AIST

2019 AIChE® ANNUAL MEETING
19AIChE Annual Meeting, Orlando, FL
Transforming the Future through Chemical Engineering
November 10-15, 2019
Hyatt Regency, Orlando

Pure Ammonia Combustion Micro Gas Turbine System

Osamu Kurata[1*], Norihiko Iki[1], Takahiro Inoue[1], Tadahiro Fujitani[1], Yong Fan[1], Takayuki Matsunuma[1], Taku Tsujimura[1], Hirohide Furutani[1], Masato Kawano[2], Keisuke Arai[2], Ekenechukwu C. Okafor[1], Akihiro Hayakawa[3], and Hideaki Kobayashi[3]

[1] National Institute of Advanced Industrial Science and Technology (AIST), Japan

[2] Toyota Energy Solutions Inc., Japan

[3] Tohoku University, Japan

SIP

TOYOTA ENERGY SOLUTIONS

TOHOKU UNIVERSITY

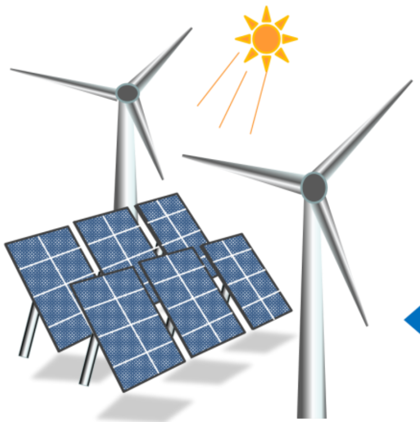
Institute of Fluid Science Tohoku University IFS

Outline

- Why ammonia...
- Challenges of ammonia combustion
- The pure ammonia micro gas turbine
  - the achievements and challenges
- Fundamental studies
- Development of a low-NOx combustor

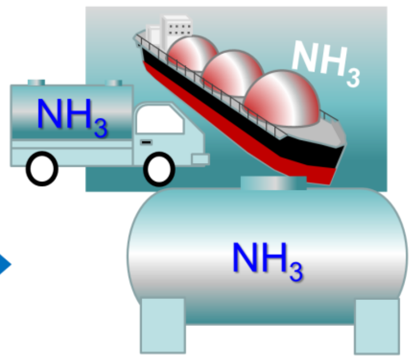
1. Why ammonia...

Has a high H_2 density (17.6 %wt)



Can be produced from renewable energy sources.
Has long history of production through Haber-Bosch process.

Ammonia is a promising carbon-free fuel and a hydrogen carrier!



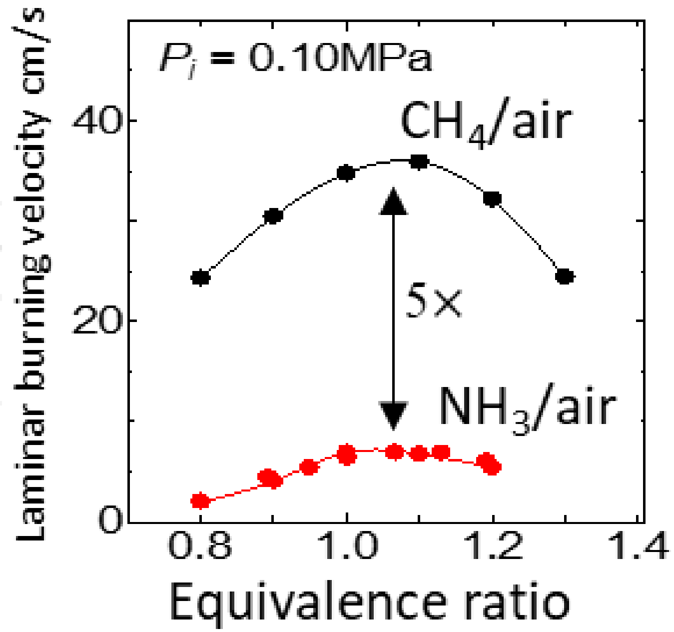
Is easier to store and transport than hydrogen - liquid at 8.5 bar at 25 °C.

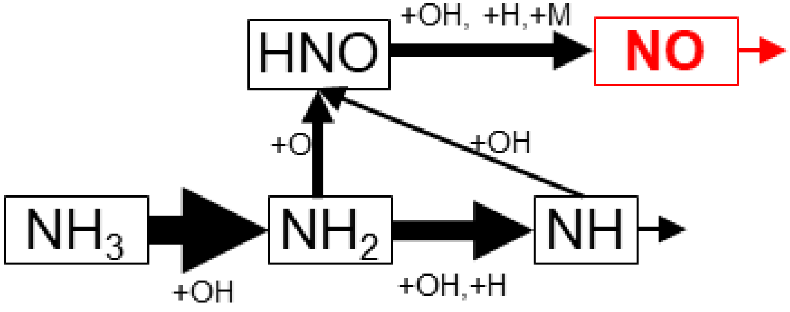
Zero CO_2
Zero soot
Zero SOx

Ammonia-air flame in a swirl combustor

Wide use of ammonia as a gas turbine fuel would ensure a huge reduction in global CO_2 emissions.

CHALLENGES OF AMMONIA COMBUSTION





Low burning velocity

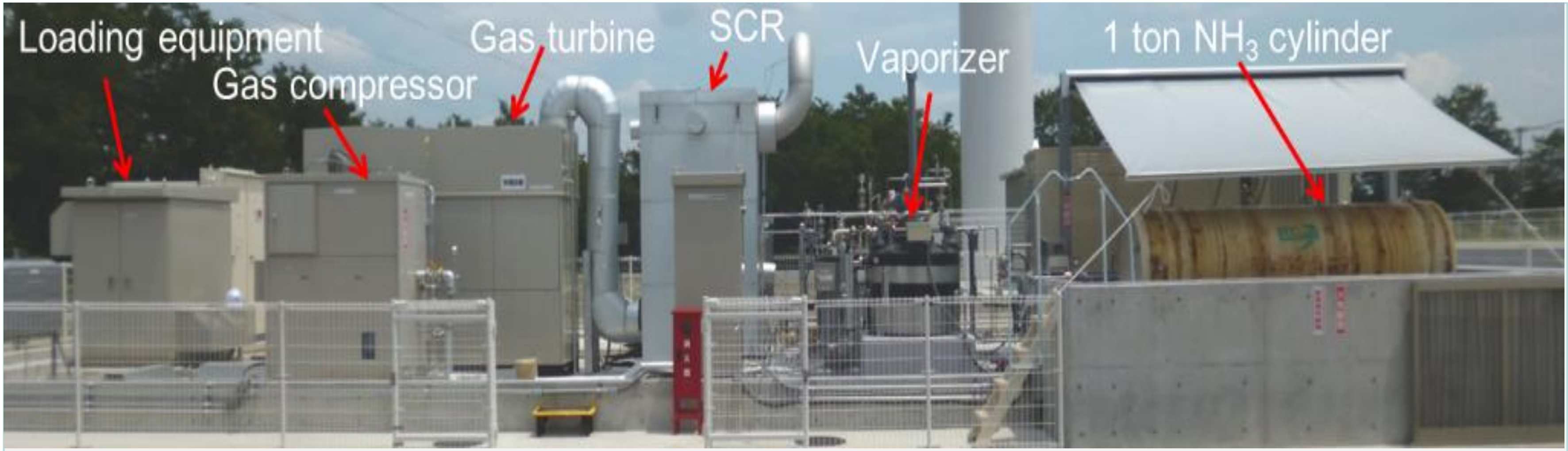
- Inhibits flame stabilization
- May lead to low combustion efficiencies in turbine combustors

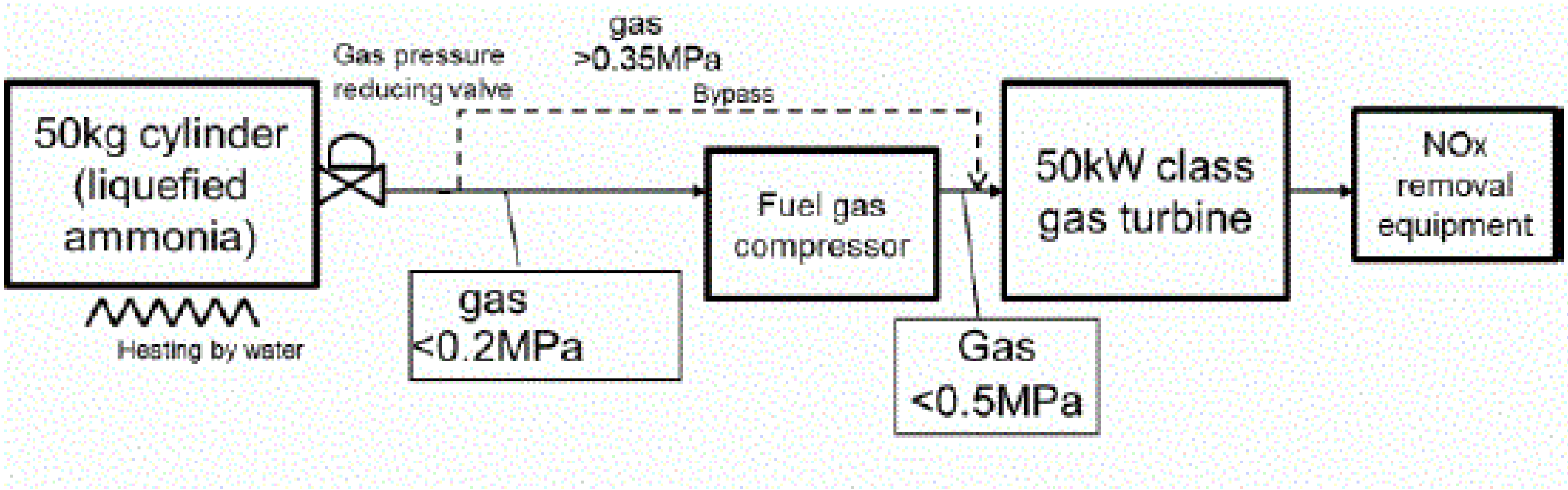
High NO emissions at fuel-lean conditions

- Fuel-lean ammonia flames produce high NOx emissions.

These challenges discouraged the application of ammonia as a fuel until recently.

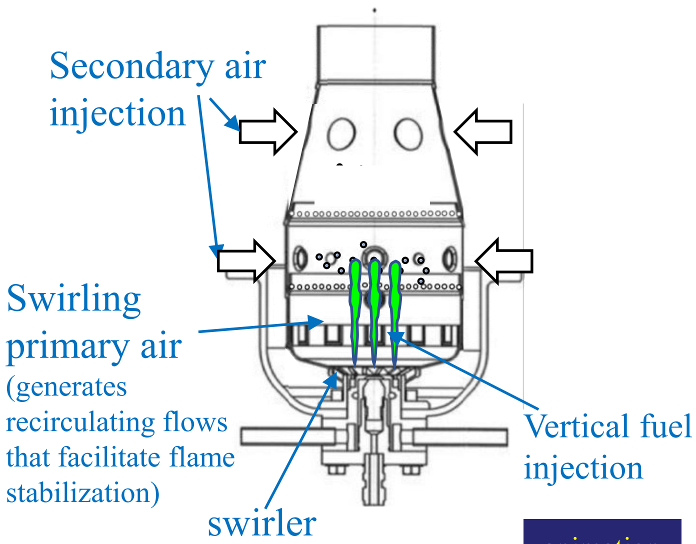
Generation of 41.4 kW from pure ammonia in a micro gas turbine





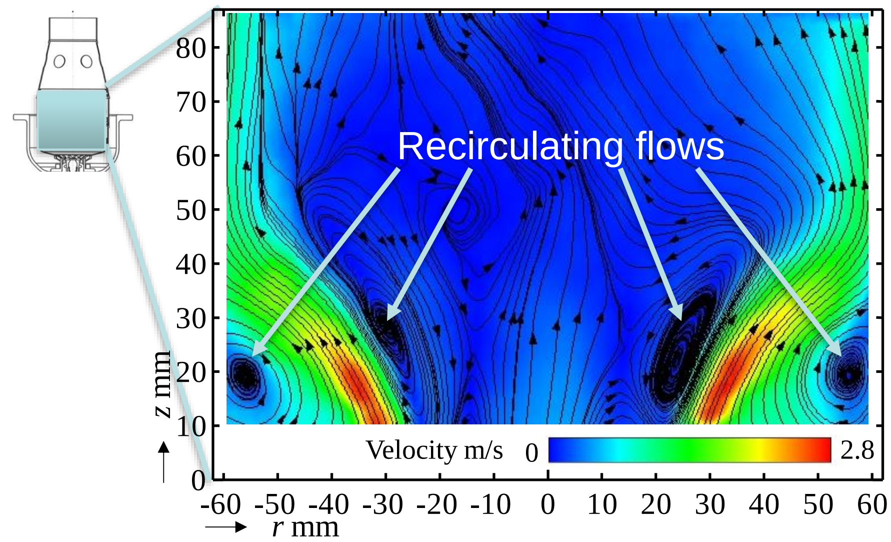
AIST CHARACTERISTICS OF THE AMMONIA COMBUSTOR

THE ORIGINAL COMBUSTOR



animation

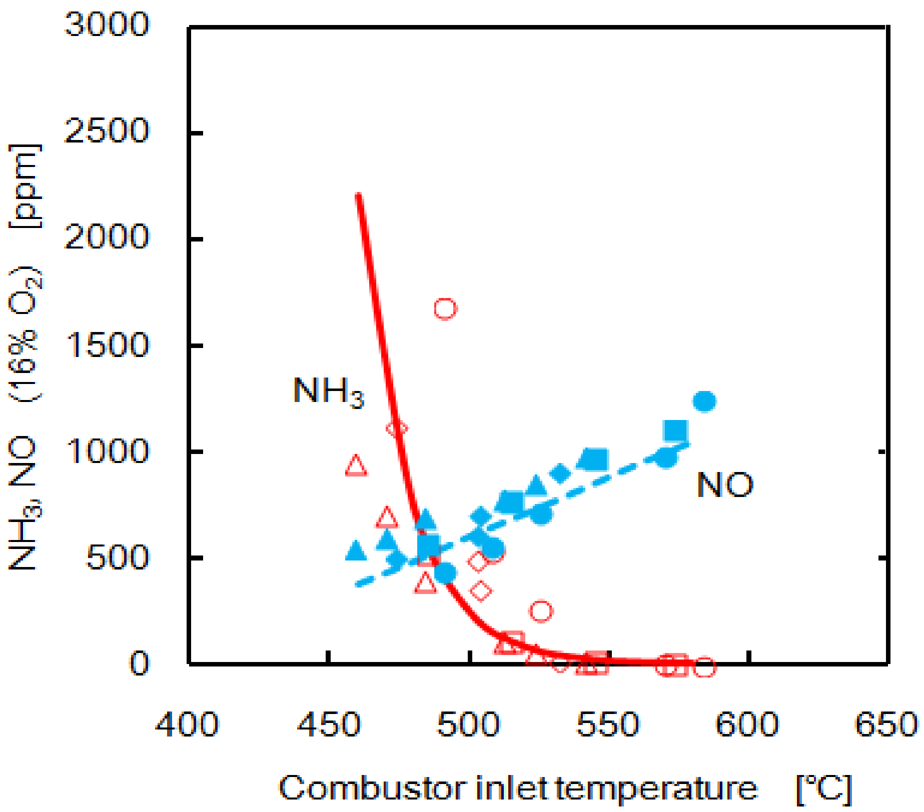
ACTUAL FLOW FIELD IN THE COMBUSTOR



Swirling flows generate recirculating flows that recirculate heat and active radicals in the combustor, enhancing the stability of the flame.

Pure ammonia swirling flame

EMISSIONS FROM THE ORIGINAL COMBUSTOR

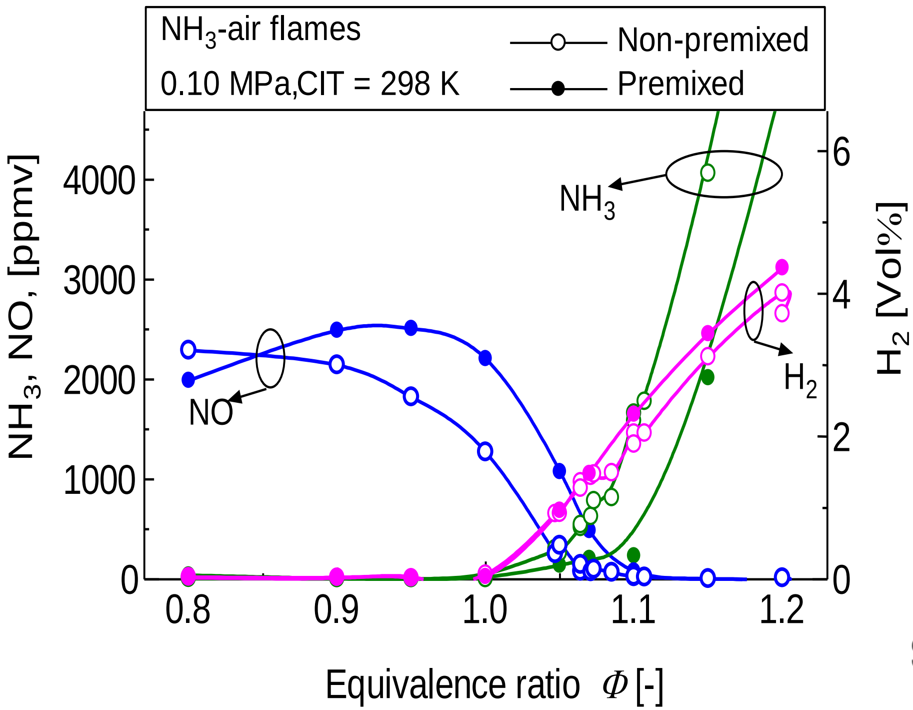


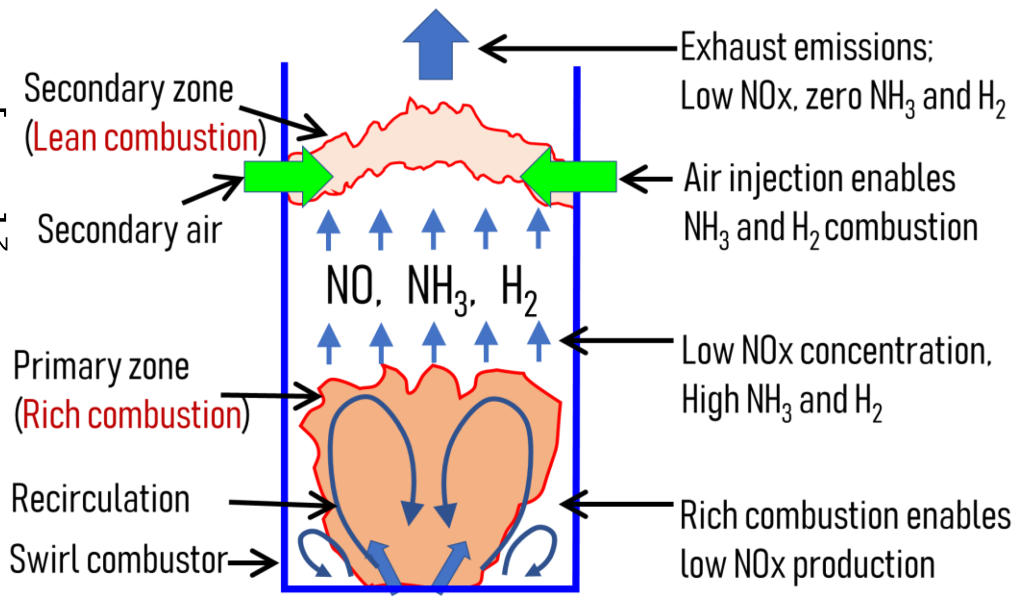
- NO emission was high
- Combustion efficiency was low for CIT less than 500ºC

NOx EMISSION TARGET

© Kurata et al., Proc. Combust. Inst. 36 (2017) 3351

Emissions control method in ammonia combustion





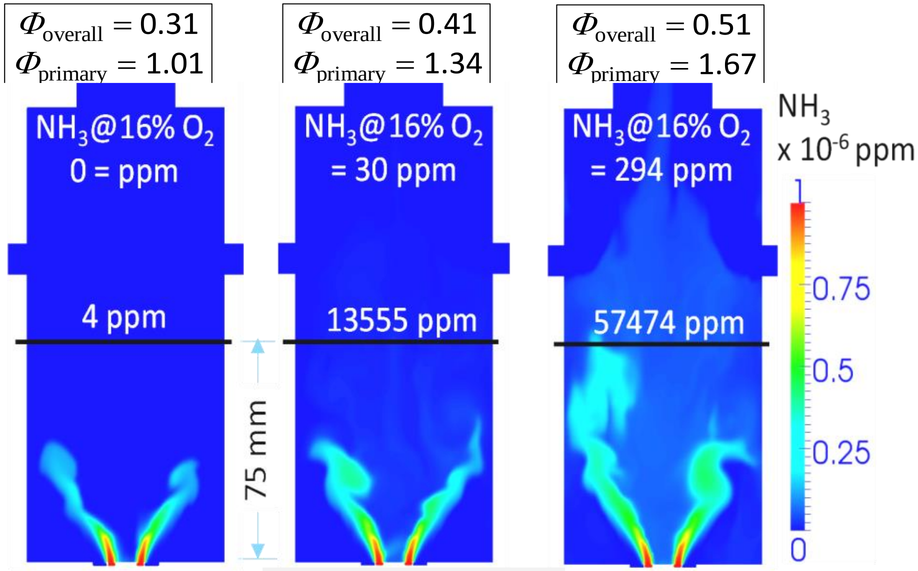
Emissions characteristics of ammonia

Concept of two-stage combustion

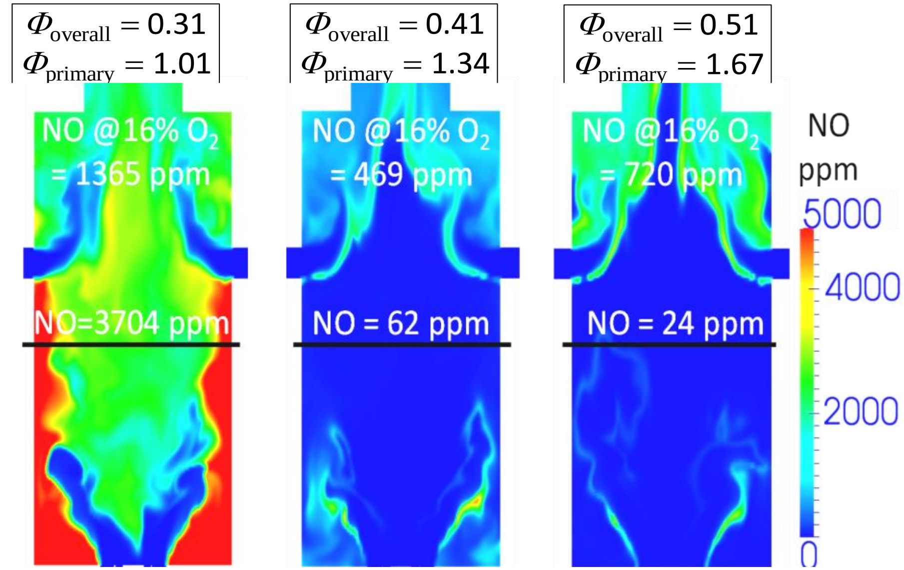
Two-stage rich-lean combustion leverages the <u>low NOx production in fuel-rich ammonia flames</u>

© Okafor et al., Proc. Combust. Inst. 37 (2019)

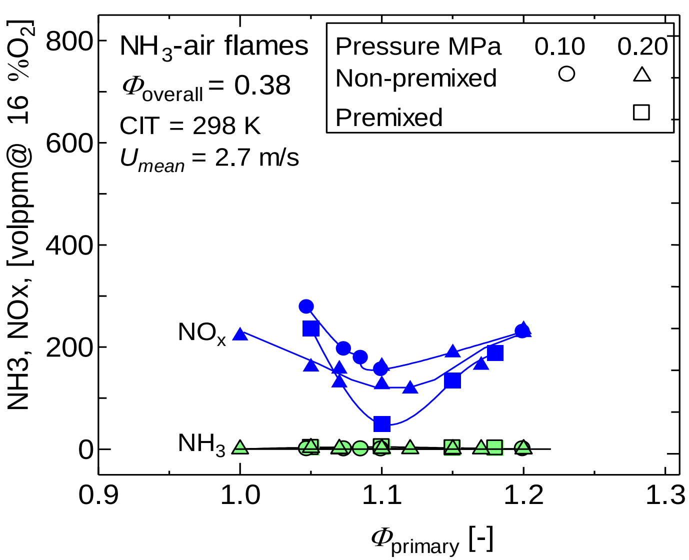
EMISSIONS FROM TWO-STAGE COMBUSTORS



NH$_3$ profile



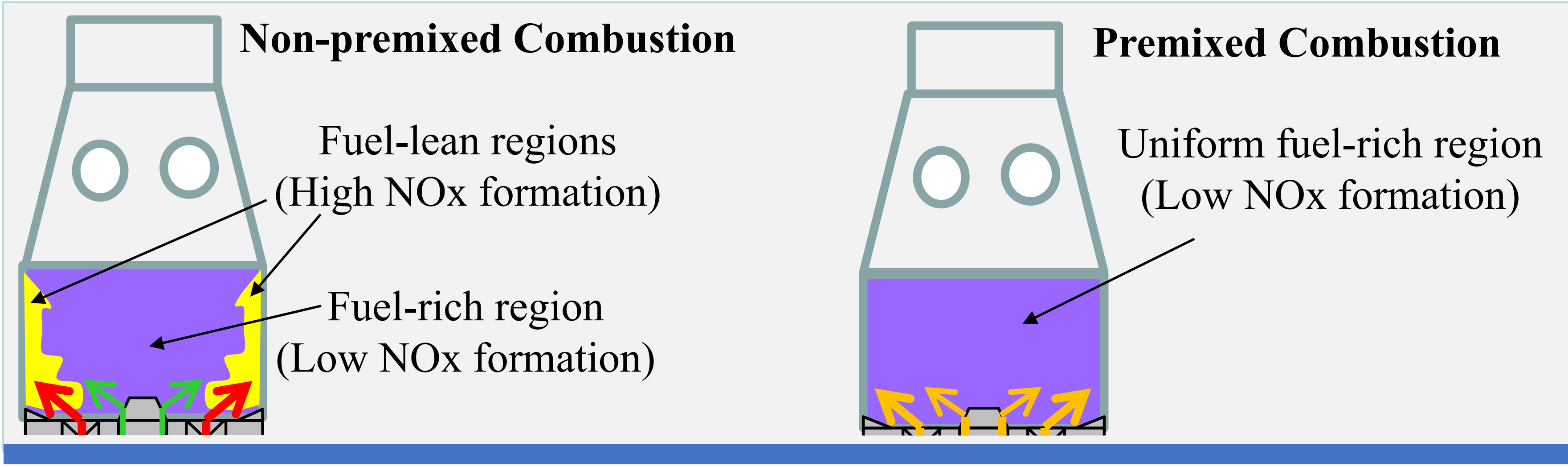
NO profile

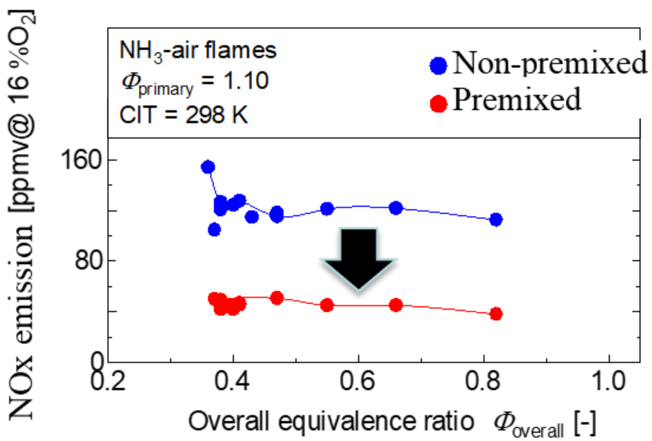


A control of the equivalence ratio of the primary zone is necessary for NOx control in two-stage rich-lean combustors. Optimum value ≅ 1.10

© Okafor et al., Proc. Combust. Inst. 37 (2019)

INFLUENCE OF MIXTURE UNIFORMITY





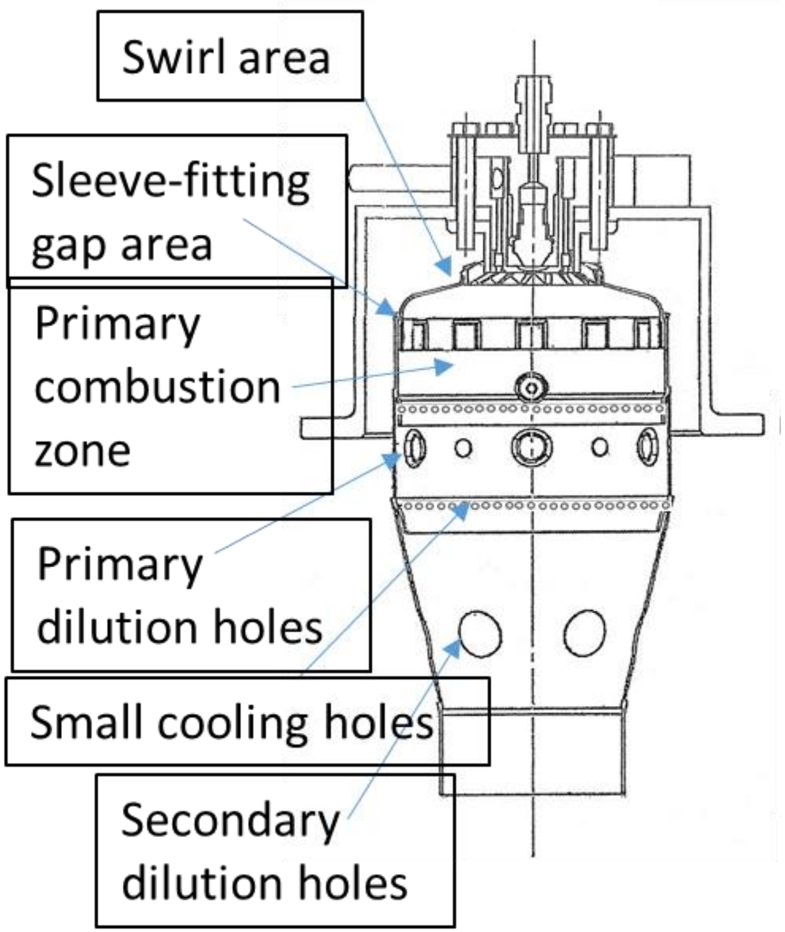
- Non-premixed combustion leads to non-uniform mixture formation.
- Regions of fuel-lean combustion in non-premixed flames produce high amounts of NOx.
- Lower NOx emissions is recorded with premixed combustion.

© Okafor et al., Proc. Combust. Inst. 37 (2019)

DESIGN OF A LOW-NOx COMBUSTOR

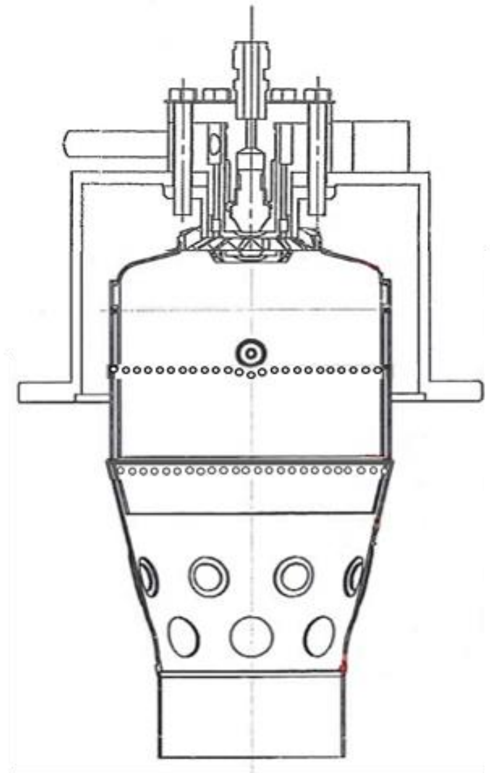
The Laboratory studies enabled the design of a low NOx combustor

Original combustor



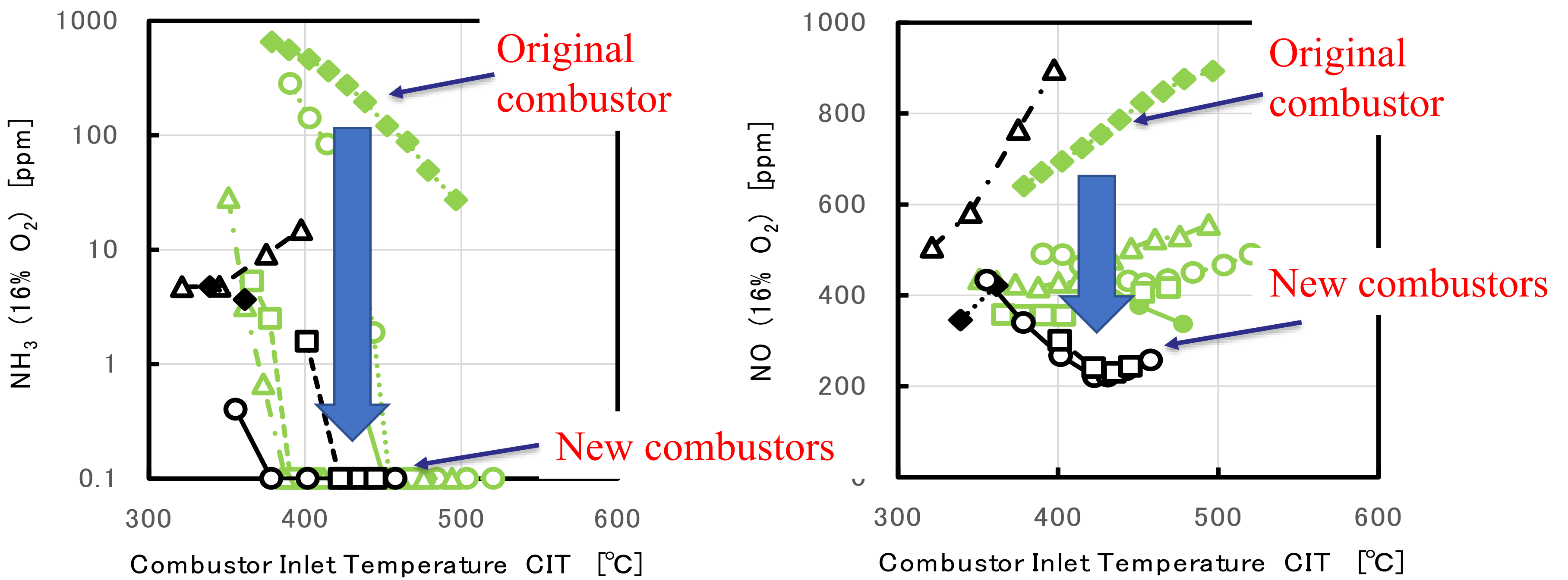
Low NOx combustor

Two-stage rich-lean combustor



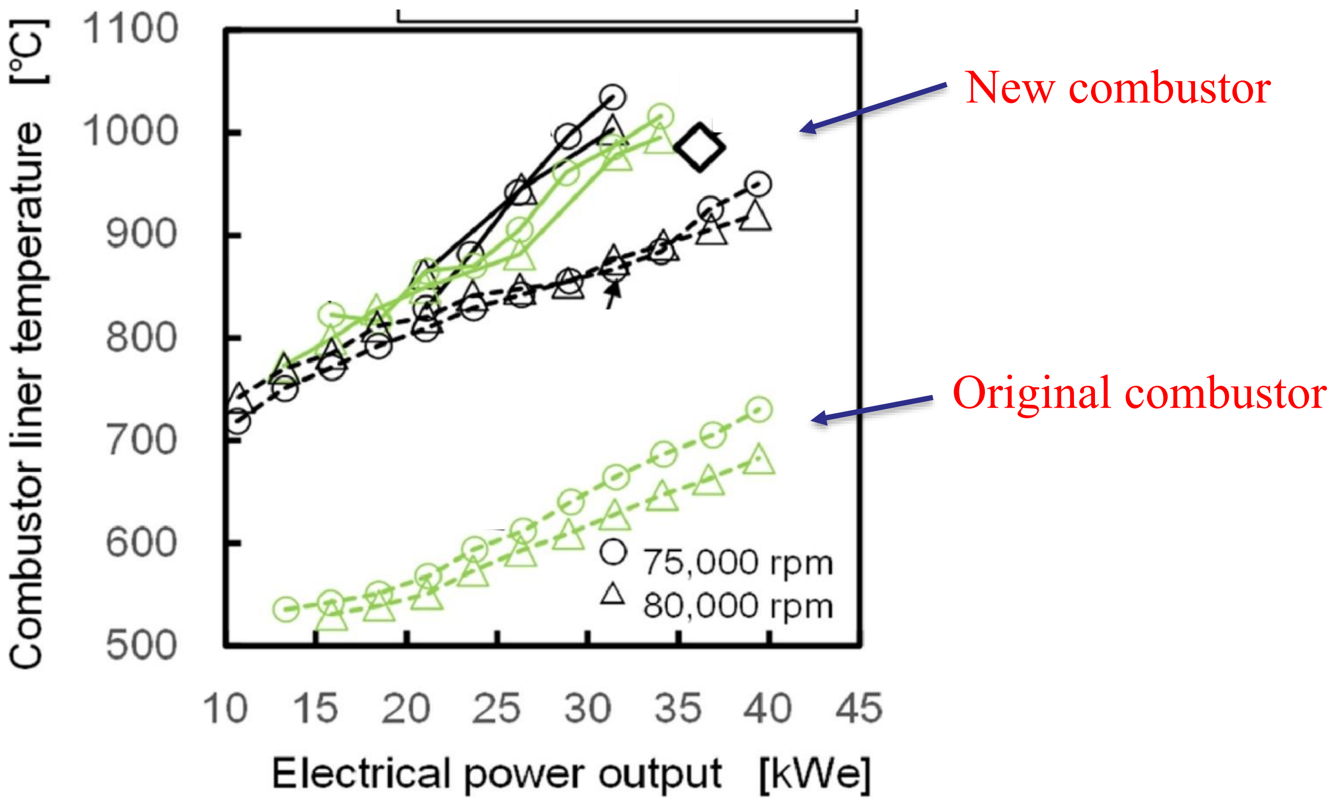
EMISSIONS FROM THE MICRO GAS TURBINE EXPERIMENTS

Significant improvement in combustion efficiency and reduction in NO emission using two-stage rich-lean combustion.



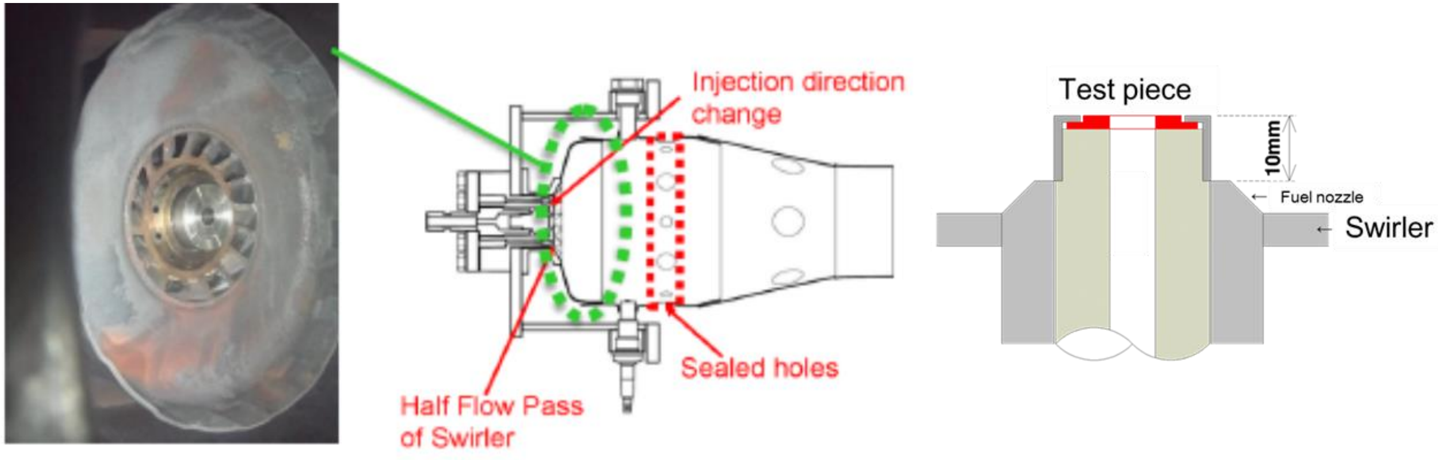
© Kurata et al., Proc. Combust. Inst. 37 (2019)

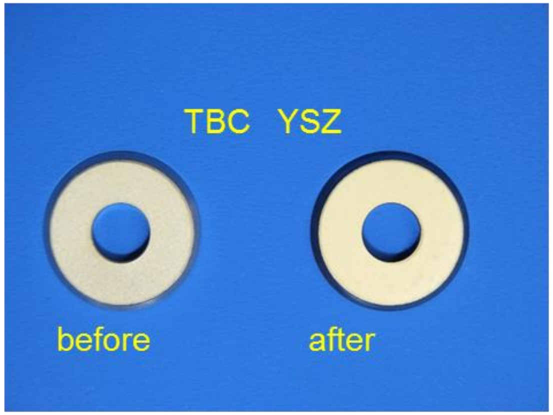
Combustor wall Temperature



The new combustors resulted in higher combustor liner temperatures

Temperature resistance testing of materials





Thermal barrier coating using Yttria Stabilized Zirconium powder showed good high temperature resistance for ammonia combustors.

Summary

- Two-stage rich-lean combustion has been proposed and demonstrated for the control of emissions from ammonia gas turbines.
- NOx emission was reduced to 1/3 times of that from the original combustor.
- The new low NOx combustor leads to relatively high combustor liner temperatures.
- Temperature resistance of materials was tested under ammonia combustion conditions and thermal barrier coating using Yttria Stabilized Zirconium powder was found more appropriate than Inconel600.

Acknowledgement

Supported by

SIP Cross-ministerial Strategic Innovation Promotion Program

Funded by

JST Japan Science and Technology Agency