KAUST Research Conference

Near Zero-Carbon Combustion Technology

On-line

June 22, 2021

Laminar flame characteristics of ammonia: burning velocity and product gas

High Speed Reacting Flow lab.,

Institute of Fluid Science (IFS), Tohoku University, Japan

Akihiro Hayakawa

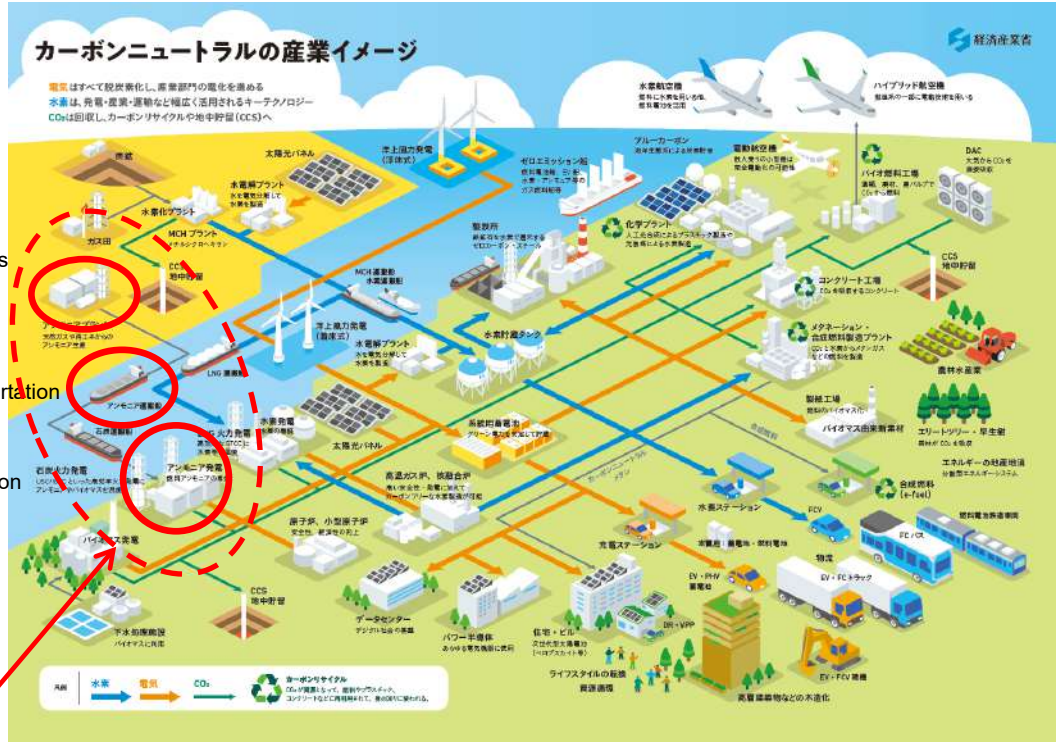
contact: akihiro.hayakawa.b2@tohoku.ac.jp

TOHOKU UNIVERSITY

Institute of Fluid Science Tohoku University IFS

Green Growth Strategy Through Achieving Carbon Neutrality in 2050

Carbon neutral industry proposed by METI (Ministry of Economy, Trade and Industry)



N_2 H_2

NH_3 Synthesis

NH_3 transportation

Power generation

Ammonia utilization

https://www.meti.go.jp/press/2020/12/20201225012/20201225012.html

- By 2030: 46% reduction
- By 2050: Carbon neutral

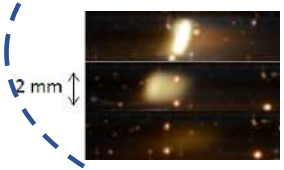
- The Green Growth Strategy was proposed by Japan's Ministry of Economy, Trade and Industry on Dec. 2020 (modified on Jun. 2021)
- Ammonia is one of the important parts of the strategy.
- METI prepared 18 billion USD foundation for the R&D in this strategy.

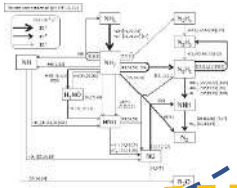
Ammonia combustion study at IFS

IFS

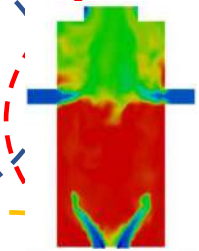
2013 ALCA -> 2014 SIP ->2019 NEDO

Reaction kinetics
Prof. Nakamura

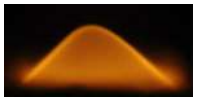


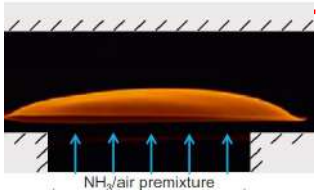


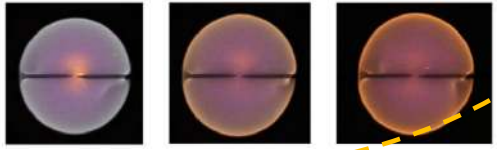
Gas turbine like combustion



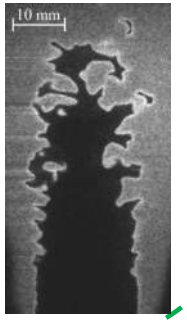
Laminar flames







Turbulent flames

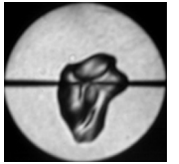


Industry and National institute

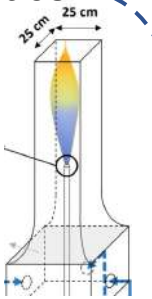
AIST, FREA

IHI

Universities



Hokkaido



CARDIFF UNIVERSITY
PRIFYSGOL CAERDYDD

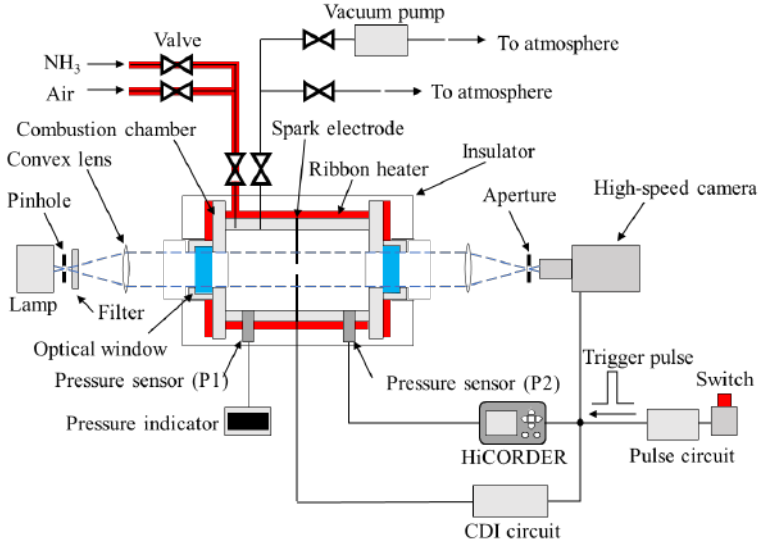
INSA-Lyon

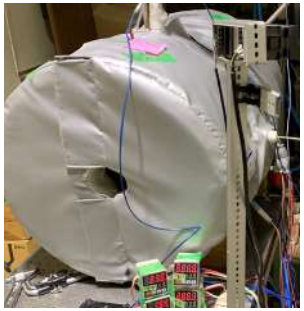
+JSPS core-to-core

Topics for this presentation

- Effects of initial mixture temperature on laminar burning velocity
  - ✓Kanoshima et al., under review
  - ✓Partially presented at ICFD2020
- Product gas characteristics of ammonia in stagnation flows
  - ✓Ammonia/air : A. Hayakawa et al., PROCI, vol. 38
  - ✓Ammonia/methane/air : M. Kovaleva et al., WiPP, 38th Symp. Combust.
  - ✓Ammonia/hydrogen/air : To be presented at ICFD 2021 (Nov.)

Constant volume combustion chamber

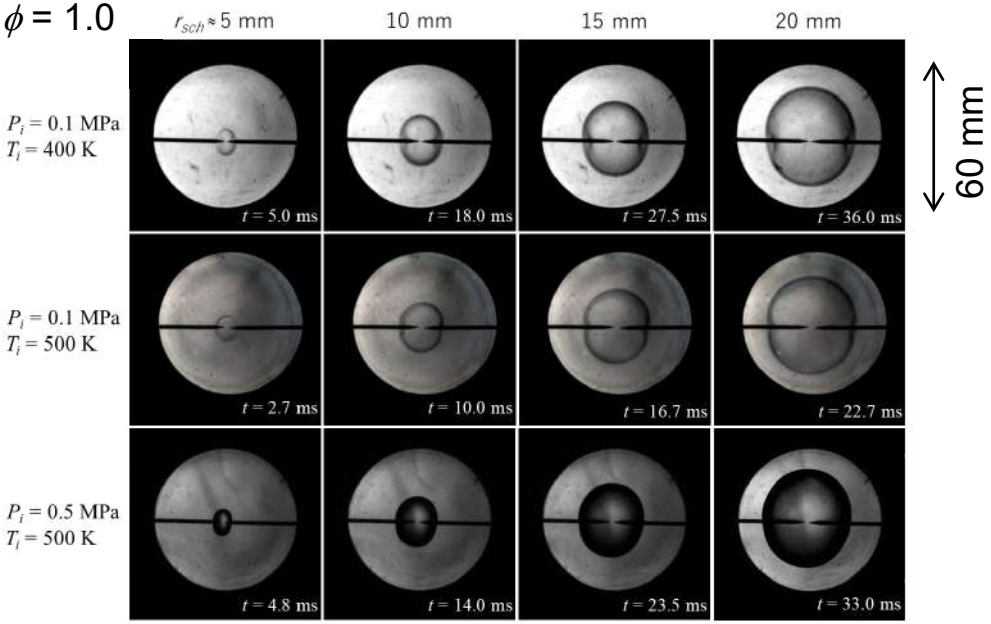




Constant volume combustion chamber covered with an insulator at IFS

- ✓ Flame image can be observed through two optical windows up to 60 mm in diameter.
- ✓ Operatable initial mixture condition up to 0.5 MPa and 500 K

Schlieren images of stoichiometric ammonia/air flames under elevated temperature and pressure conditions



Difficulty of ammonia flame holding on a burner

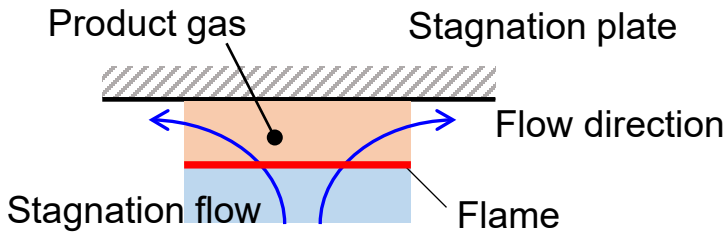
Ammonia flame

Methane flame

- Because of slow burning velocity of ammonia, holding of ammonia flame is difficult.
- Thus, product gas sampling from laminar ammonia flame was difficult.

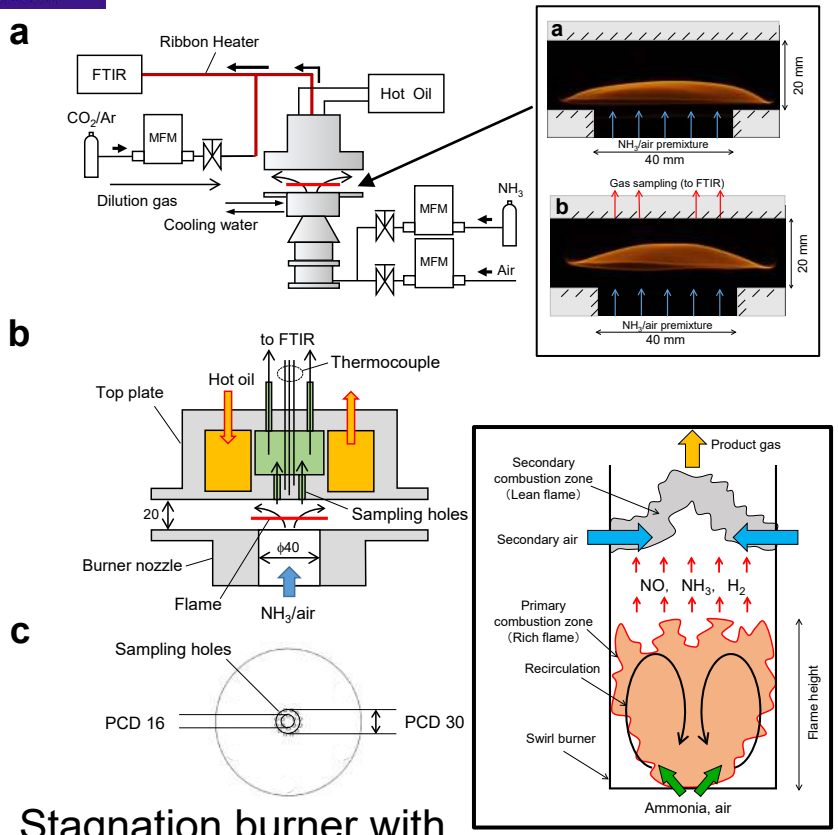
Brackmann et al. (CNF, 2016)

Succeeded flame stabilization using stagnation flow configuration.

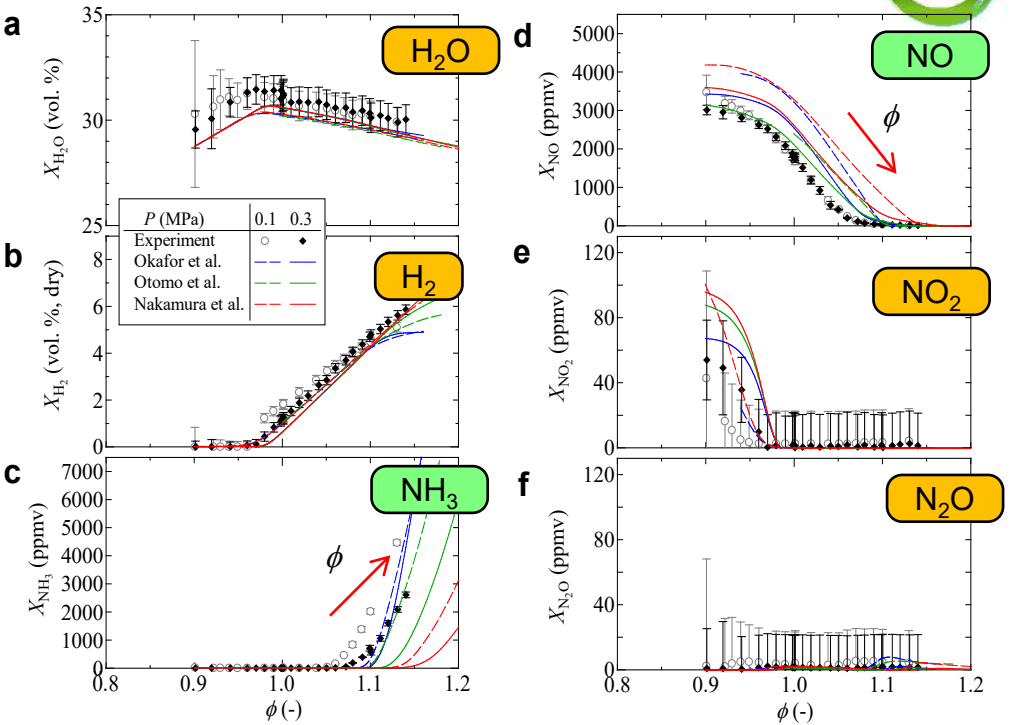


We considered product gas sampling from stagnation flame.

Product gas characteristics of ammonia/air premixed flames



Stagnation burner with sampling holes



- Trade-off relationship between NO unburnt NH_3
- Optimum equivalence ratio for simultaneous NO and unburnt NH_3 is around 1.06.

Figures are reprinted from "Hayakawa et al. PROCI 38 (2021)" with permission from Elsevier.

Conclusions

- To achieve GHG reduction, Japanese government formulated the "Green Growth Strategy Through Achieving Carbon Neutrality in 2050". Ammonia use as fuel is one of important parts in this strategy.
- At IFS, Tohoku University, we have carried out ammonia combustion study from 2013. Flame characteristics for various flame configurations were experimentally and numerically investigated.
- Laminar burning velocity at elevated temperature and pressure conditions were clarified experimentally. The temperature dependence on laminar burning velocity were clarified from the standpoint of reaction flow.
- Product gas characteristics of ammonia laminar flames were investigated experimentally using stagnation flame configuration.