UNIVERSITY OF PATRAS
MECHANICAL ENGINEERING AND AERONAUTICS DEPARTMENT

Division of Energy, Aeronautics & Environment
Laboratory of Thermodynamics and Statistical Applications

"Investigation of stabilization of hydrogen mixture turbulent flames in a bluff body by solving Navier-Stokes equations with Reynolds averaging (RANS) and the partially premixed combustion model using Flamelet-generated manifold (FGM)."

Lina Athanasopoulou - 1085193
Supervisor: Professor Panagiotis Koutmos

Introduction

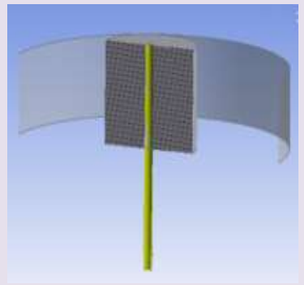
Global efforts to meet net-zero targets require a shift towards carbon-free fuels. Hydrogen (H_2) offers zero emissions, while Ammonia (NH_3) is a practical carbon-free energy carrier. Blending these fuels is a crucial step towards that goal. However, their contrasting properties (e.g. flame speed, NOx formation) necessitate the use of advanced stabilization techniques to manage combustion efficiency and pollutant emissions.

Objective

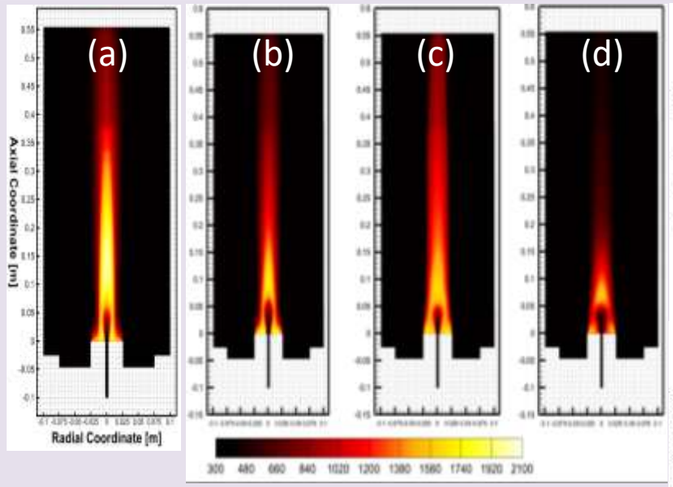
The present work describes a Computational Fluid Dynamics (CFD) investigation on the effect of the H_2 to NH_3 ratio on the stabilization of turbulent, partially premixed flames anchored to an annular bluff body. This study explores four different mixture compositions (0%, 25%, 50% and 72% NH_3 concentration) to examine the resulting flame structure, recirculation zone activity, and NO emissions, along with the existence of intermediate species. The ammonia – hydrogen mixture enters through the inner cavity of the solid body at a temperature of 300 K with a parabolic velocity profile that varies depending on the case being studied. The oxidizer (air) enters through the air duct at a temperature of 300 K with a constant uniform velocity of 12,84 m/s.

Computational Methods

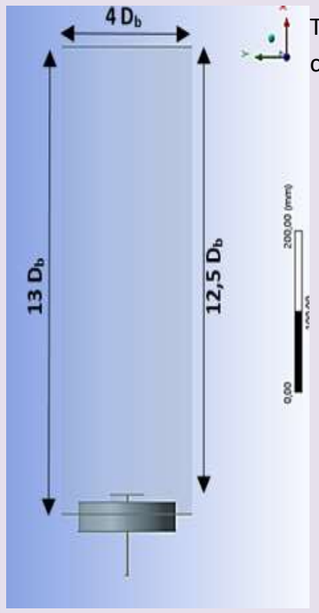
All simulations were carried out using the k-ε Realizable model, as well as the FGM model for a mechanism of 33 elements and 214 reactions, as implemented in the *Ansys Fluent* software.



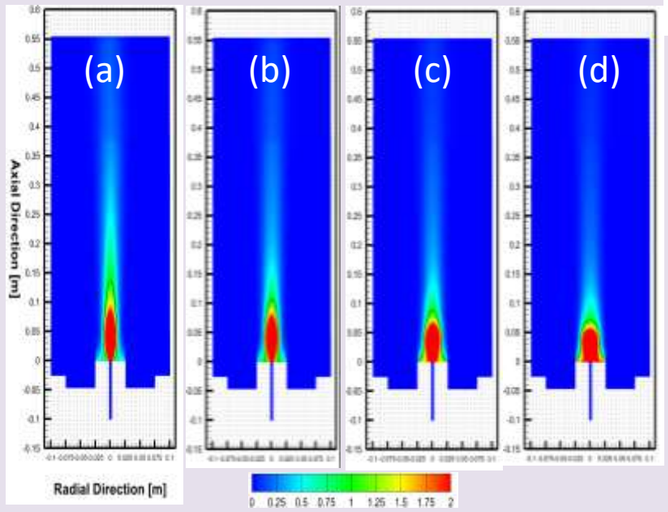
Cross–section of geometry



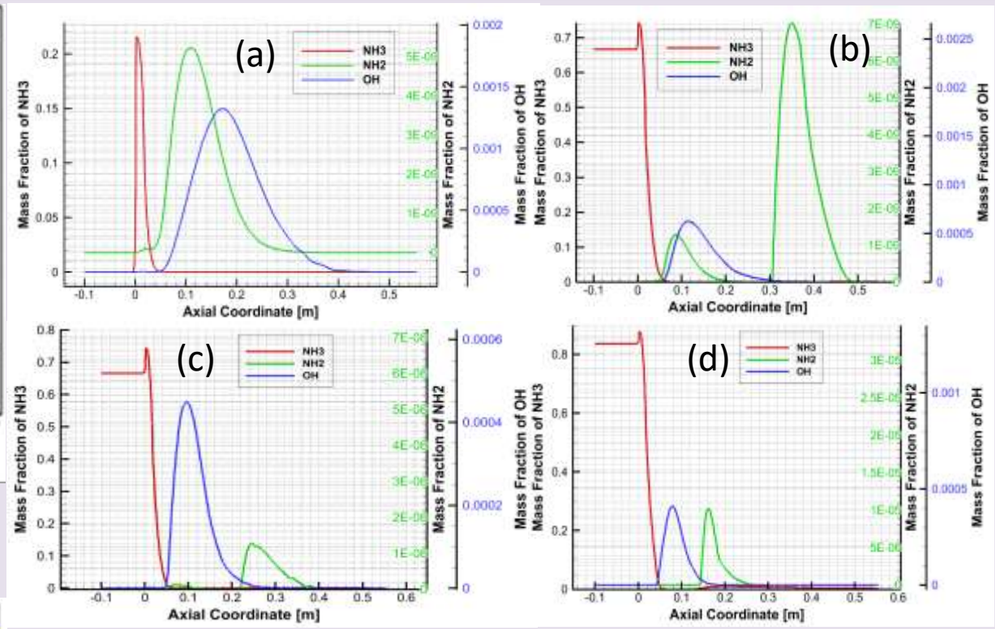
Temperature profile at the cross-section for each fuel mixture case. *a)FNH3-0, b)FNH3-25, c)FNH3-50 and d)FNH3-72.*



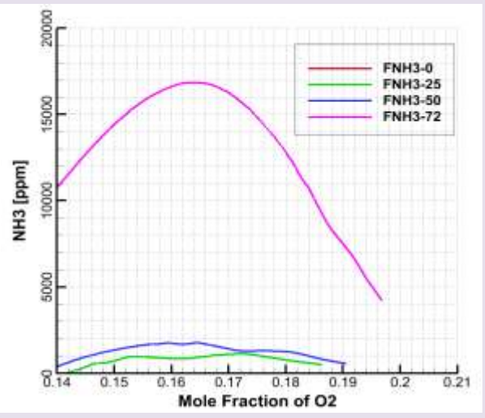
Fluid domain

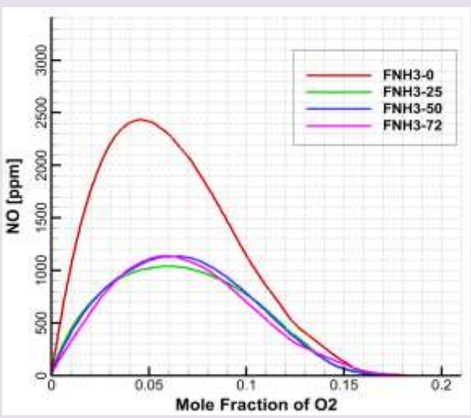


Equivalence ratio profile at the cross-section for each fuel mixture case. *a)FNH3-0, b)FNH3-25, c)FNH3-50 and d)FNH3-72.*



Axial mass fraction profiles of NH_3, NH_2 and OH for each case a)FNH3-0, b)FNH3-25, c)FNH3-50 and d)FNH3-72.





NO and NH_3 concentrations for different oxygen concentrations within the flame region.

Results

The study found that increasing the concentration of NH_3 in the fuel blend leads to significant changes, explained by the fuels' properties. Specifically, the absence of NH_3 resulted in a longer flame and a narrower recirculation zone due to hydrogen's fast combustion, while the maximum concentration of it yielded a shorter, wider flame with a broader, more active recirculation zone, attributed to ammonia's slow combustion speed. Additionally, in the latter case unburnt ammonia was present downstream due to saturation of the recirculation zone. Across all mixtures, NO emissions were negligible, thanks to the ability of flame stabilizers to capture pollutants. Based on these findings, the 50% NH_3 blend is the most promising for further investigation.