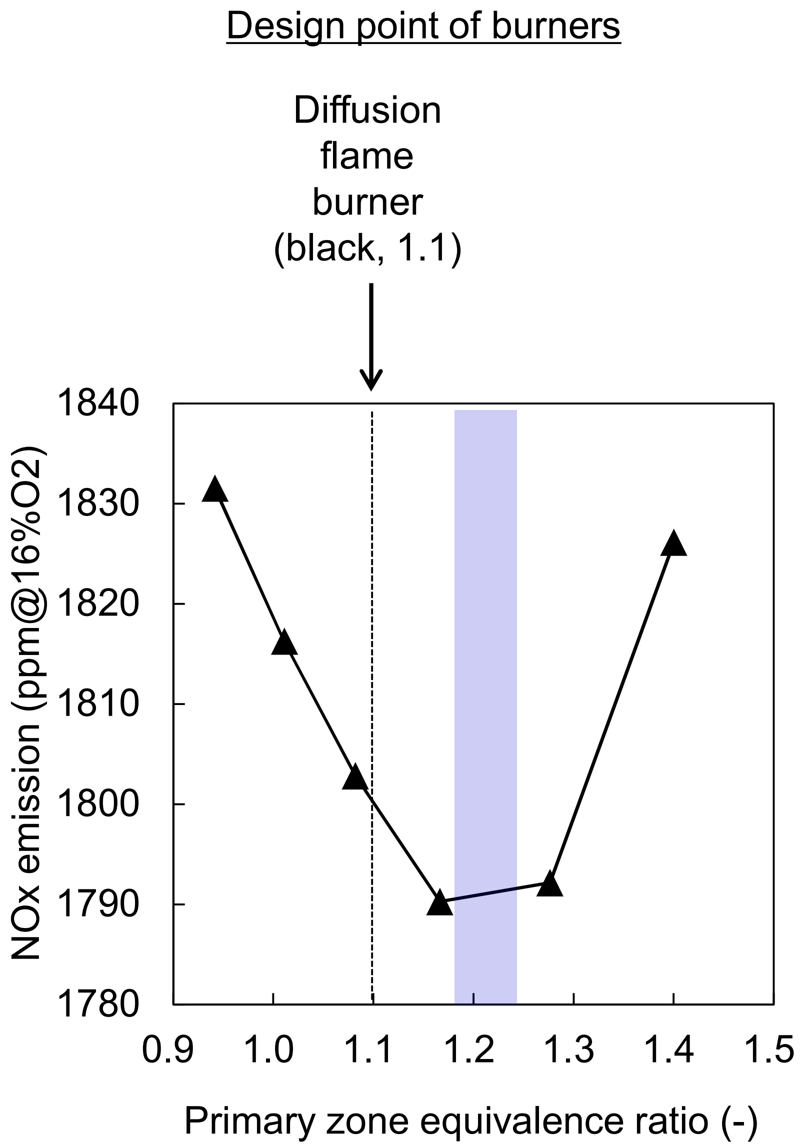
Main: NH_3-Air diffusion flame

Secondary:NH_3-Burned gas (Natural gas -Air) diffusion flame

- Local progress of mixing and reactions might effects NOx emissions

  Direct contact of ammonia and air

  Radical and intermediate species distributions



Results of engine test

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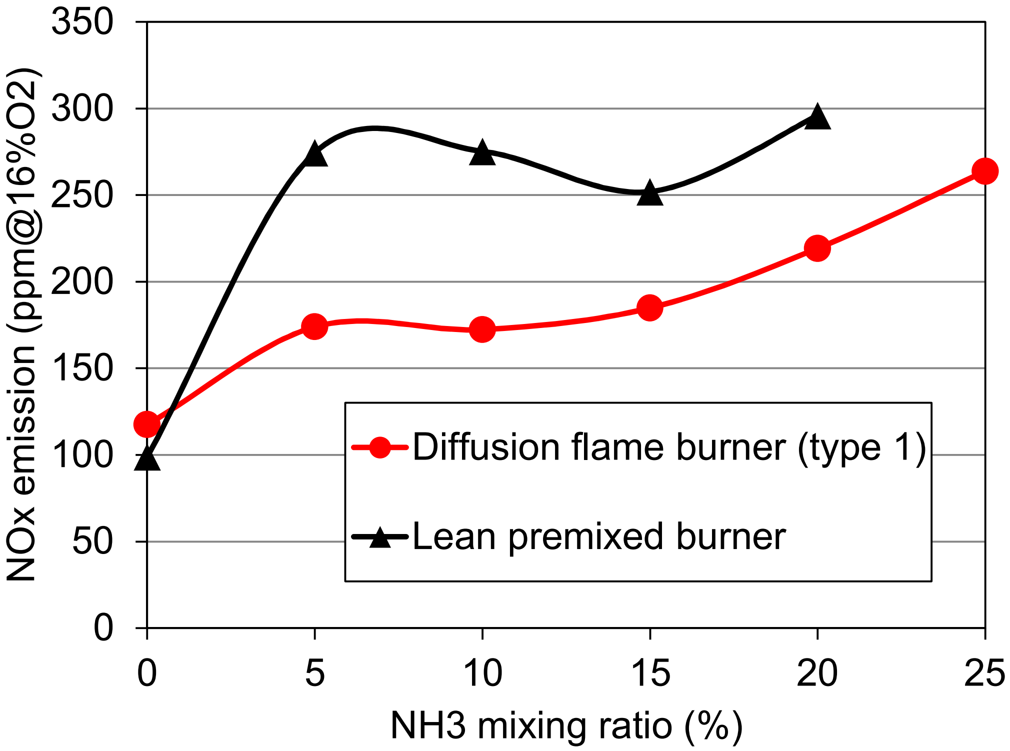
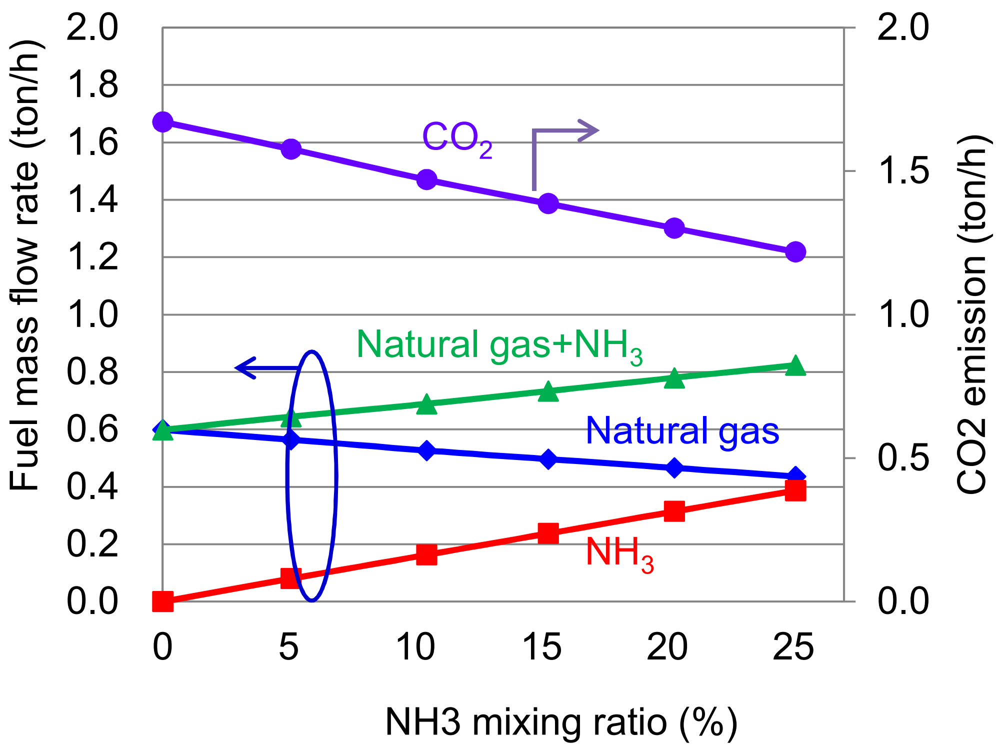
Diffusion burner with primary equivalence ratio of 0.85

NH3 is injected from secondary burner

- NOx emission: 230ppm @ NH3 mixing ratio = 20%
- Reduction of CO_2 is confirmed in engine test





Composition of NOx emission in engine test

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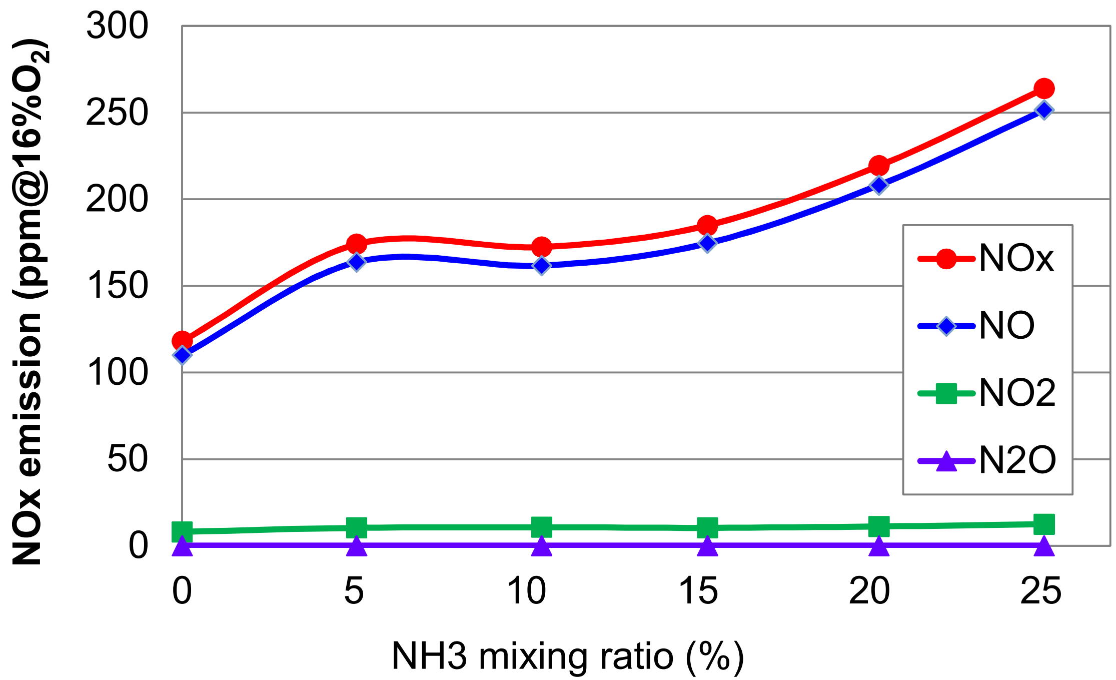
- Composition of NOx is also measured with QL-NX of Horiba LTD

  QCL-IR (Quantum Cascade Laser – Infrared Spectroscopy) is adopted
- Reduction of N2O is important due to its high GWP

  GWP(Global Warming Potential) CO_2: 1, CH_4: 25, N_2O: 298
- N_2O emission is suppressed in GT condition,

  though NOx emission is higher than NG combustion case

  N_2O < 1ppm (under measurements range)



Other performance in engine test

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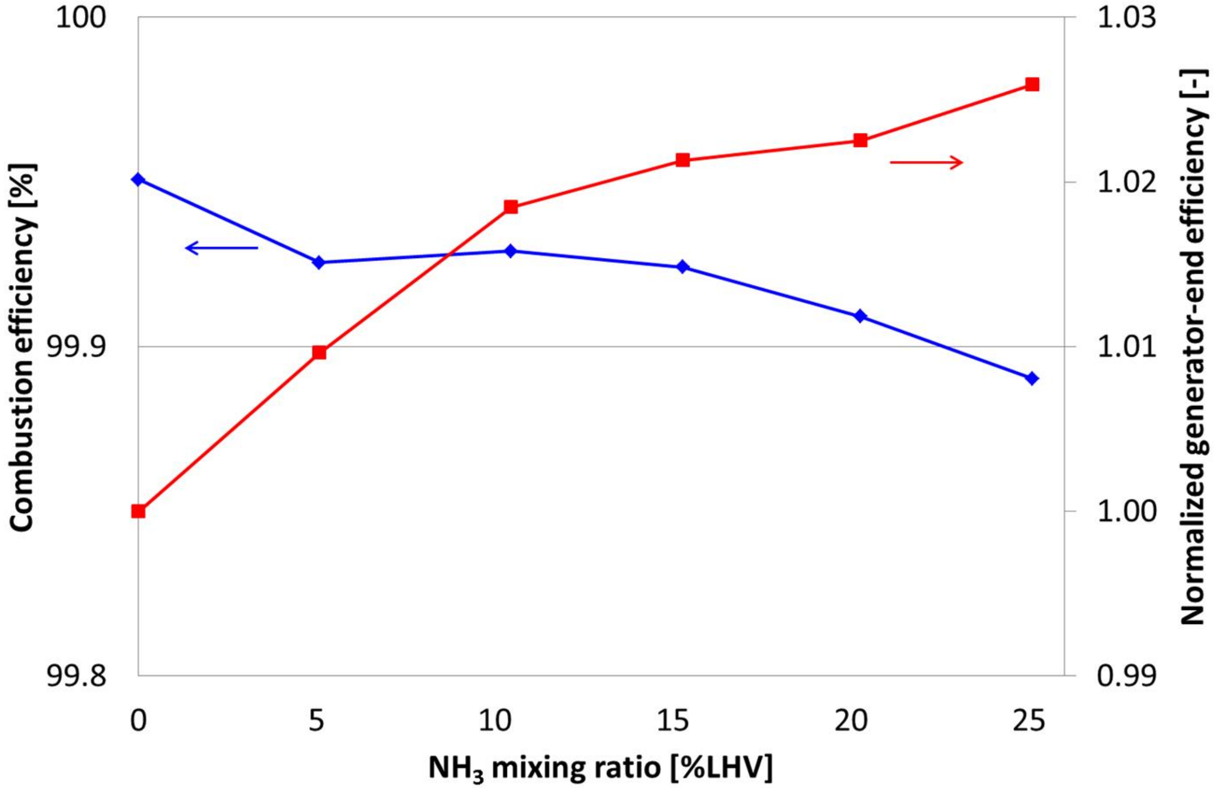
- Other unburned components are also suppressed

  NH_3 < 12 ppm, CO < 4ppm, Total Hydro Carbon < 1ppm

  As a results, combustion efficiency of over 99.85% is achieved in all test conditions
- Generator-end efficiency slightly improved by increasing ammonia mixing ratio

  This is because flow rate of burned gases are increased by increasing ammonia, due to low calorific value of ammonia than natural gas.



Concluding remarks

Effects of primary zone equivalence ratio and secondary NH3 injections are investigated by rig testing and engine testing.

Results of rig testing show that,

- Optimal primary equivalence ratio depends on the ammonia injection method
- The lowest NOx combustion is achieved with secondary injection case

Results of engine testing show that,

- NOx emissions can be reduced by diffusion flame burner
- Two-stage combustion method is effective in reducing NOx even for secondary ammonia injection method, but the mechanism might be slightly different

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SIP 戦略的イノベーション創造プログラム Cross-ministerial Strategic Innovation Promotion Program

JST 国立研究開発法人 科学技術振興機構 Japan Science and Technology Agency