2017 AIChE Annual Meeting
October 29 – November 3, 2017, Minneapolis, MN, USA

Topical Conference NH_3 Energy+ - Enabling Optimized, Sustainable Energy and Agriculture
560a NH_3 Fuel End Use

Combustion Emissions from NH_3 Fuel Gas Turbine Power Generation Demonstrated

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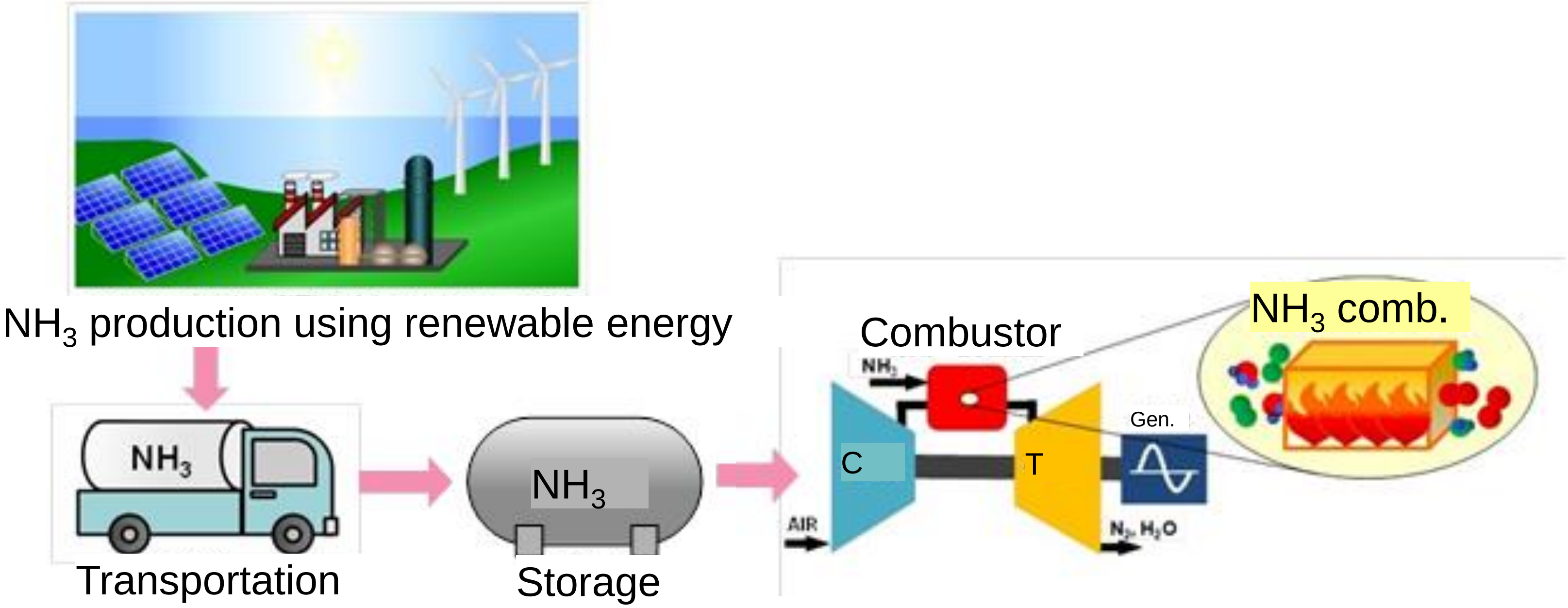
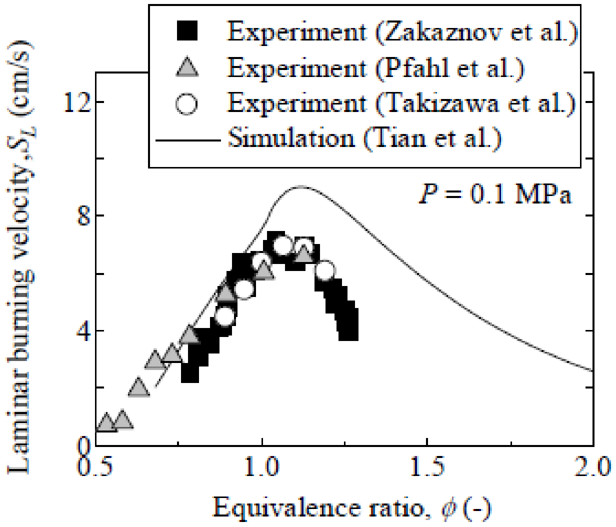
NH_3 as a hydrogen energy carrier

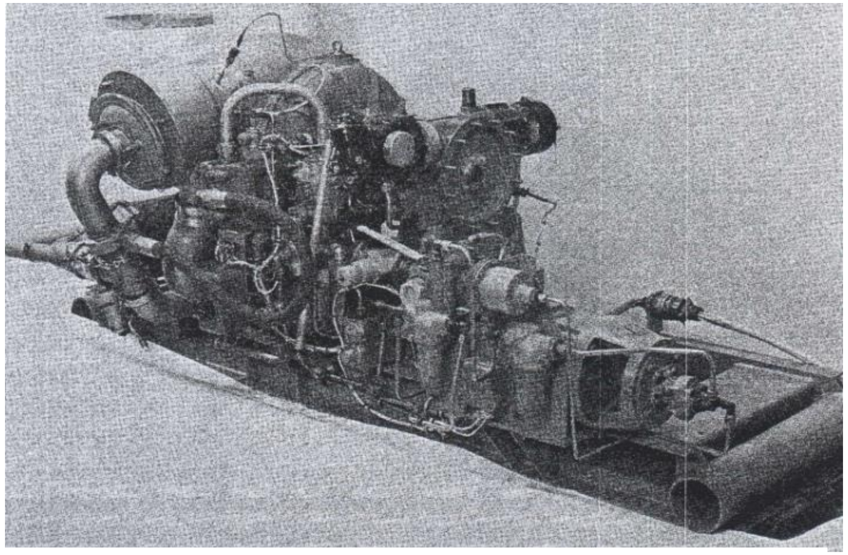


- To protect against global warming, a massive influx of renewable energy is expected.
- Although hydrogen is a renewable media, its storage and transportation in large quantity has some problems.
- Ammonia, however, is a hydrogen energy carrier and carbon-free fuel, and its storage and transportation technology is already established.
- As ammonia utilization, ammonia combustion and ammonia fuel cell are expected.

NH_3-air combustion



S_L of NH_3-air laminar premixed flame (Hayakawa,2015)

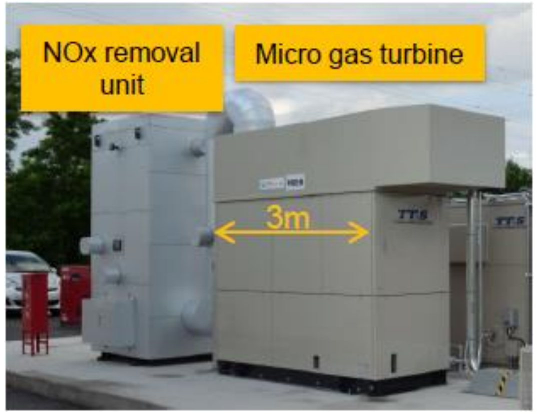


Solar model T-350 engine (Solar, *Final Technical Report*, DA-44-009-AMC-824, 1968)

- NH_3-air combustion is difficult because the laminar burning velocity is much lower than that of conventional hydrocarbon fuels.
- In 1967, Pratt examined an NH_3-fired gas-turbine combustor, and concluded that combustion efficiencies were unacceptably low.
- Verkamp showed that the pre-cracking of NH_3 and the additives improved the flame stability
- Because of those difficulties, the research and development of NH_3-fueled gas turbines were abandoned, and it has not been retried until recently.

Recent work of NH_3 fueled gas turbine

NH_3-air combustion gas turbine (Evans, 2013)



NH_3-kerosene-air micro gas turbine in our institute (AIST)

- Recent demand for hydrogen energy carrier revives the interest of NH_3 fuel.
- Evans proposed NH_3-air combustion gas turbine using pre-cracked NH_3.
- Valera tested NH_3-CH_4-air gas turbine combustors.
- AIST successfully performed ammonia-kerosene co-fired gas turbine power generation in 2014, and ammonia-fired gas turbine power generation in 2015.
- AIST plans developing a low NOx combustor using combustor test rig.
- Since emission characteristics of test rig combustor differ from that of gas turbine, emission data of gas turbine re-characterized with the other parameters is needed.

Emissions of NH_3 and NOx

NH_3, Air → Combustion → N_2, H_2O, Pollutant emissions NH_3, NO, …

Unburnt NH_3 ↓ → Combustion efficiency ↑

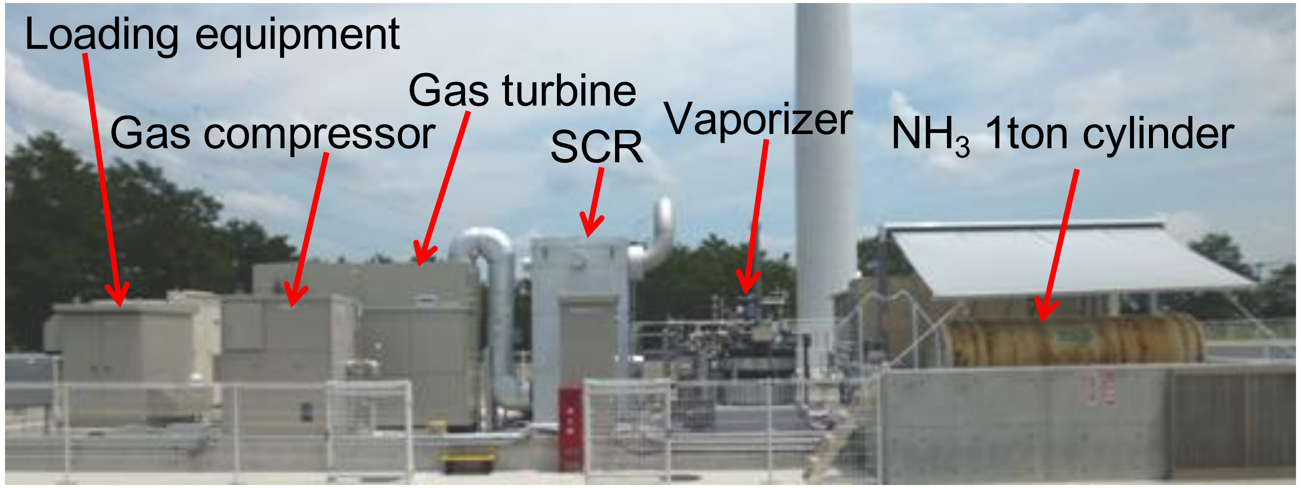
NH_3 fuel → Source of fuel-NO

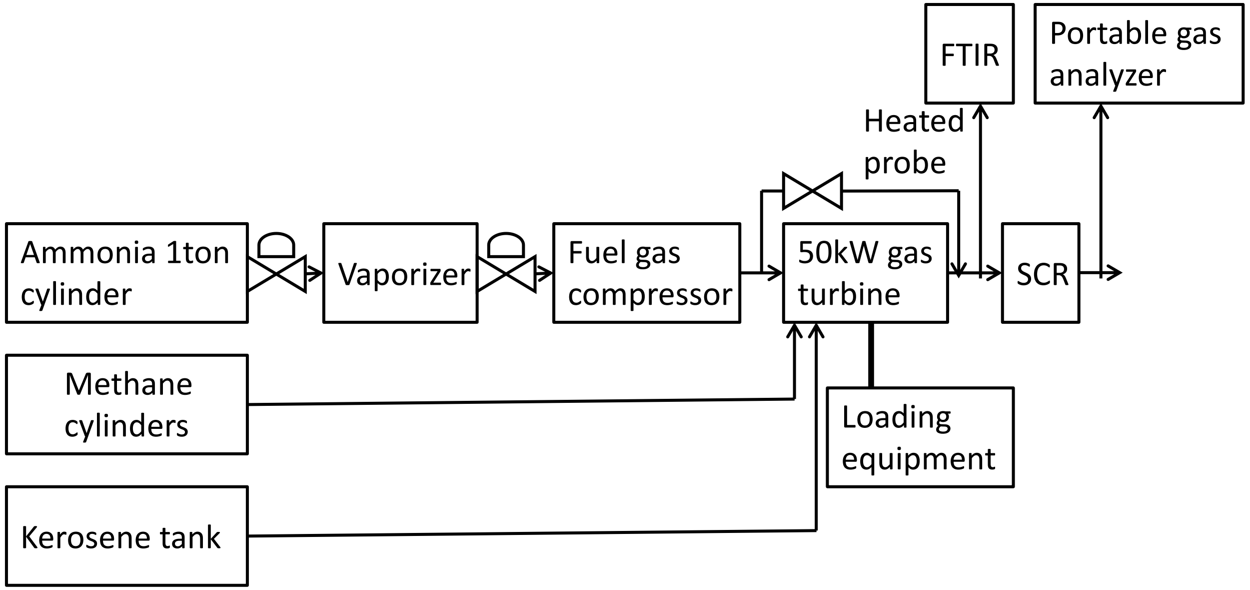
- In the case of NH_3-air combustion, most products are N_2 and H_2O.
- Small amounts of NH_3 and NO are detected as pollutant emissions.

- If the emission of unburnt NH_3 increases, combustion efficiency decreases; this is prone to occur because the laminar burning velocity of NH_3-air pre-mixture is very low. Combustion efficiency had been unacceptably low in the 1960s.
- In order to improve combustion efficiency, unburnt NH_3 must be minimized.

- The emission of NOx is thought to increase because NH_3 is the source of fuel-NO.
- A small amount of NH_3 has been used for additives to study combustion chemistry of NOx formation.

Gas turbine power generation demonstrated





- The demonstration facility consists of an NH_3 fuel-supply system, NH_3 gas compressor, 50 kWe-class micro gas turbine, SCR NOx-reduction apparatus, and loading equipment.

Regenerator-heated gas turbine

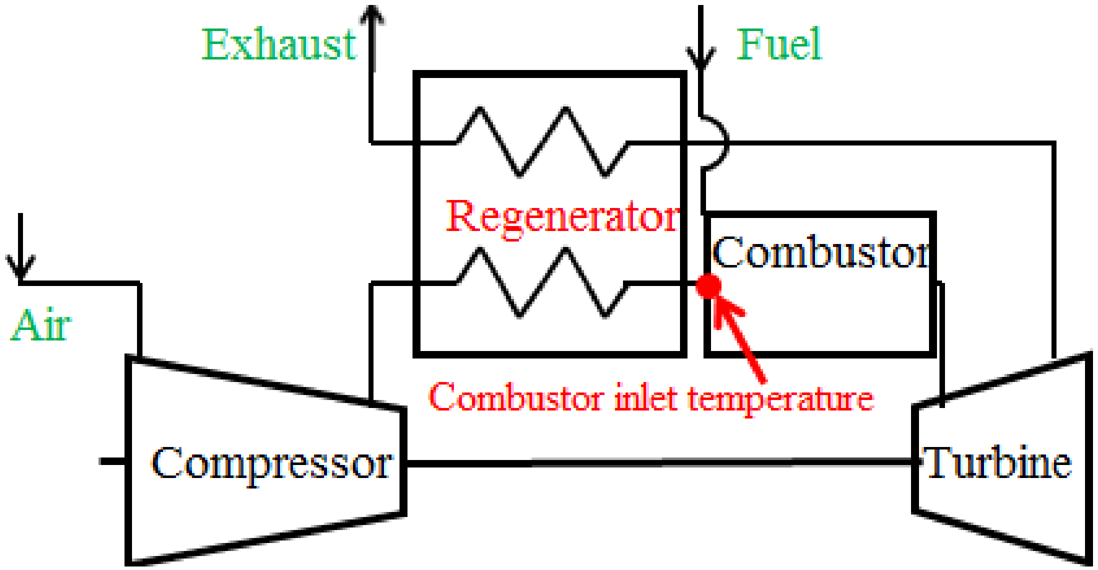
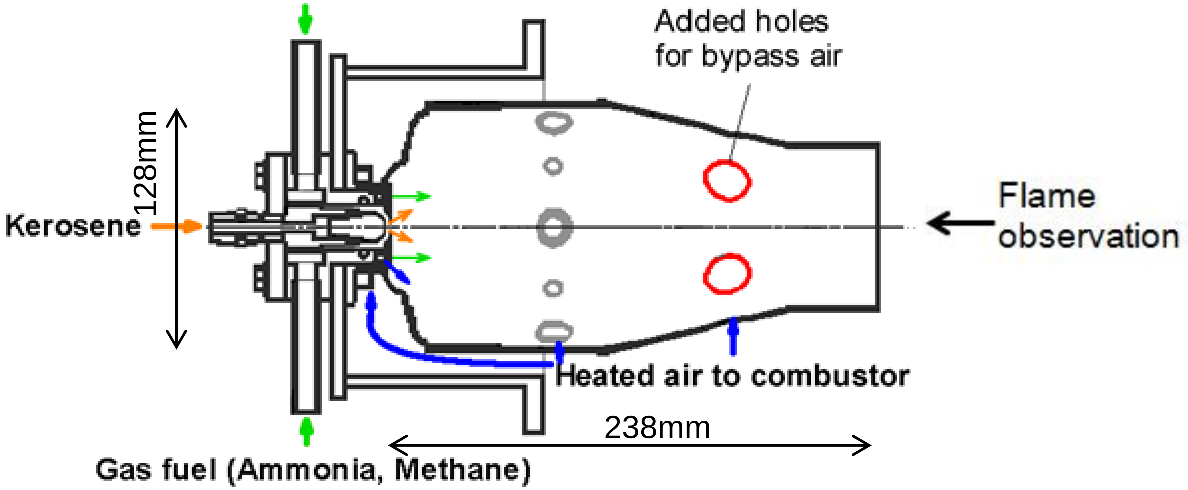


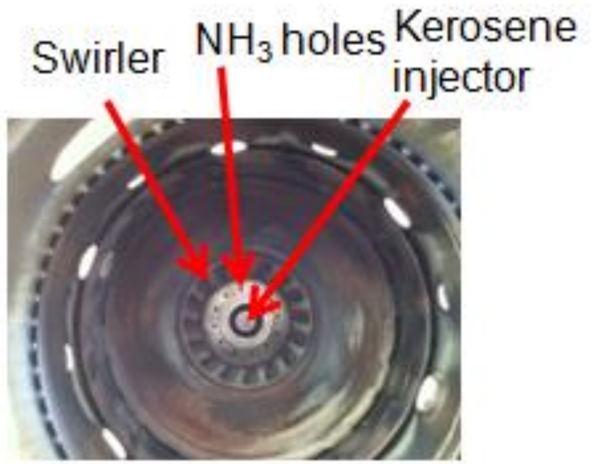
Fig.　Heat-regenerative-cycle gas turbine

- Micro gas turbines utilize a regenerative heat exchanger to improve the thermal efficiency of the gas turbine cycle.
- Regenerative heat exchangers transfer exhaust heat after the turbine into combustion air after the compressor.
- Thus, the combustor inlet temperature increases to around 500 ° C.
- This high combustor inlet temperature enhances the flame stability of NH_3-air combustion and reduces the unburnt NH_3.

Combustor



Prototype NH_3 fueled gas turbine combustor



- A diffusion-type combustor was employed with the expectation of realizing a higher flame stability.
- NH_3 gas was injected from 12 holes located around the kerosene injector, and an air swirler was positioned around the NH_3 gas-injection holes.

Emission after SCR

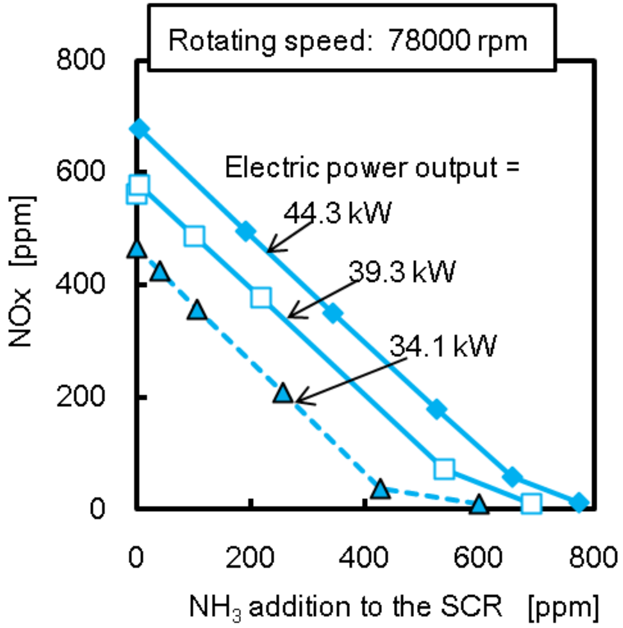


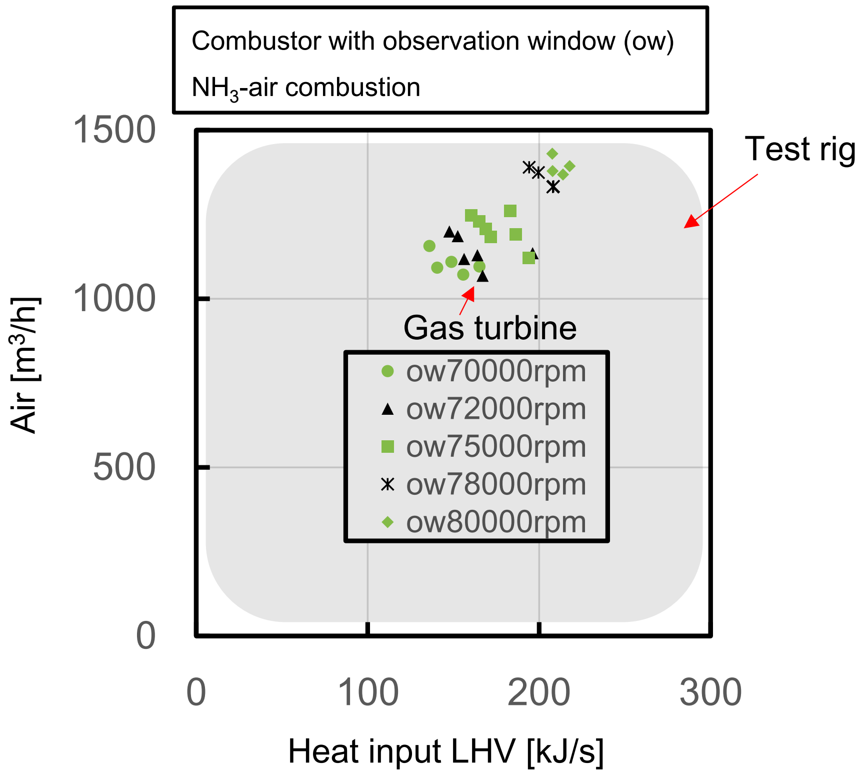
Fig. NOx emission after the SCR

- NOx reduction equipment using SCR was placed after the micro gas turbine.
- The NH_3 addition to the SCR for NOx reduction was carried out in the piping, after the micro gas turbine combustor.
- Although NOx emission after the micro gas turbine combustor is sufficiently high, the SCR NOx reduction equipment can reduce it below the regulation limit

Combustion emissions from gas turbine

- Although NOx emission after SCR is below the regulation limit, the NOx emission from a micro gas turbine combustor is so high that it requires a large-size SCR.
- If a low NOx combustion method is developed, the size of the facility could be reduced.
- In order to achieve low NOx combustion, a combustor test rig was built in the same place with a common NH_3 fuel supply facility.
- Meanwhile, in the gas turbine, the results arise from the restriction of the eigen balance of fuel, air, and heat, because the compressor and turbine are connected by a single shaft.
- It is difficult to characterize combustion emissions from the combustor test rig with the former parameters because there is no restriction of the quantity of fuel, air, and combustor inlet temperature.
- Thus, this paper reports combustion emissions of the NH_3 fuel gas turbine before SCR, re-characterized with the other parameters, such as fuel flow rate, overall equivalence ratio, combustor pressure, and combustion temperature.

Eigen balance of fuel and air



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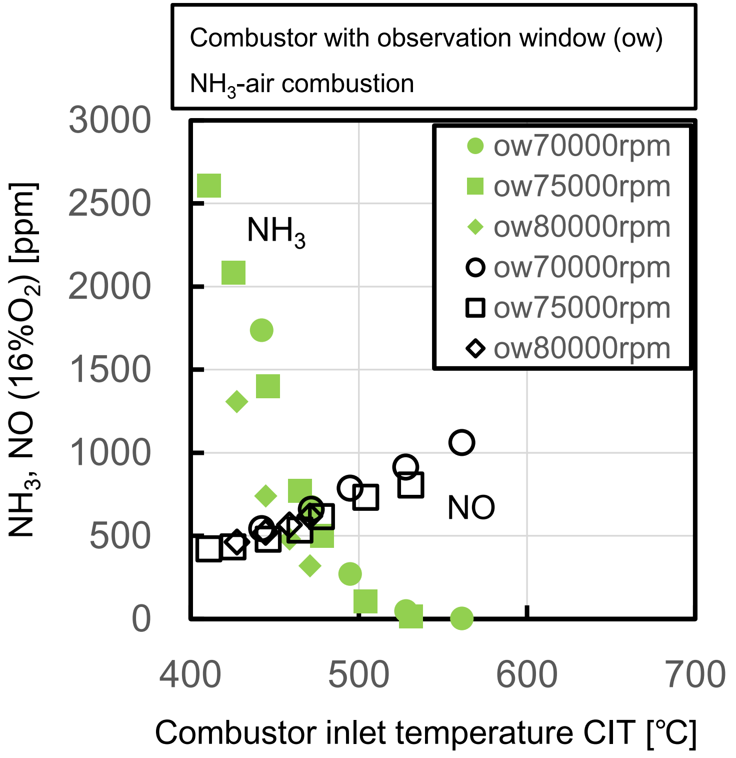
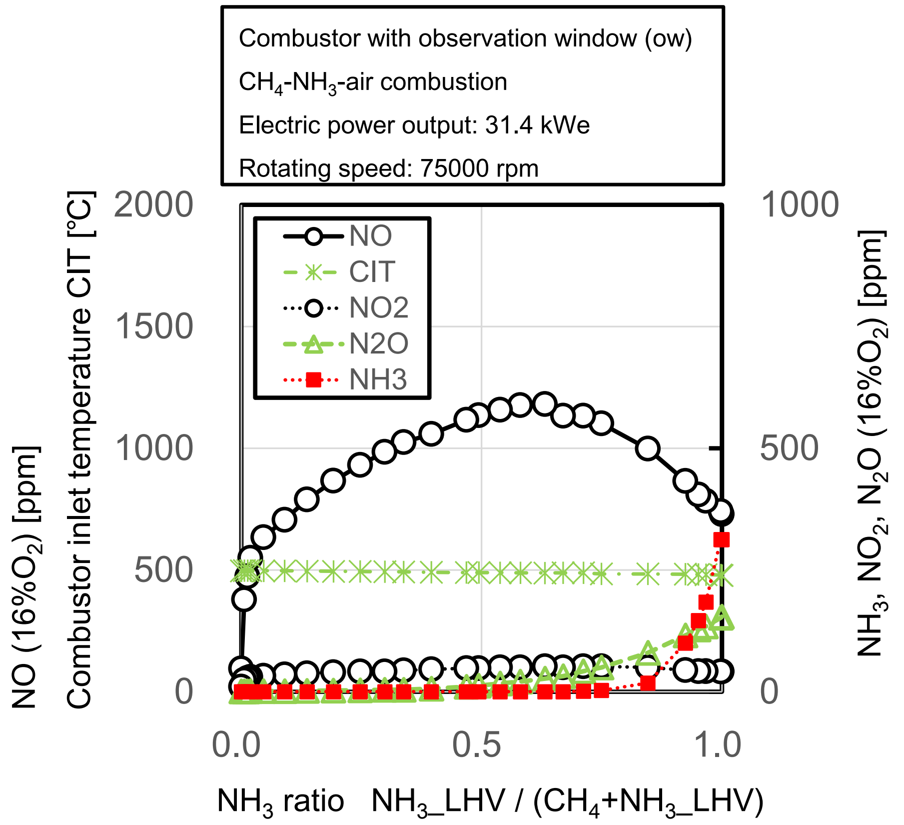
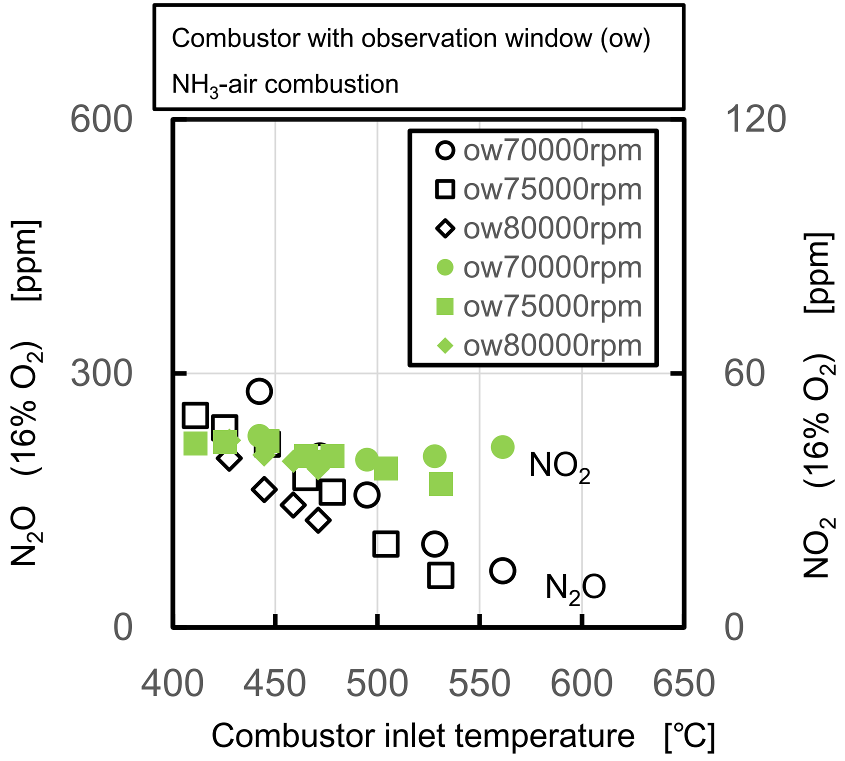
Former reports on emissions





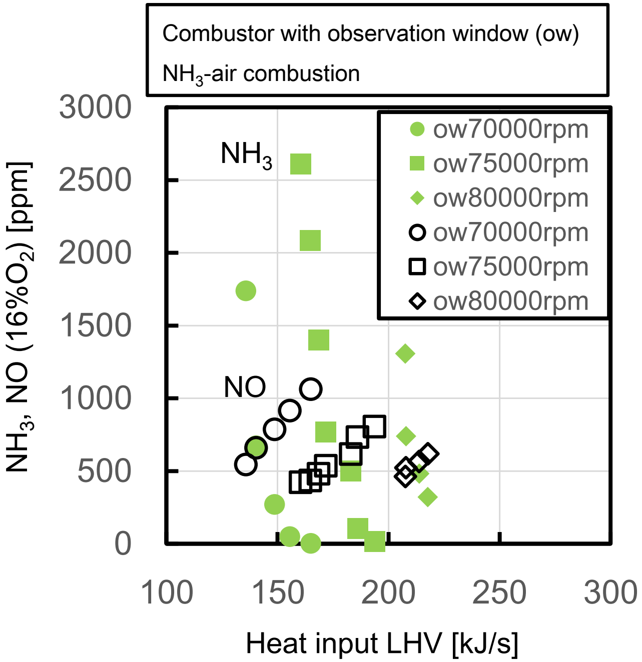
- In the case of NH_3-air combustion, the NH_3 and NO emissions strongly depend on the combustor inlet temperature.
- In the case of CH_4-NH_3-air combustion, the emissions depend on the NH_3 ratio.

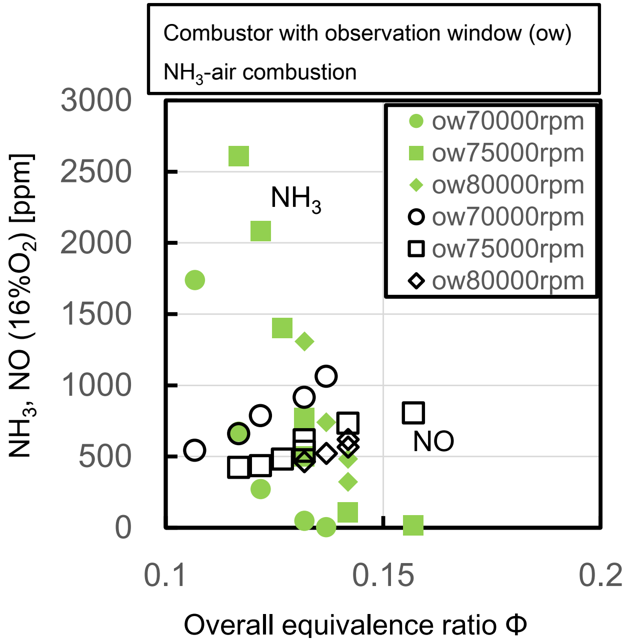
NO_2 and N_2O emissions



- The global warming potential (GWP) of N_2O is 298, and thus, N_2O emission needs to be minimized.
- The N_2O emission decreases with increase of combustor inlet temperature, i.e., electric power output, and stays below 46 ppm at a combustor inlet temperature of 560 ° C.

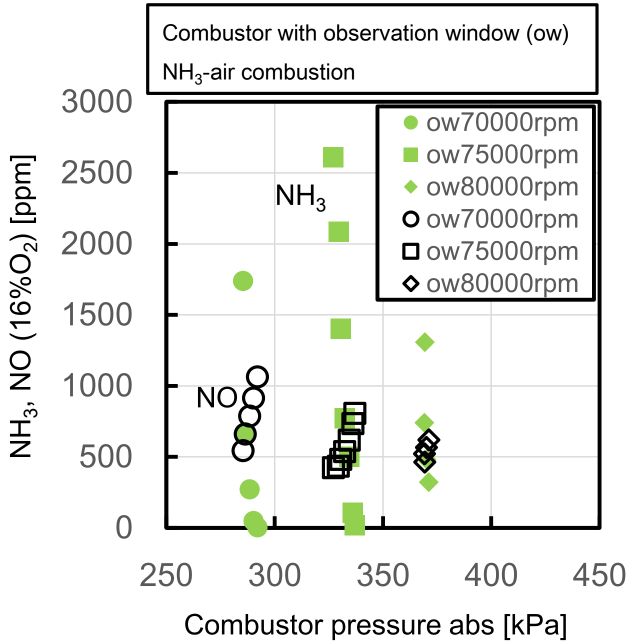
Combustion emissions re-characterized with the other parameters

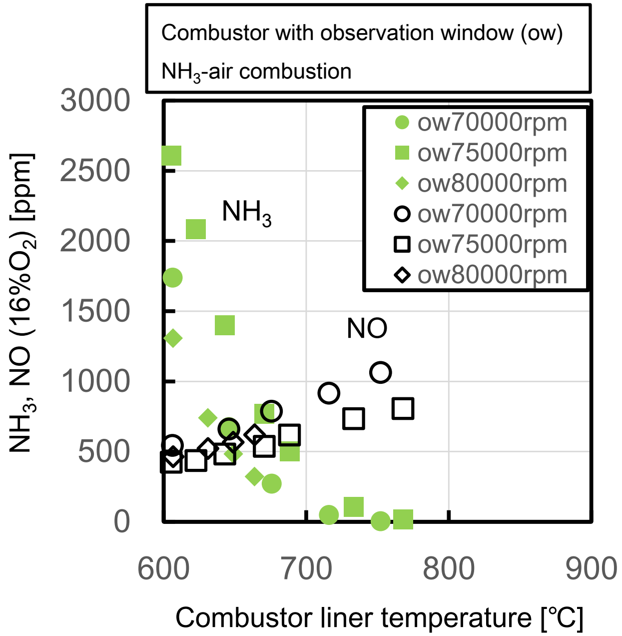




- The emissions of NO and NH_3 characterized by the fuel flow rate show one set of emission pattern repeated in three heat input ranges.
- The overall equivalence ratio for 70000, 75000, and 80000 rpm were in the range 0.107–0.137, 0.117–0.157, and 0.132–0.142, respectively, which have overlaps.
- It is shown that the equivalence ratio alone does not determine the combustion emissions.

Combustion emissions re-characterized with the other parameters





- The combustor pressures for 70000, 75000, and 80000 rpm were in the range 285–292, 327–337, and 369–371 kPa abs, respectively.
- It shows one set of emission patterns repeated in three pressure ranges.
- The temperature of the combustor liner is dependent upon the temperatures of the combustor inlet and combustion.
- Although the dependency is most apparent in the former reports on emissions, it arises from the eigen balance of fuel, air, and heat.
- It is expected that the accuracy of the results can be improved in the future combustor rig tests.

Acknowledgement

- This work was supported by the Council for Science, Technology and Innovation (CSTI), the Cross-ministerial Strategic Innovation Promotion Program (SIP), “Energy Carriers” (Funding agency: Japan Science and Technology Agency (JST)).
- The authors also thank “Toyota Turbine and Systems Inc.” for their assistance with the operation of the micro gas turbine system.

SIP

Thank you for your attention !!

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