13th Annual NH3 Fuel Conference
September 18 – 21, 2016 • Los Angeles, CA

Power Generation and Flame Visualization of Micro Gas Turbine Firing Ammonia or Ammonia-Methane Mixture

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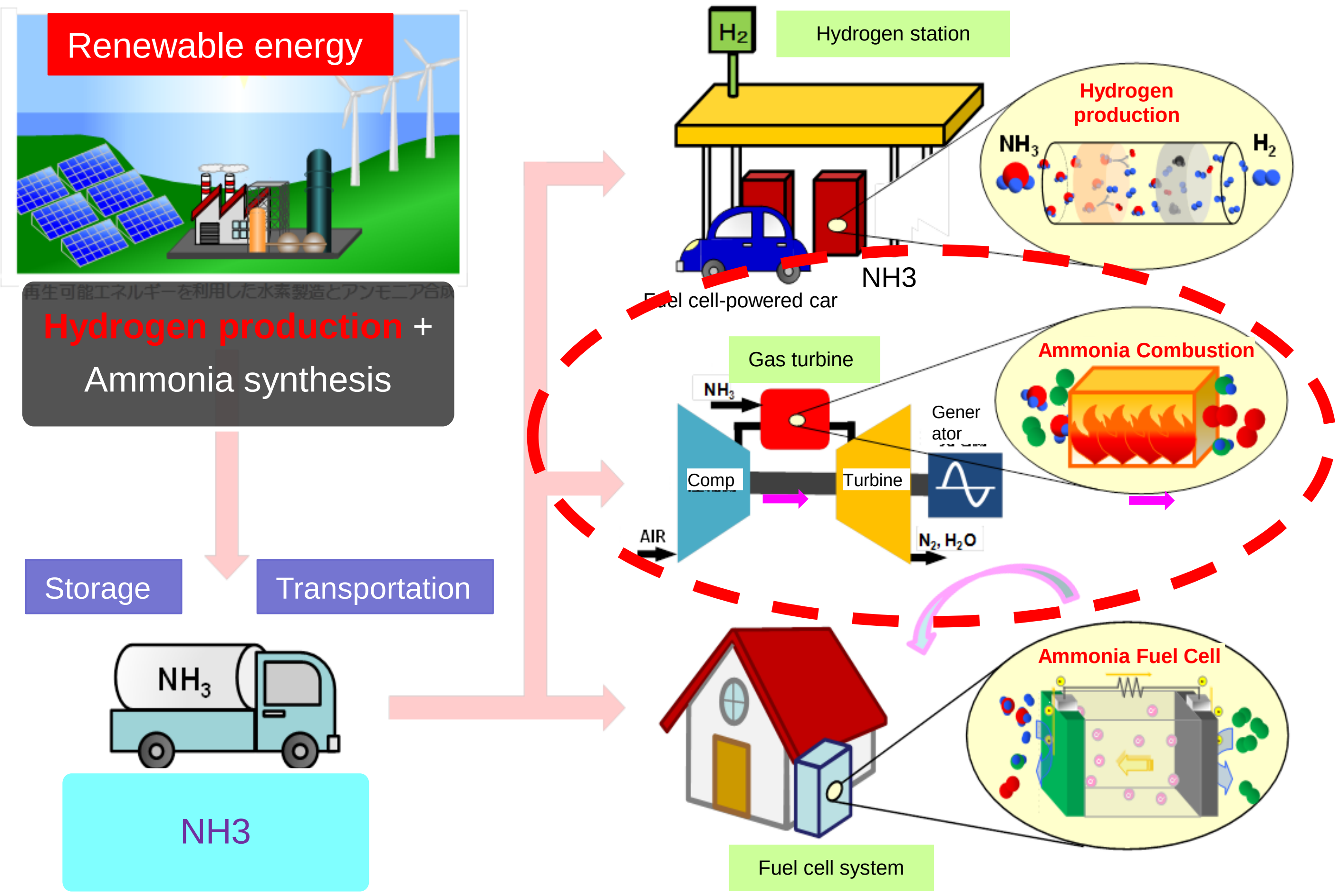
Image of NH3 Production and Use

- Japan starts the project of R&D focusing on energy carriers in 2013.
- Ammonia has become one of the attractive energy carriers.
- This project includes ammonia production and ammonia utilization.
- AIST has been responsible for the demonstration of gas turbine firing ammonia to show the potential of ammonia as a fuel.
- As the first step of the project, AIST tried to demonstrate a small gas turbine firing ammonia gas with kerosene to obtain the knowhow concerning to ammonia gas handling and combustion of ammonia.



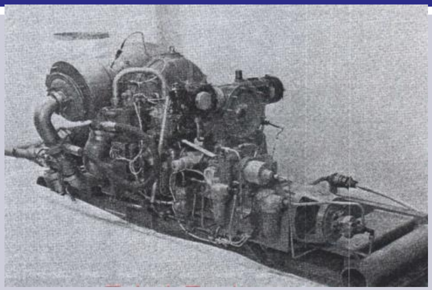
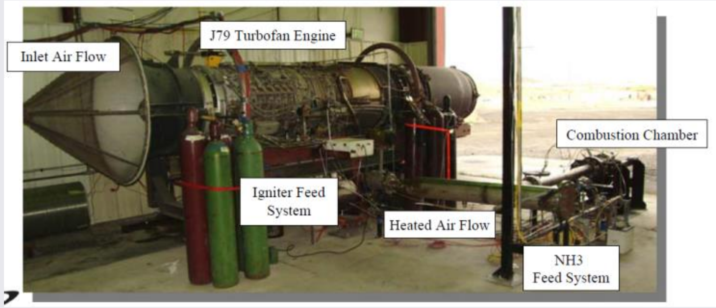
Characteristics of NH3

Nonignitable fuel

- Boiling point：−33.4ºC
- Vapor pressure: 1.177MPa (30ºC)
- Vapor density: 0.76 g/l (gas, 0ºC,0.1013MPa)
- Specific gravity: 0.59 (Air =1；25ºC)
- Flammability：inflammable in air
- Auto-ignition temperature: 651ºC
- Decomposition temperature: 840ºC-930ºC
- Explosion mixture limits : 15 – 28%
- Laminar Burning Velocity : 7cm/s at max.(NH3-Air Mixture)
  1/5 of that of CH4-Air Mixture
- High NOx Emission
- Lower radiation than hydrocarbon flame

Source：Takachiho Chemical Industrial Co. Ltd, MSDS Sheet
Ube Industries Ltd., MSDS sheet
Hayasaka, et.al, 12th NH3 Fuel Conference, 2015

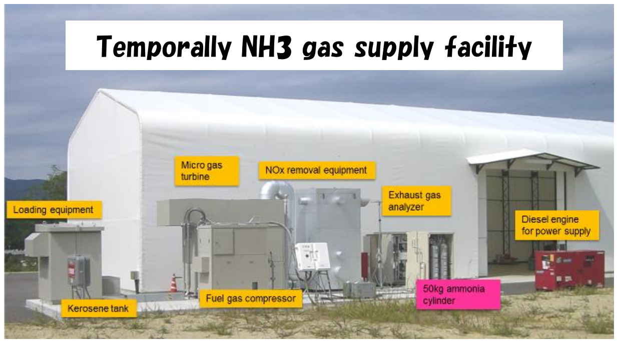
Gas turbine firing ammonia

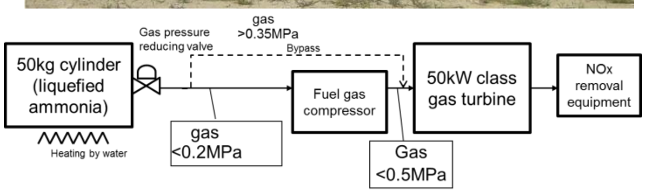
Project	year	
T-350 gas turbine (USA)	1960's	R&D of vapor combustor R&D of catalytic combustor Engine test 
Space Propulsion Group Inc. (Sunnyvale, CA)	2010's	Jet engine test 
Cardiff University	2010's	R&D of ammonia-methane combustor
IHI (SIP energy carrier)	2013-	R&D of methane-ammonia combustor

source：http://nh3fuelassociation.org/introduction/、Brian Evans, 10th NH3 Fuel Conference
Program of 12th NH3 Fuel Conference,
Agustin Valera-Medinaa, et. al., Applied Energy, 2016.02.073

R&D of Gas Turbine Firing Ammonia in AIST

Phase I :
NH3-Keosene Combustion
FY 2013-2014

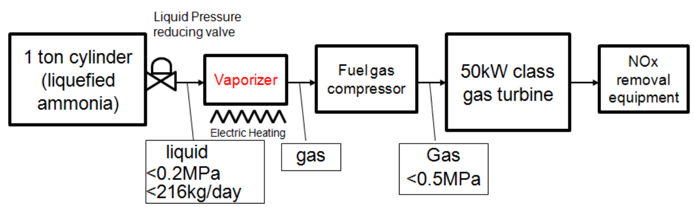




21kW power generation was achieved with about 30% decrease of kerosene by supplying ammonia gas.

Ammonia gas supply to the NOx removal equipment can decrease NOx emission very well.

Phase II :
NH3 Combustion
CH4-NH3 Combustion
FY 2015



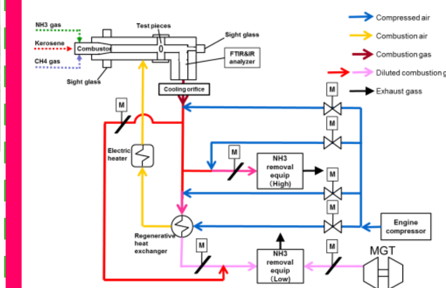
41.8kW power generation firing ammonia gas was achieved.
Goal : CO_2 free Power Station

41.8kW power generation co-firing of methane and ammonia gas was achieved.
Goal : NH3 cofiring at Power Station firing natural gas

This presentation

Phase III :
Combustor Test Rig
CFD
FY 2016 -

Start of combustion test by Combustor Test Rig



Development of low NOx combustor by cooperation with Tohoku university

This work was supported by Council for Science, Technology and Innovation (CSTI), Cross-ministerial Strategic Innovation Promotion Program (SIP), "energy carrier" (Funding agency: JST).

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2. Experimental Apparatus
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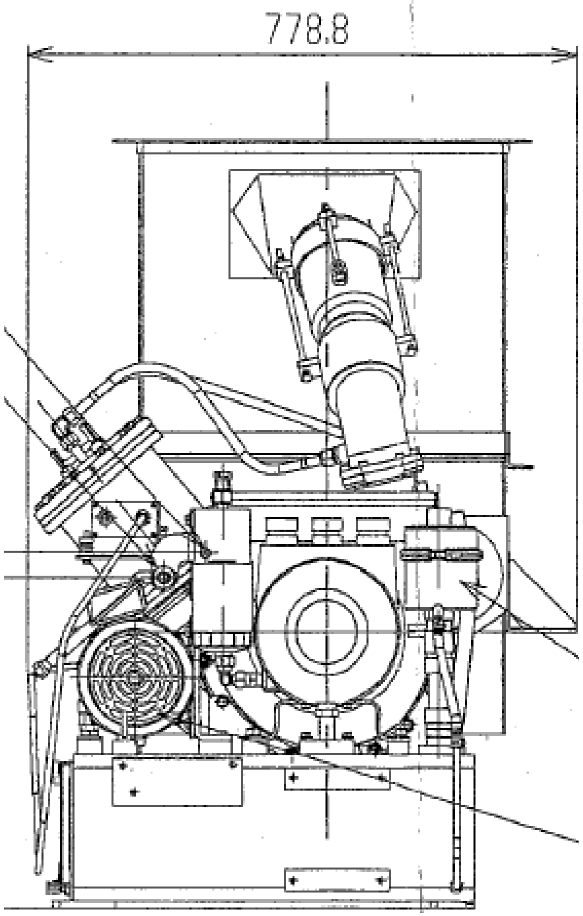
Base Micro Gas Turbine

- A 50kW class micro gas turbine was selected as the base engine of ammonia fueled gas turbine.
- This gas turbine was made by TOYOTA TURBINE AND SYSTEMS INC (TTS).

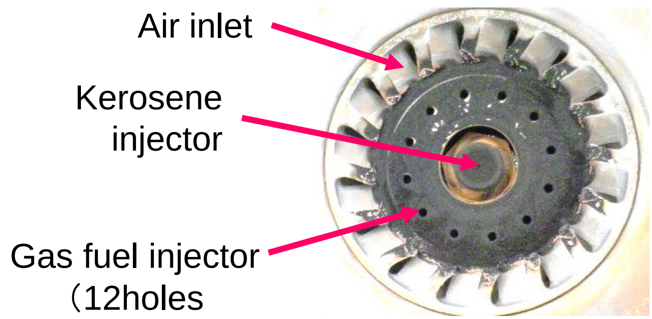


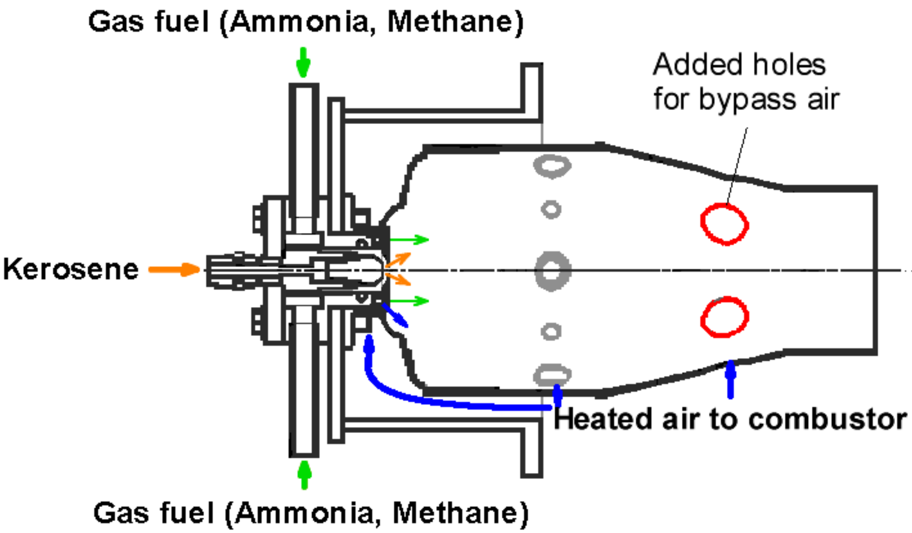
Specification of base micro gas turbine

Manufacturer	Toyota Turbine and System Inc. (TTS)
Cycle	Regenerative cycle
Shaft	Single shaft
Compressor	Centrifugal one-stage
Turbine	Radial one-stage
Rotating Speed	80,000rpm
Electric Power Output	50kW
Fuel	Kerosene
Combustor	Single can, Diffusion combustion

Prototype combustor

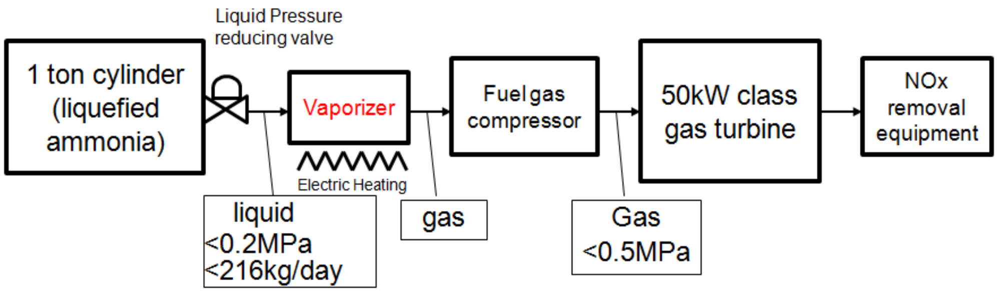
- The standard combustor is replaced by a prototype combustor.
- Diffusion combustion is employed in the prototype combustor due to its flame stability.
- Prototype combustor is designed for bi-fuel operation of kerosene and gas fuel.
- A conventional swirl injector for kerosene is set in the center of the combustor inlet.
- Gas fuel is supplied from 12 holes outside of the kerosene injector.
- Recuperator can supply hot combustion air.
- 6 holes for bypass air are added on the combustor liner to reduce air velocity of around fuel injector and to increase the temperature of combustion gas.

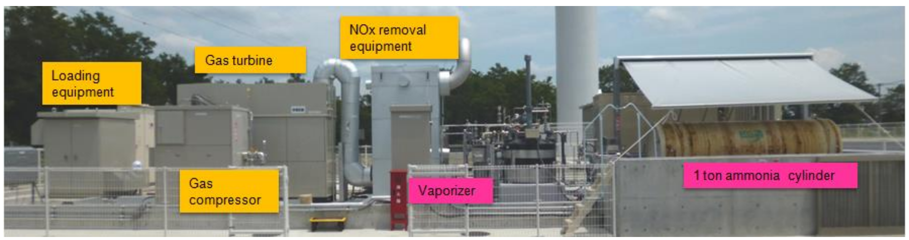


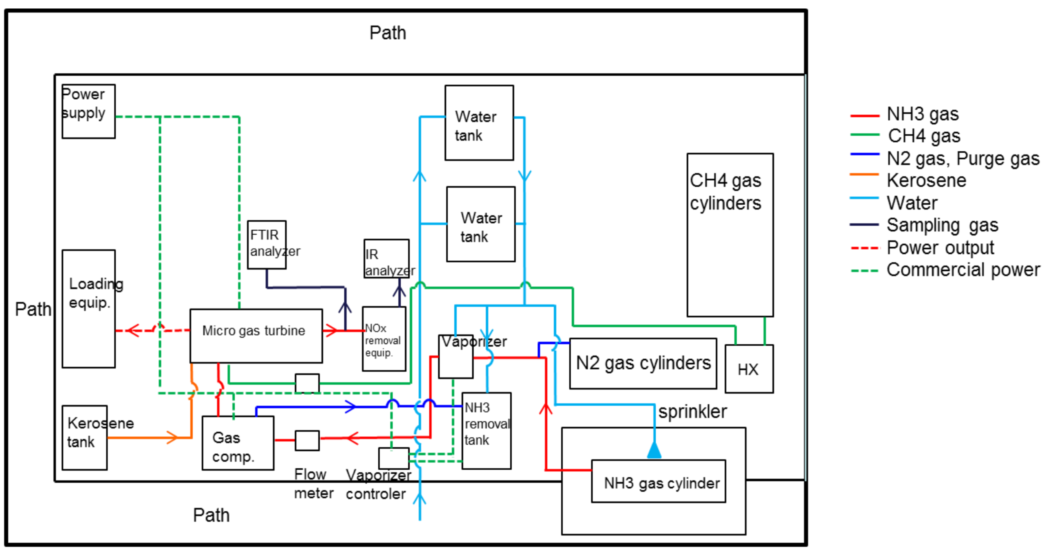


Ammonia combustor
(prototype bi-fuel combustor)

A test facilities for micro gas turbine power generation



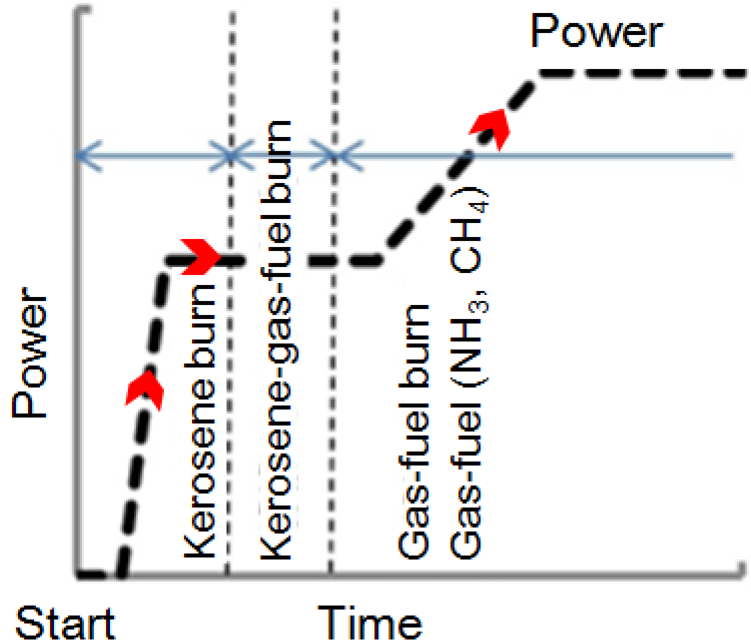




Test facilities for micro gas turbine power generation scale —— 1000

- 50kW class gas turbine needs about 200kW of fuel input (17kg//h) in the case that 25% of thermal efficiency.
- Latent heat of vaporization is about 6% of higher heating value. Over 12kW of heat is necessary for evaporation of ammonia supply for 50kW class gas turbine.
- Hence planed ammonia supply facility includes 1 ton gas cylinder and vaporizer as shown in figure.
- Liquid ammonia is supplied from 1 ton gas cylinder and evaporates by vaporizer using hot water.
- Fuel gas compressor compresses ammonia gas to over 0.5MPa and compressed ammonia gas supplied to a gas turbine.
- Exhaust gas of a gas turbine passes through NOx removal equipment and is emitted.
- A methane gas supply facility is also prepared for basic research of natural gas-ammonia co-firing. As the first step, methane gas is mixed to pressurized ammonia gas near the gas fuel inlet of the prototype combustor.

Starting-up procedure



- Because the ignition of pure NH_3 was difficult (ignition energy is high), ignition by kerosene firing was adopted during the start-up procedure.
- After starting up, gas-fuel (NH_3, CH_4) was supplied gradually replacing kerosene, then the ratio of gas-fuel to kerosene was increased until the kerosene supply was stopped.
- Finally, gas-fuel-air combustion was established, and the test conditions of the NH_3-air and NH_3-CH_4-air combustion gas turbine were set.

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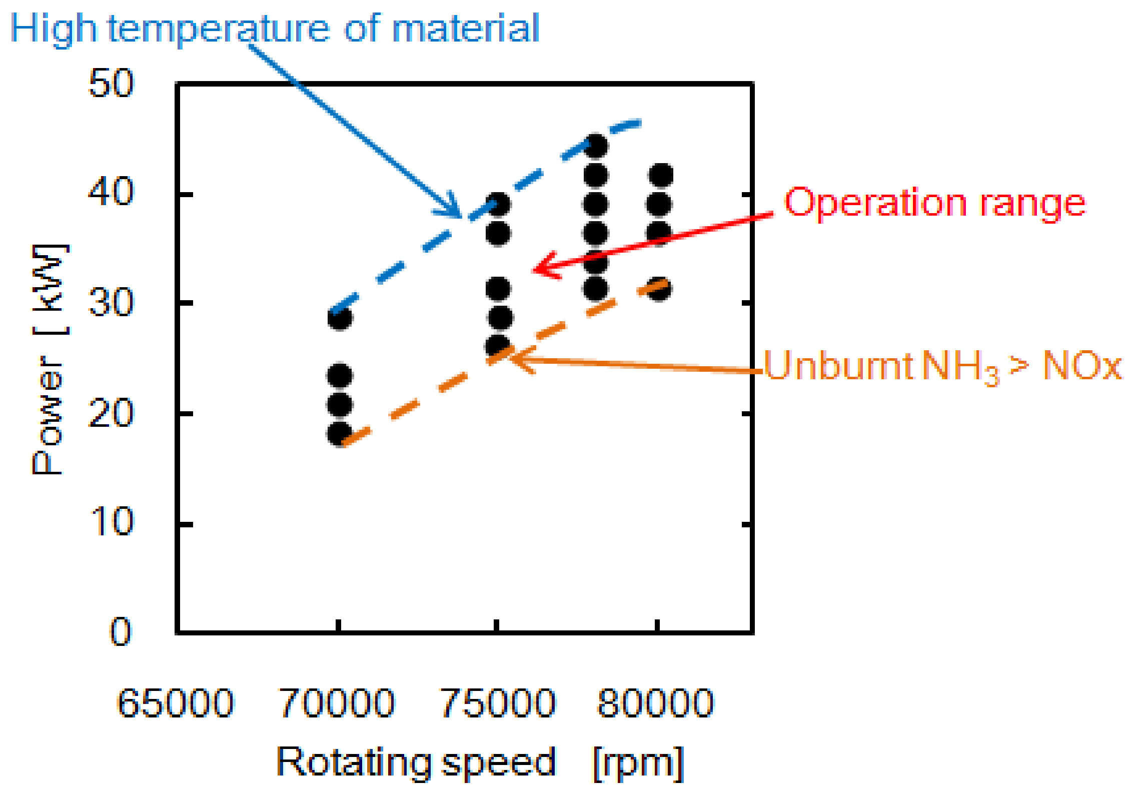
Operation range for NH_3-air combustion

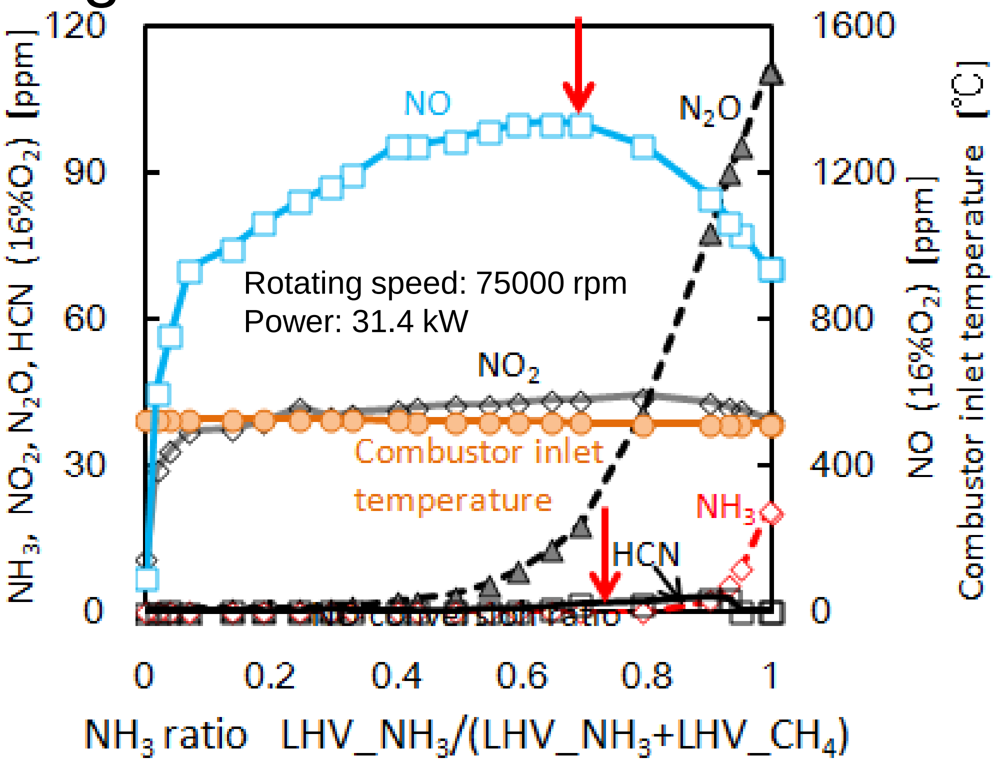


- The operation was successfully performed over the electric power range of 18.4 kW to 44.4 kW, and for rotating speeds ranging from 70000 rpm to 80000 rpm.
- There are two limits. The limit is not due to instability of NH_3-air combustion. The higher power limit is due to high temperature of material. The lower power limit is due to unburnt NH_3 > NOx.
- The SCR NOx reduction apparatus enables an increased concentration of unburnt NH_3 until it exceeds the concentration of NOx.

Effect of NH_3 ratio on emissions of CH_4-NH_3-air combustion

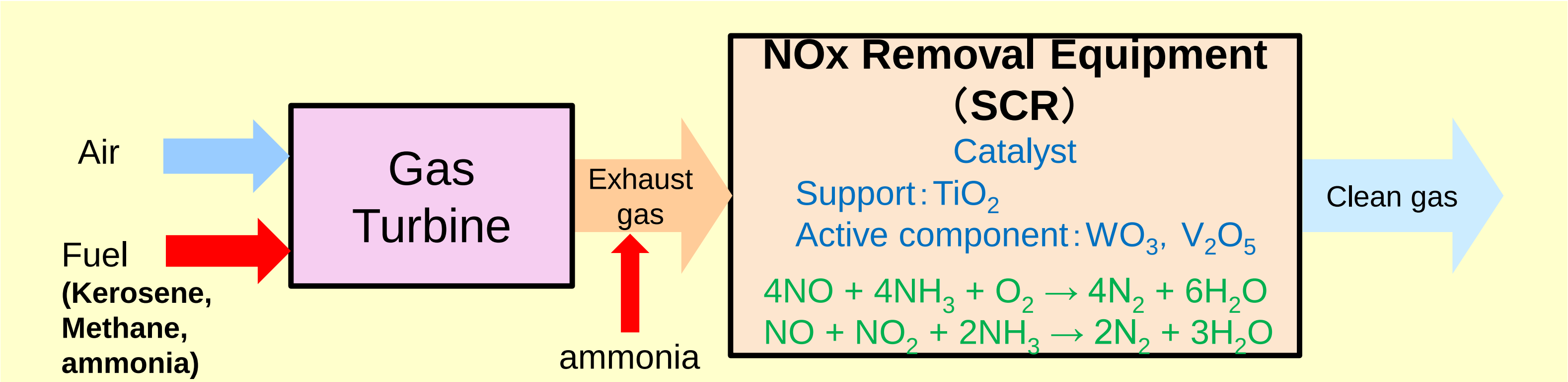
NH_3 ratio

$$= \frac{LHV_{NH_3}}{(LHV_{NH_3} + LHV_{CH_4})}$$

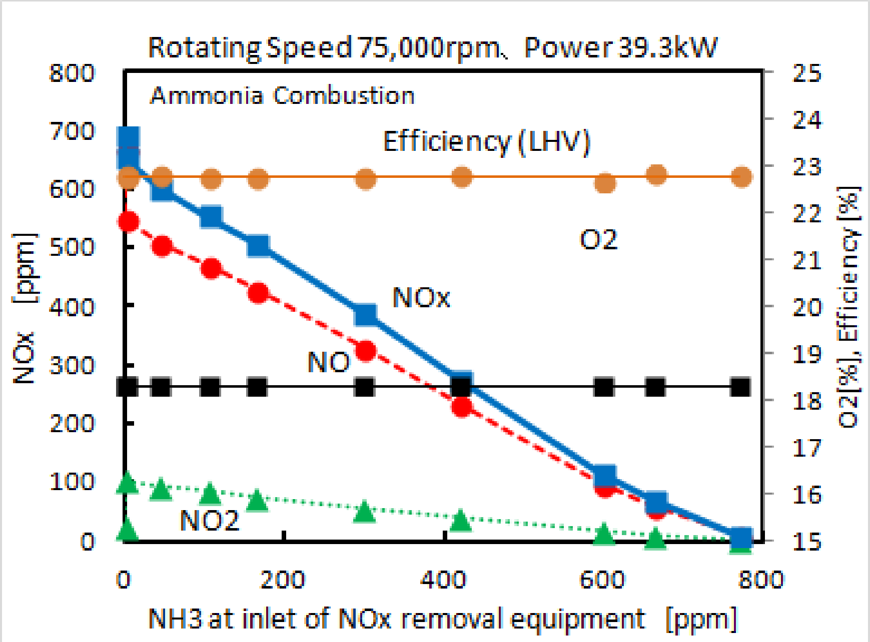


- NO emission increases dramatically with an increase of NH_3 ratio.
- NO emission have a peak concentration.
- However, from a certain point, unburnt NH_3 increases and NO decreases as NH_3 ratio increases further.
- This is due to NO reduction before SCR. It is expected that Selective Non-Catalytic Reduction (SNCR) occurred.

NOx Emission and NOx Removal



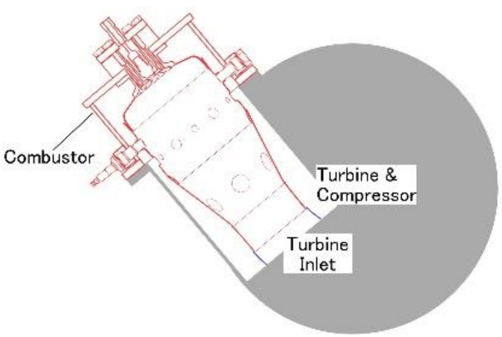
Outline of NOx removal process



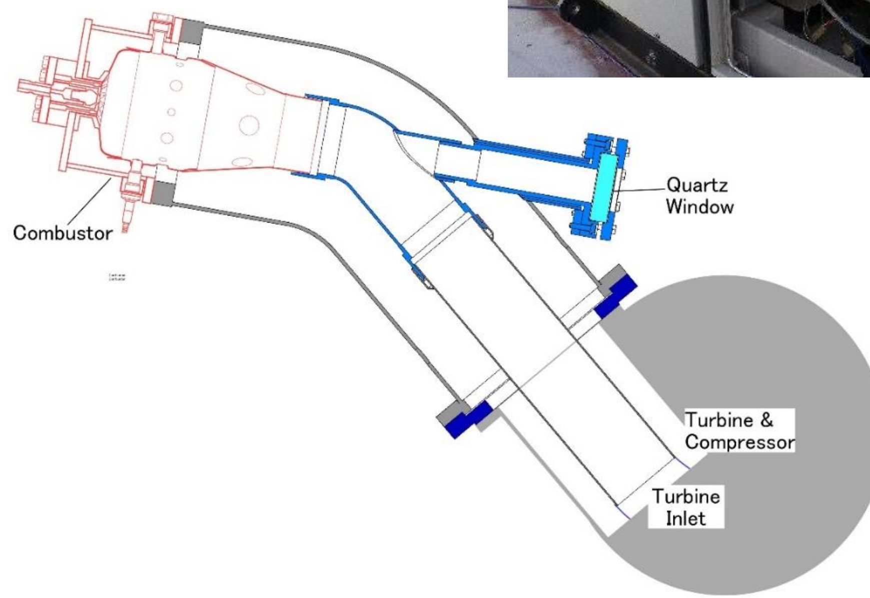
- NOx removal equipment employs SCR (Selective Catalytic Reduction) method.
- Ammonia gas was added to the exhaust gas for NOx removal.
- NOx, here summation of NO and NO_2, is about 700ppm and O_2 was 18.3%.
- Ammonia gas added to the exhaust gas decrease NOx emission.
- When added ammonia gas to the exhaust gas was 700ppm, its amount was only about 2% of total ammonia gas.

Flame observation

- The adaptor for the flame observation from the combustor exit was prepared.
- The adaptor is the bent coaxial tubes with the quartz window.



Normal setting



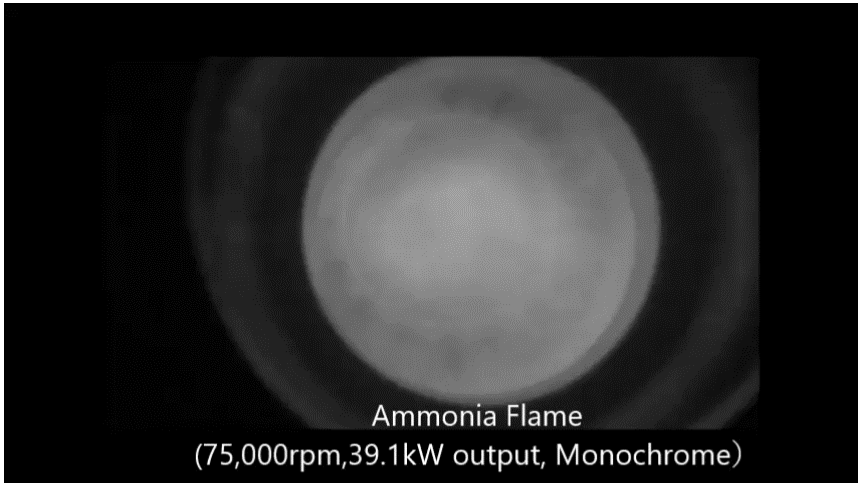
Flame observation

Flame observation

Ignition and Kerosene Flame
at Starting-up of Gas Turbine

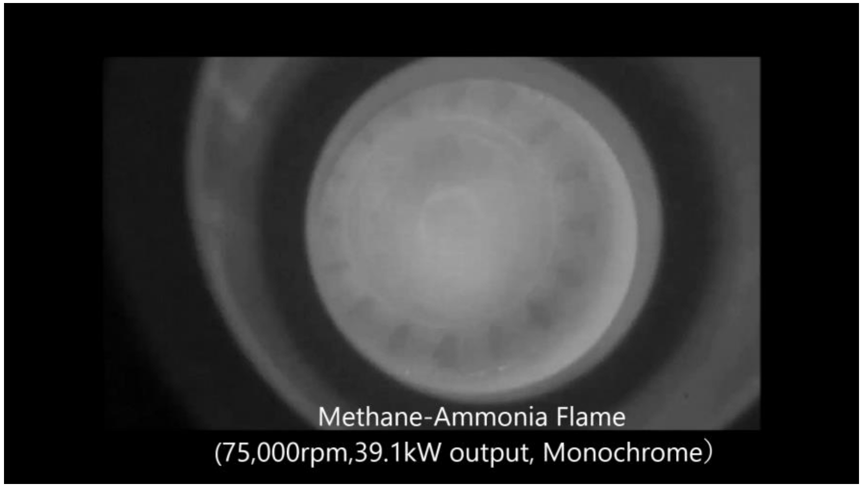
240fps image ,1/8 slow

Ammonia Flame



240fps image ,1/8 slow

Methane-Ammonia Flame (LHV Ratio 1:1)



240fps image ,1/8 slow

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Future task

Near future

- Flame observation under the operation

Future task and under planning

- Flame observation and measurement with a combustor test rig
- Modification of combustor (fuel injector, combustor linear, etc.)
- Development of low NOx combustor
- Starting up of a gas turbine firing methane or natural gas

Contents

Summary

50kW class micro gas turbine firing kerosene was remodeled for power generation firing ammonia.

A standard combustor is replaced with a prototype combustor which enables a bi-fuel supply of kerosene and gas fuel. Adapter for flame observation was prepared.

[Prototype combustor]

- The operation firing ammonia was successfully performed over the electric power range of 18.4 kW to 44.4 kW, and for rotating speeds ranging from 70000 rpm to 80000 rpm.
- There are two limits. The limit is not due to instability of NH_3-air combustion. The higher power limit is due to high temperature of material. The lower power limit is due to unburnt NH_3 > NOx.

[With adapter flame observation]

- Flame observation was succeeded while the prototype gas turbine generated electric power.

Thank you for your attention !!

Acknowledgement

- This work was supported by Council for Science, Technology and Innovation (CSTI), Cross-ministerial Strategic Innovation Promotion Program (SIP), "energy carrier" (Funding agency: JST).
- The authors also thank to Mr. Imura, Mr. Okada, Ms. Namatame, and "Toyota Turbine and Systems Inc." for the advice on the combustion technology and the operation of micro gas turbine.