2018 AIChE Annual Meeting

Performance of Ammonia–Natural Gas Co-fired Gas Turbine for Power Generation

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Background

Fossil fuel fired gas turbine (GT)

○ high thermal efficiency

△ large amounts of CO_2

➡ CO_2 reduction by (partial?) ammonia fueling

Difficulties in NH_3 co-fired gas turbine development

△ Low combustion temperature and low flame speed

Flame blow-off, low combustion efficiency …

△ Complex reaction mechanism

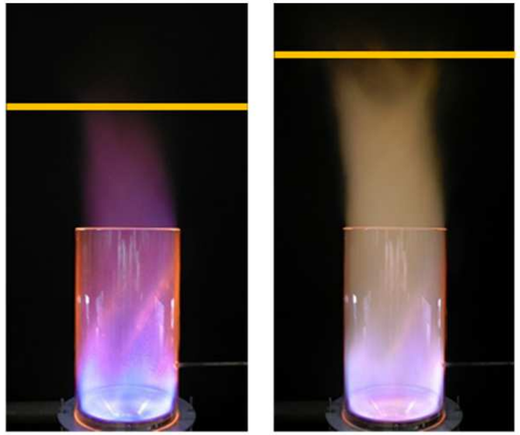
➡ Fuel-NO_x, De-NO_x mechanism

important to develop low emission combustion method suitable for ammonia

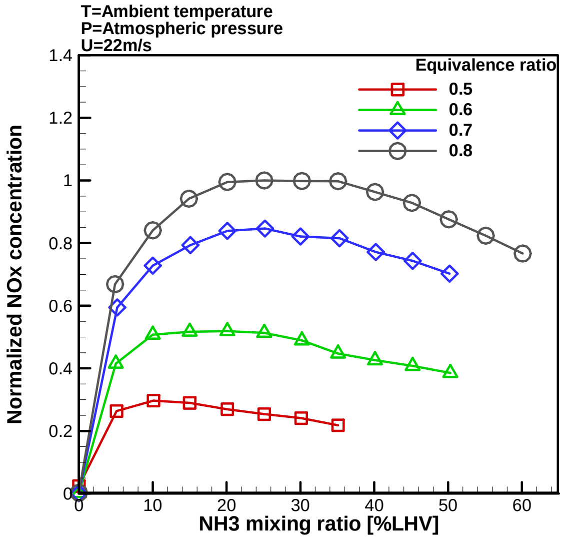
Objective

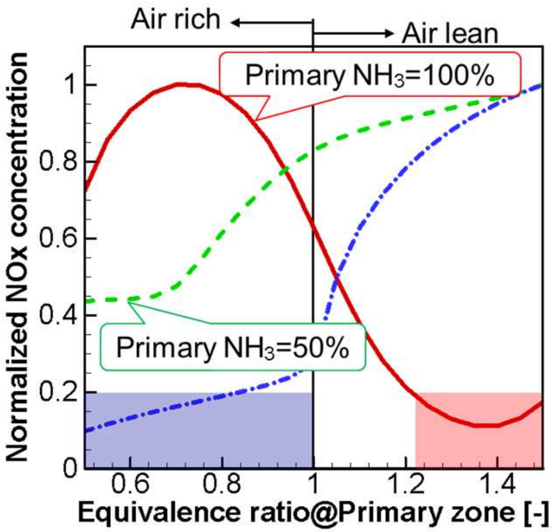
Previous work: Experimental and numerical study on combustion technology for low emission **NH_3/natural gas co-fired gas-turbine** in a combustor

➡ NH_3/natural gas co-fired **two-stage combustor**



Natural gas   NH3/natural gas





NH_3 conference 2015 @Argonne

NH_3 conference 2016 @Los Angeles

2017 AIChE Annual Meeting @Minneapolis

Present work: Power generation test using the two-stage combustor mounted in an **actual gas turbine**

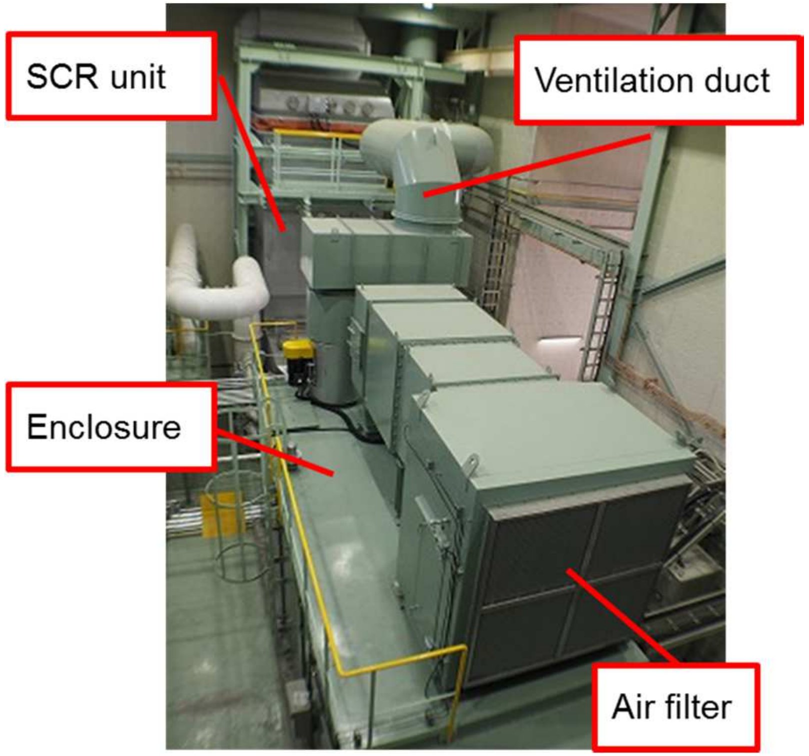
Engine test condition

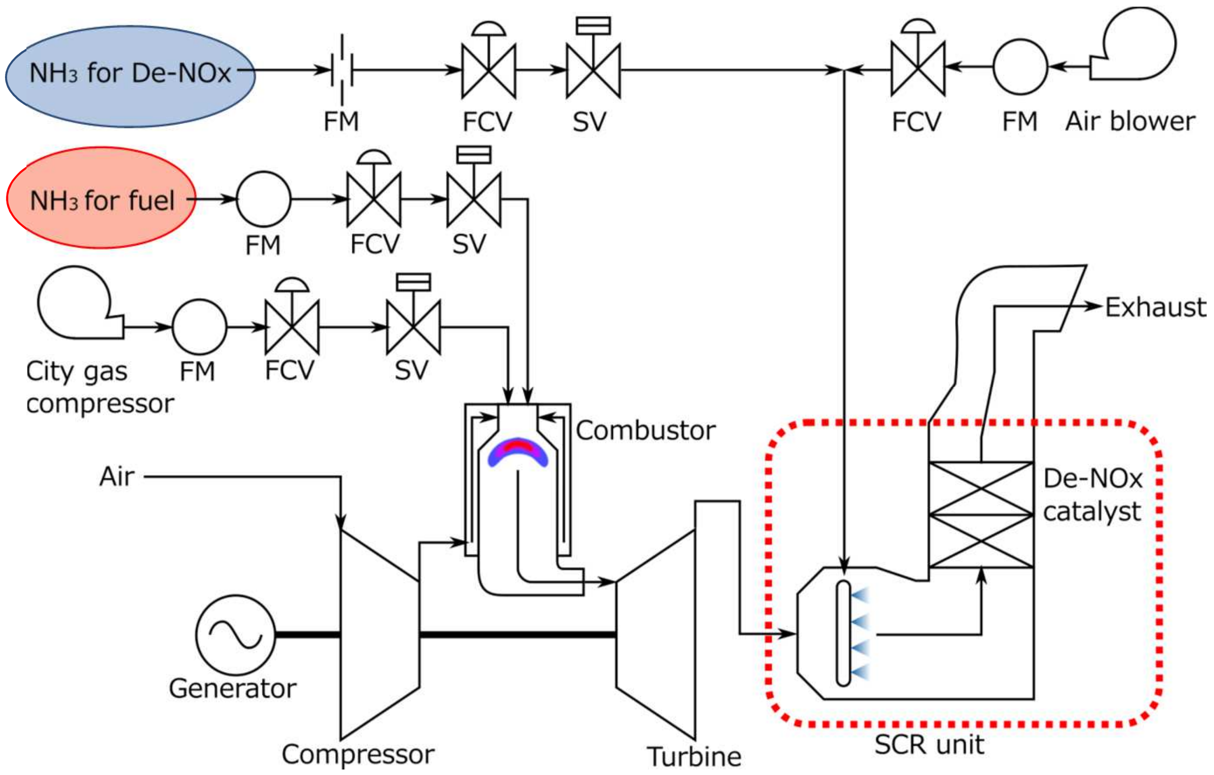
Item	Value
Engine	IM270 manufactured by IHI Corporation
Power generation output	2MWe
Cycle	Simple cycle
NH_3 mixing ratio	Maximum 20%LHV

NH_3 mixing ratio（based on LHV）

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

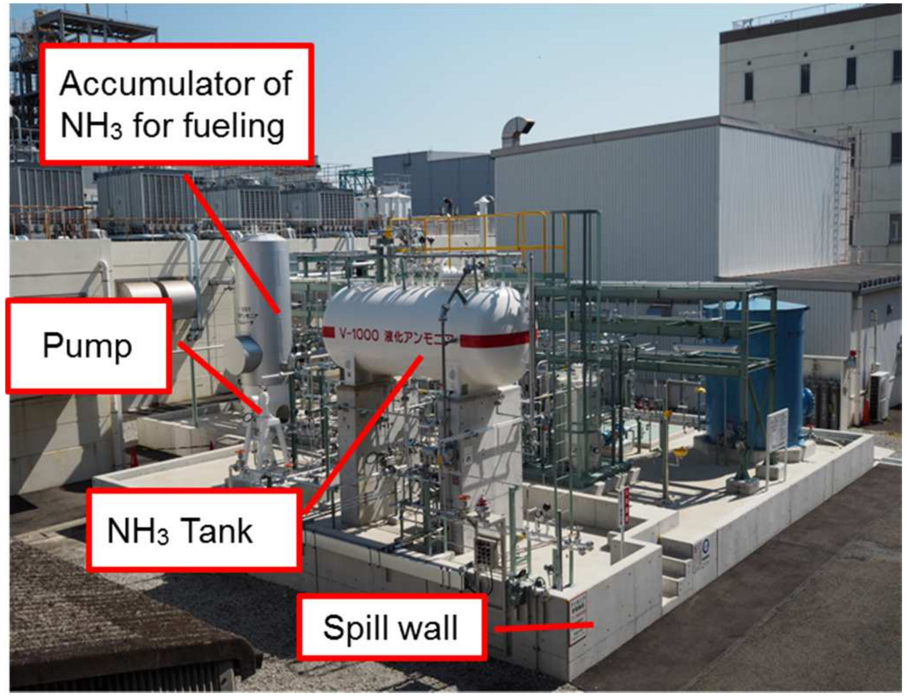
Simple cycle GT system

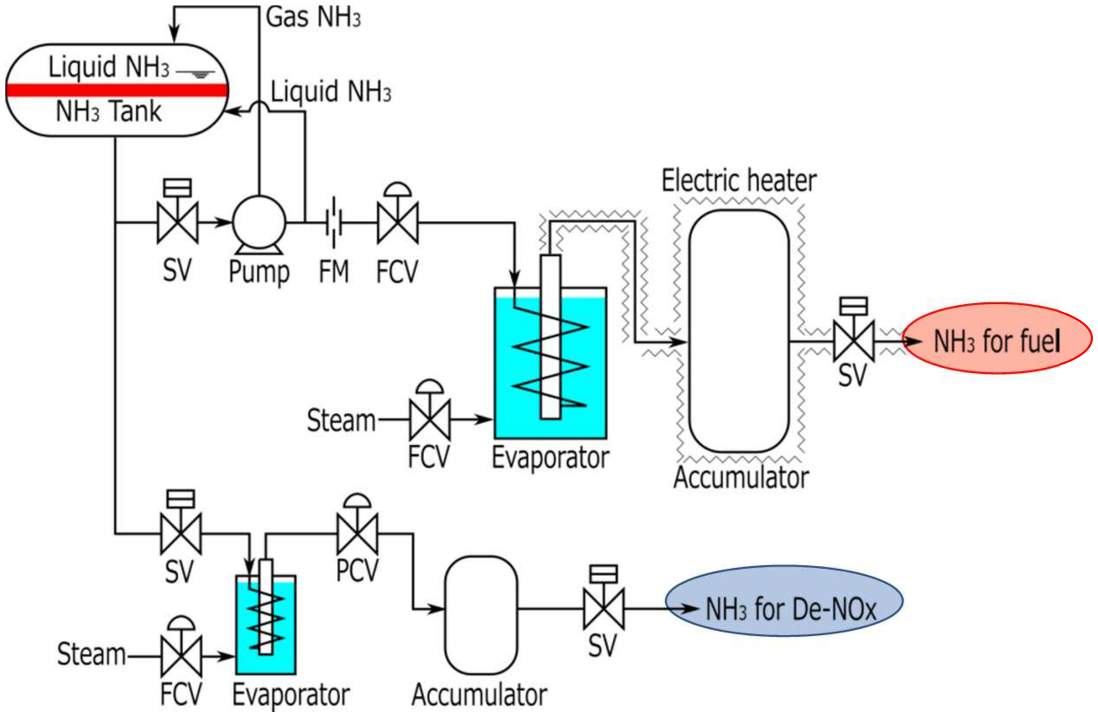




- Adjustment of commercial engine for NH_3-firing only in connection with combustor
- Selective Catalytic Reduction (SCR) unit attached to engine exhaust for NOx reduction in exhaust gas
- Pressurized gasified NH_3 provided by NH_3 supply system

Supply system providing highly pressurized, gasified NH_3

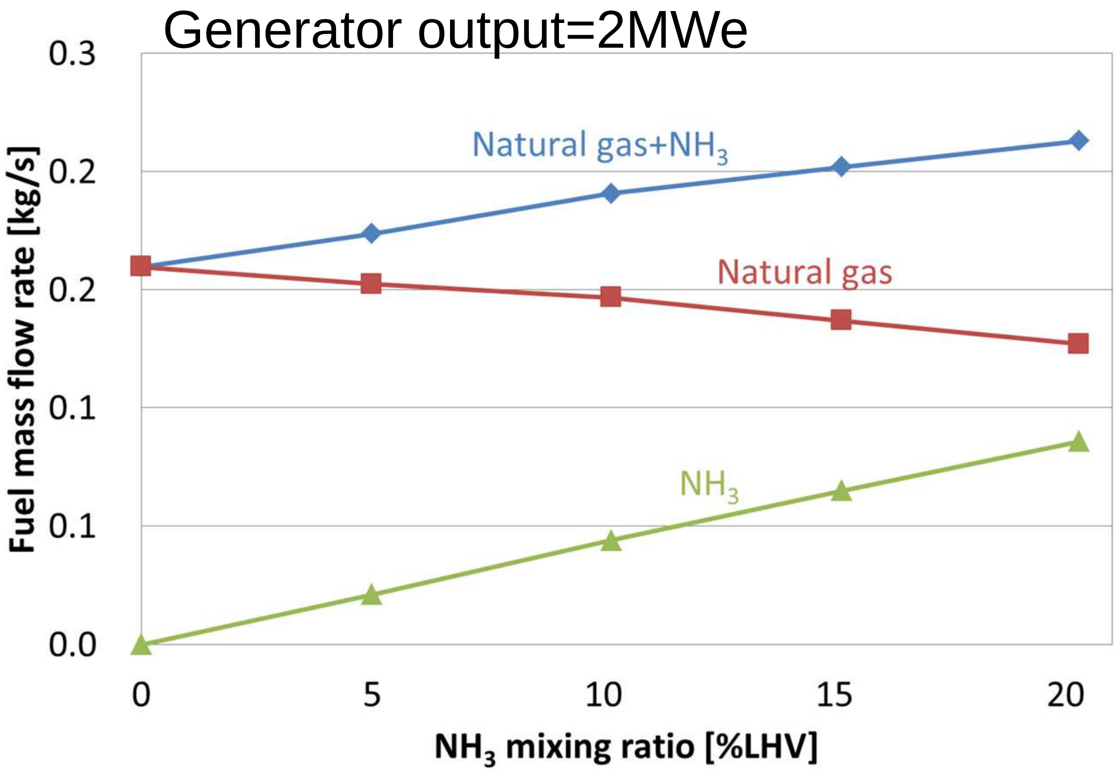




- Liquid NH_3 pressurized by canned motor pump and

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

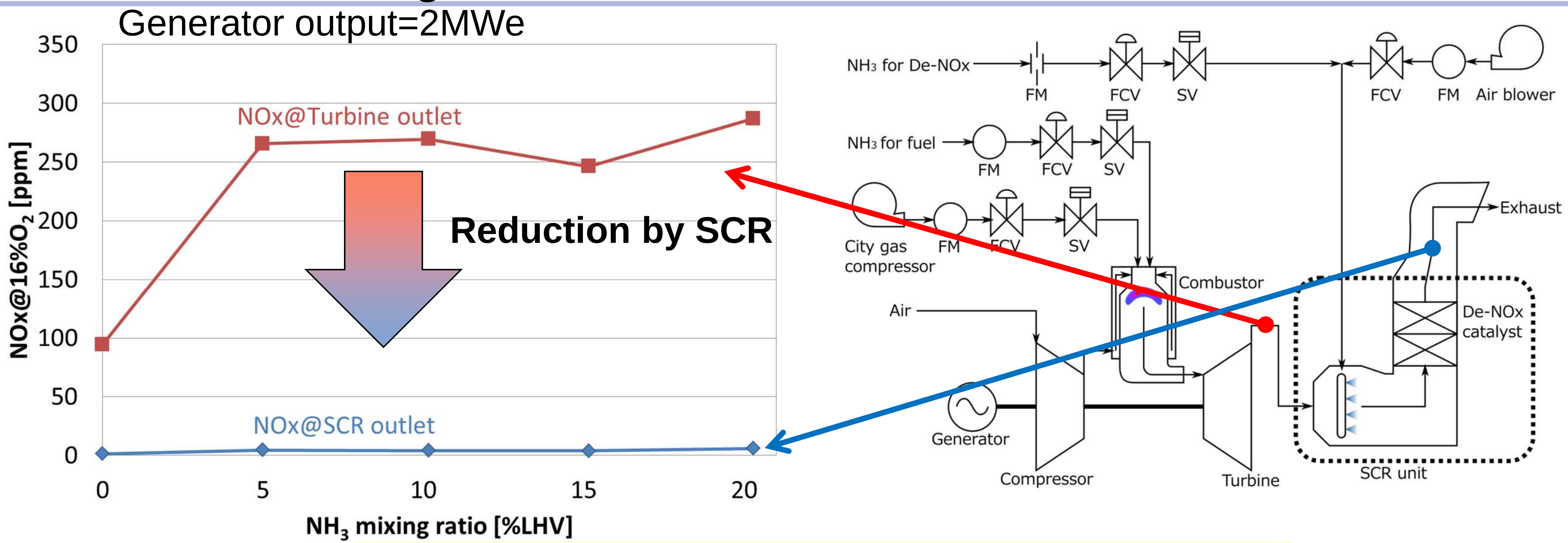
Effect of NH_3 mixing ratio on fuel mass flow rate



- NH_3 mass flow rate manually increased while maintaining 2MWe power generation
- Natural gas supply simultaneously decreased automatically to keep generator output constant
- Total fuel mass flow rate increased when NH_3 mixing ratio increased

➡ LHV of NH_3 only **40%** that of natural gas (NH_3: 18.6MJ/kg, natural gas: 49.3MJ/kg)

Effect of NH_3 mixing ratio on NOx concentration



<u>NOx@Turbine outlet</u>

- 0→ 5%LHV：Rapidly increased
- 5→20%LHV：Saturated to 290ppm

<u>NOx@SCR outlet</u>

- NOx reduced below 6ppm by SCR

Effect of NH_3 mixing ratio on generator-end efficiency

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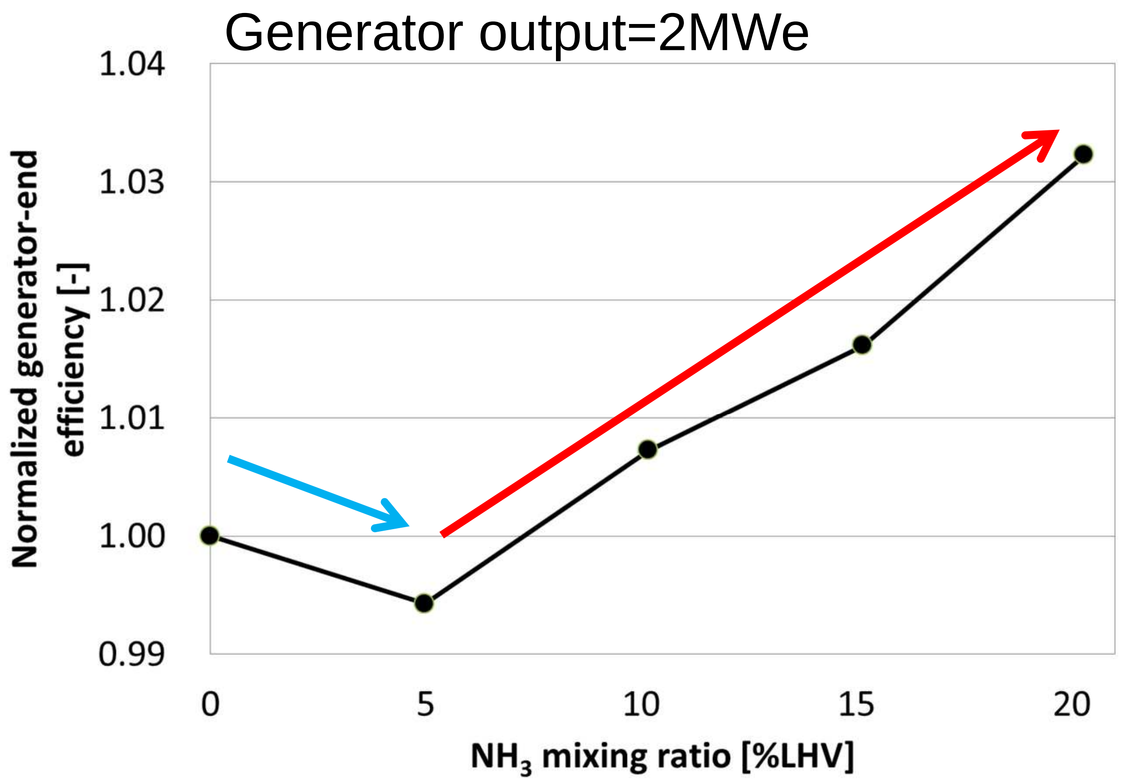

Generator-end efficiency, η_{GE}

$$\eta_{GE} = 100 \times \frac{Generator\ output}{Total\ fuel\ energy\ input}$$

Normalized by value of NH_3 mixing ratio=0%LHV

- NH_3 mixing ratio=0→ 5%LHV： η_{GE} decreased
- NH_3 mixing ratio=5→20%LHV： η_{GE} monotonically increased

➡ This interesting behavior is explained on the next page.

Effect of NH_3 mixing ratio on generator-end efficiency

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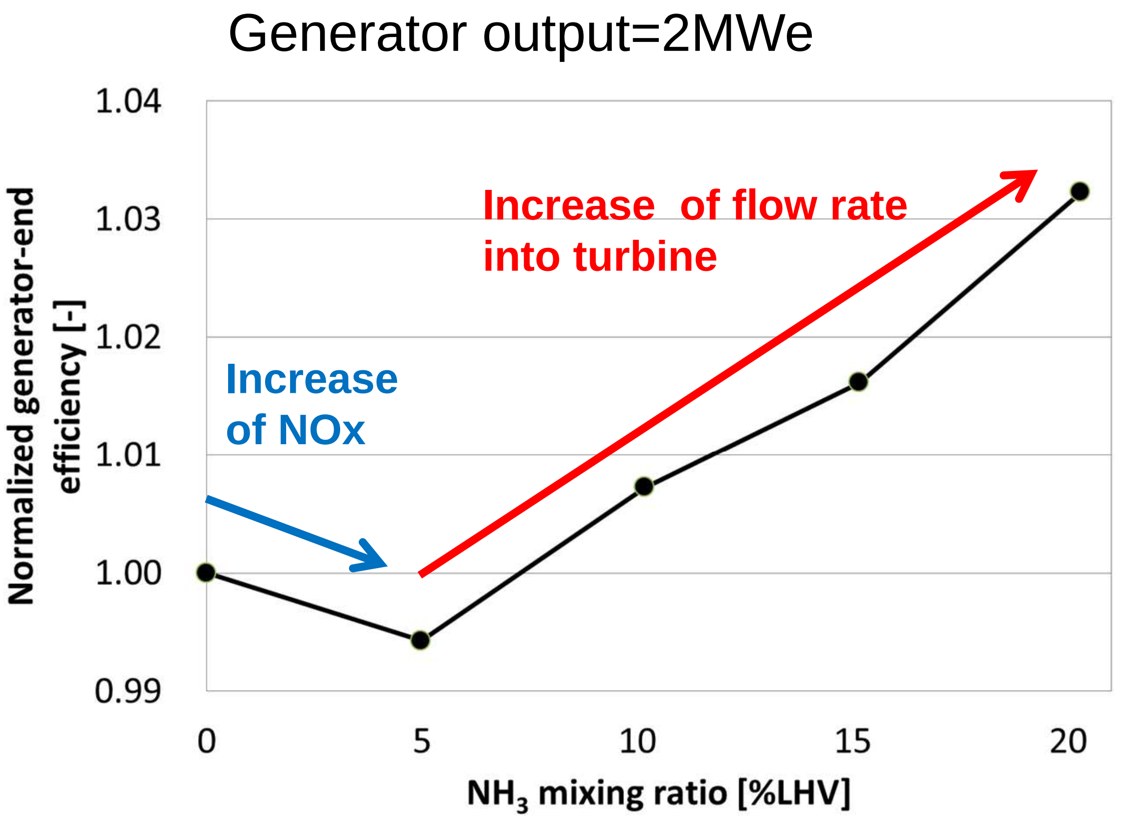

Effect of NOx formation

In the combustion of NH_3, the energy obtained from NOx formation is lower than that from complete combustion.

$$NH_3 + 0.75O_2 \rightarrow 0.5N_2 + 1.5H_2O + \mathbf{318}\,kJ/mol$$

$$NH_3 + 1.25O_2 \rightarrow NO + 1.5H_2O + \mathbf{226}\,kJ/mol$$

Effect of NH_3 supply on gas flow rate into turbine

NH_3 mixing ratio ⬆

➡ Total volume flow rate of fuel ⬆

➡ Flow rate into turbine ⬆

➡ Generator output ⬆

➡ To maintain generator output, total fuel energy input ⬇

Summary

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Demonstration tests were conducted with 2MWe gas-turbine to evaluate the effect of NH_3/natural gas co-firing on the performance of an actual GT.

Results

- It is demonstrated that NH_3 can be used as fuel in a 2MWe GT.
- NOx concentration of NH_3 co-firing GT is higher than that of natural gas fired GT, but it is within a range that can be kept extremely low by SCR unit.
- If NOx concentration can be kept lower, NH_3 co-fired GT yields higher generator-end efficiency compared to natural gas-fired GT.

Acknowledgment

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Thank you for your attention!

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