PhD Position at CORIA

UMR 6614 CNRS, Université Rouen Normandie, INSA Rouen Normandie

Project Title: ***Experimental investigation of ammonia-air swirl flames***
Supervisor: Gaetano Magnotti
Co-Supervisor: David Honoré

Context

The ambitious goal of decarbonizing power generation and transportation will likely rely on a portfolio of innovative strategies that combine renewable energies, with novel combustion concepts. Solar and wind energy will take an increasing share of the power generation sector, but because of their intermittent nature, and variability in the energy demand, they need to be coupled with storage technology (batteries, hydro, thermal, or e-fuels). Of particular interest are carbon-free e-fuels such as ammonia and hydrogen, since they offer the possibility of converting excess electricity from renewables into a commodity that can be exchanged on the global market. In particular, ammonia is a promising route since it can be stored in liquid form at ambient temperature and modest pressures, and it can rely on a mature infrastructure for distribution, having been used for more than a century as a feedstock to produce ammonium nitrate fertilizer. Once ammonia reaches its end-user, it can be either converted to hydrogen or employed directly as a fuel.

Ammonia is currently being investigated as fuel in marine engines [1] , heavy-duty [2], and light-duty [3] road transportation, and aircraft engines [4], and it is of interest in high-temperature manufacturing processes [5] such as glass, steel, and cement. Recent efforts have focused on partially cracked ammonia flames, as the hydrogen produced from the ammonia decomposition increases the laminar flame speed, and ensures flame stabilization [6]. The cracking unit increases the capital and operational cost of ammonia burners, and strategies to minimize or remove cracking are of great interest for practical applications. Successful design of low-NOX, non-premixed burner, fueled by uncracked ammonia requires high-quality experimental datasets in laminar [7] and turbulent [8] flames of undiluted ammonia are much needed, to improve the understanding of ammonia combustion physics, guide the choice of suitable chemical kinetics models, and validate computational fluid mechanics models [9]. This project aims to address this fundamental research gap, combining state-of-the-art laser diagnostics with carefully designed laminar and turbulent burners optimized for operation with minimal or no ammonia cracking.

PhD Objectives

The Ph.D. thesis aims to advance the understanding of undiluted ammonia combustion physics and to build a state-of-the-art dataset for validation of numerical models. Combustion of undiluted ammonia is challenging because of the low laminar flame speed of this promising e-fuel. A novel laboratory-scale burner, inspired by a successful gas-turbine combustor operated with undiluted ammonia [10-12], will be developed and tested. An outer, non-premixed cracked ammonia/air flame, combined with swirl-stabilization and pre-heating of the reactants will allow the stabilization of an inner ammonia/air non-premixed flame. The novel burner replicates key physics encountered in industrial ammonia gas turbines [11], but offers a simplified geometry, with excellent optical access and well-defined boundary conditions. Initial studies will provide a stability map of the burner as a function of the pilot flame power, reactants temperature, and cracking ratio. Detailed 1D Raman/NH_2/NO-LIF measurements of temperature, major species NH_2 and NO will be performed on selected flame series to:

1) Investigate the role of turbulence-chemistry interaction and preferential diffusion on localized extinction and re-ignition.
2) Investigate the role of pre-heating on the flame microstructure, NOx emissions, and localized extinction.
3) Understand the effect of varying cracking ratios on the combustion of the inner swirled ammonia/air flame.

Analysis of experimental results in physical and mixture fraction space will highlight the role of differential diffusion, in situ cracking, and turbulence-chemistry interaction on NO formation, flame stability, and localized extinction/re-ignition. The detailed experimental datasets will be shared with numerical modelers at CORIA and worldwide, providing a powerful validation dataset for the latest numerical models of ammonia combustion.

Complementary measurements in laminar counterflow flames will test the capabilities of existing chemical kinetics models in predicting NO levels in ammonia flames with minimal cracking. The much-needed data will help numerical modelers in the selection of chemical kinetic models to implement in their numerical simulations.

In practice, the work will be organized around the following points:

- Literature Review
- Optimization of Raman system at CORIA for measurements in undiluted ammonia flames
- Experimental and numerical study (Raman/NO-LIF) of premixed and non-premixed ammonia counterflow flames
- Set-up and testing of a dual-swirl ammonia burner for operation with minimum or no cracking.
- Detailed investigation of the role of fuel stratification, differential diffusion, turbulence-chemistry interaction, and pre-heating on the stability, NOx formation, and flame microstructure of the proposed dual-swirl flames at atmospheric pressure.
- Dissemination of the results: journal publications, presentation at national and international conferences, sharing of the dataset to numerical modelers in the framework on International Workshop on Measurements and Computation of Turbulent Flames (TNF).

WORK ENVIRONMENT

Work will be conducted at the CORIA laboratory in Rouen under the supervision of Professor Magnotti and Professor Honoré. The student will join a diverse community of researchers dedicated to accelerating and enabling the energy transition, and the decarbonization of the transportation and industrial sector. Participation in international conferences will be strongly encouraged.

GENERAL INFORMATION

- 3-year PhD thesis, at the CORIA laboratory, Rouen, France
- Salary: approx. €1,700 net/month
- Contract start date: preferably 1st October 2025

APPLICANT PROFILE

- Master's level degree in a relevant Engineering program (Aerospace, Chemical, Energy, Mechanical, ...)
- Good oral and written communication skills to present at conferences and write scientific publications. (English required, French desirable).
- Knowledge and previous experience in laser diagnostics and/or combustion is desirable

APPLICATION PROCEDURE

- Send CV, cover letter, and university transcripts (Bachelor's and Master or equivalent) to ***gaetano.magnotti@coria.fr***
- **Deadline for the application: 1st April 2025.**
- Incomplete applications will not be considered

References

[1] X. Zhou, T. Li, R. Chen, Y. Wei, X. Wang, N. Wang, S. Li, M. Kuang, W. Yang, Ammonia marine engine design for enhanced efficiency and reduced greenhouse gas emissions, Nature Communications 15 (2024) 2110.
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[10] O. Kurata, N. Iki, T. Matsunuma, T. Inoue, T. Tsujimura, H. Furutani, H. Kobayashi, A. Hayakawa, Performances and emission characteristics of NH3–air and NH3CH4–air combustion gas-turbine power generations, Proceedings of the Combustion Institute 36 (2017) 3351-3359.
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[12] A. Hayakawa, Y. Arakawa, R. Mimoto, K.D.K.A. Somarathne, T. Kudo, H. Kobayashi, Experimental investigation of stabilization and emission characteristics of ammonia/air premixed flames in a swirl combustor, International Journal of Hydrogen Energy 42 (2017) 14010-14018.