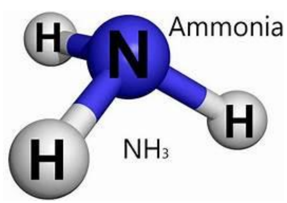
Title: Ammonia and ammonia/hydrogen mixtures combustion associated with plasma

Winter Hydrogen School
8-12th January



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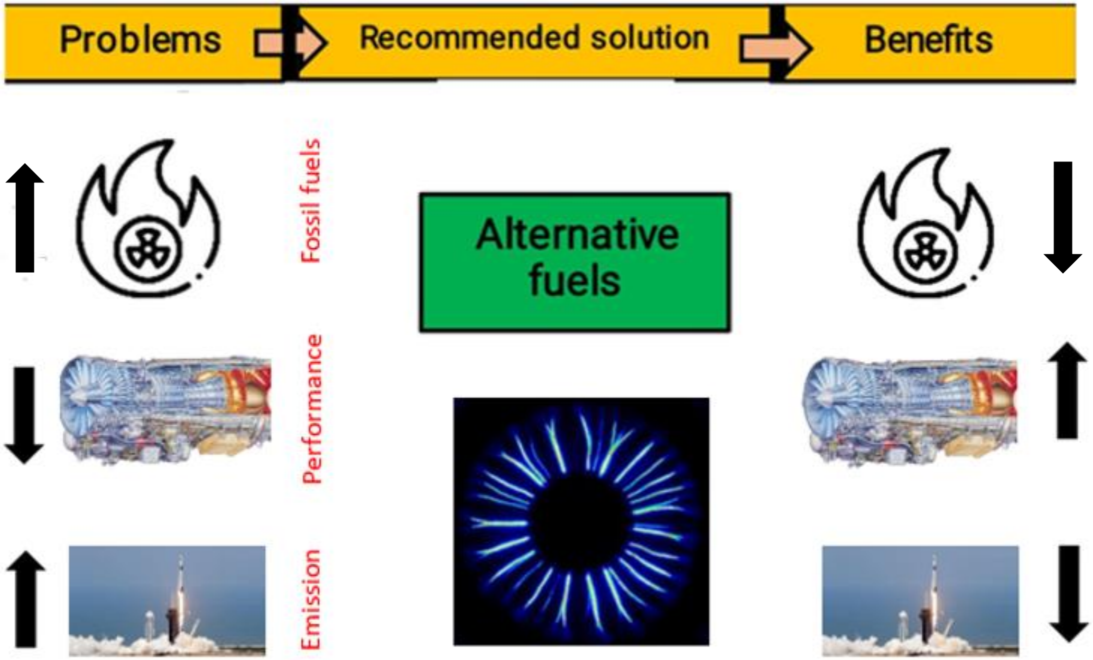
Motivation and background

- Combustion is the principal energy conversion method for electricity generation and transportation since the industrial revolution. To this day, these sectors significantly rely on fossil fuels.



Motivation and background

- Plasma Associated Combustion (PAC) is the prominent and active control technology to boost combustion and minimize pollutant emissions by controlling combustion instability.

- Enhancement of the combustion of Hydrocarbons

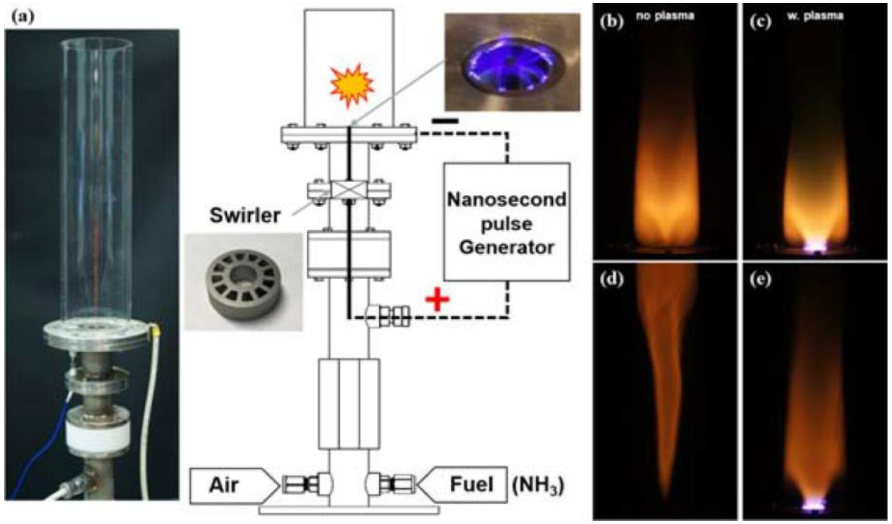
Ignition in IC engine, Scramjet…

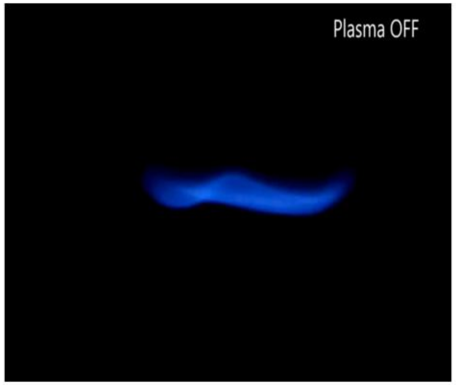
Burning velocity of laminar and turbulent flames…

Lean blow-off and stability limits

Control of thermoacoustic instabilities

Motivation and background

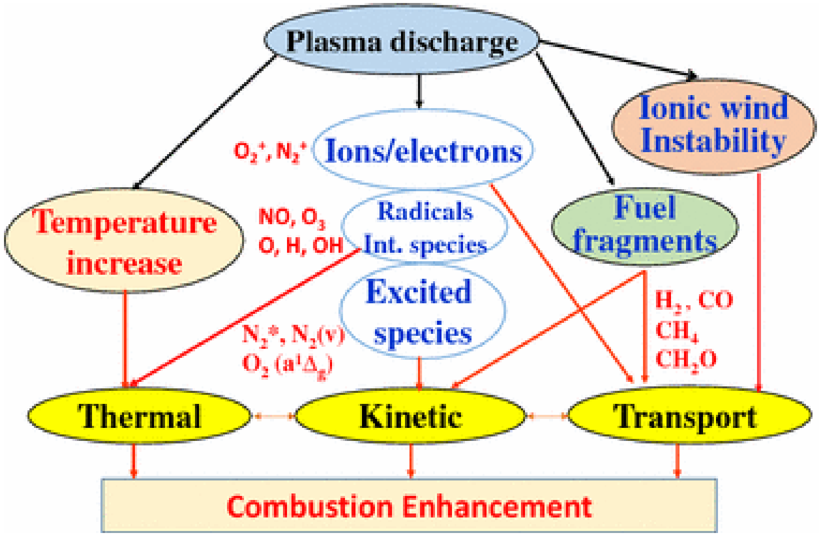




Motivation and background

❖ Plasma assisted combustion technology has the potential to enhance combustion by:

- Thermal effect via temperature rise
- Kinetic effect via plasma generated electronically and vibrationally excited molecules and active radicals
- diffusion transport enhancement effect via fuel decomposition and low temperature oxidation



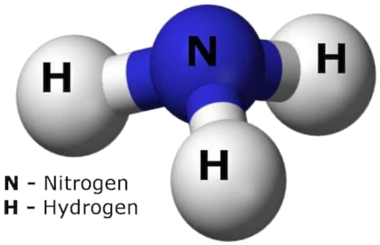
Plasma-generated ionic wind, and flow motion, via the Coulomb and Lorentz forces, which increase turbulization, mixing and alters local flow velocity.

Challenges with ammonia combustion

❖ Ammonia combustion Merits & Drawbacks

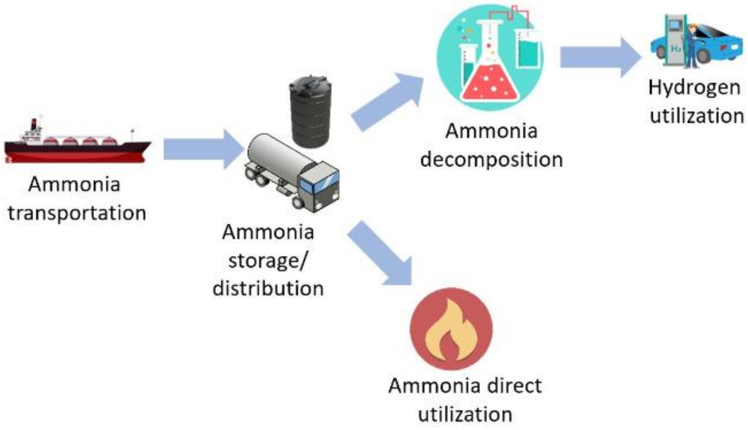
➢ Merits

- Hight hydrogen density
- Carbon free nature
- Good infrastructure



➢ Drawbacks

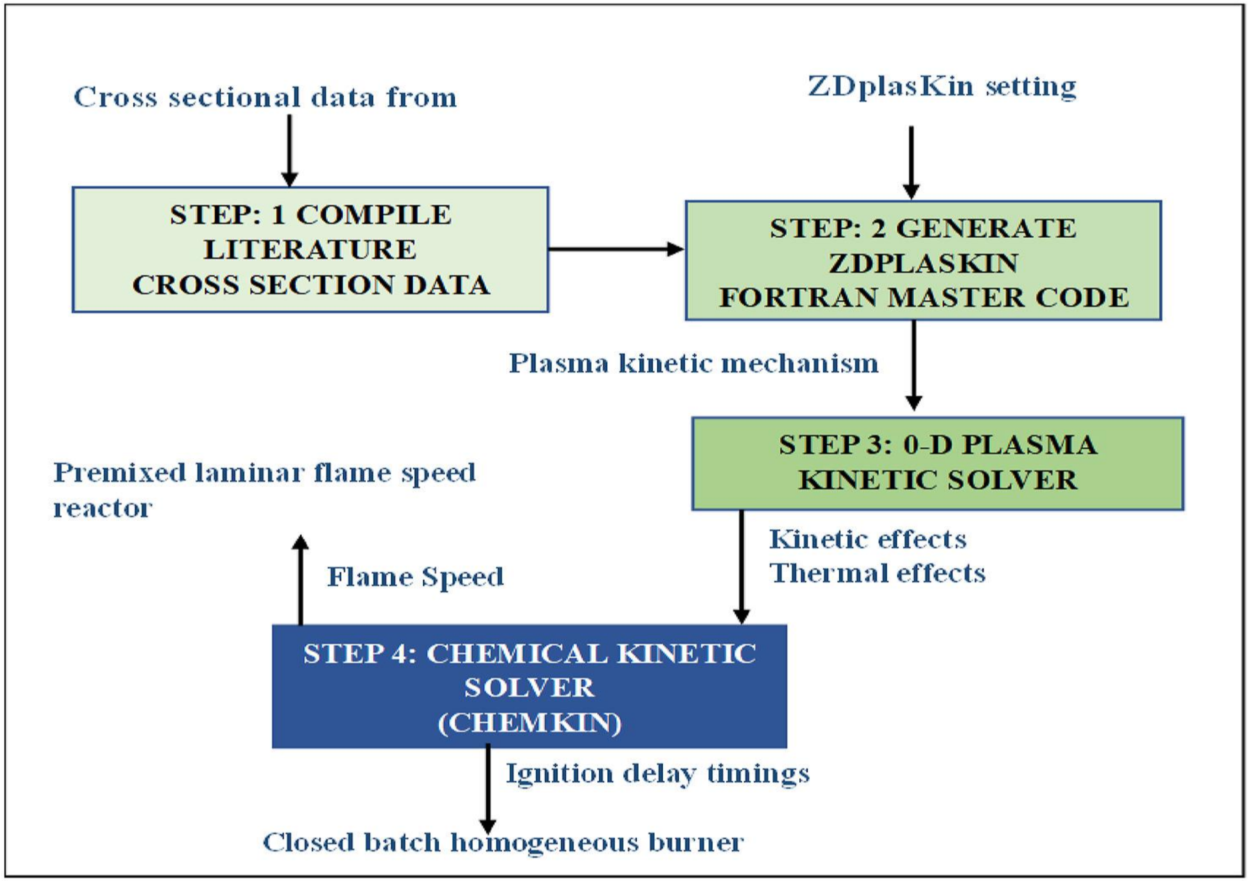
- Poor ignition timings
- Lower burning velocity
- Shorter flammability limits an
- High NO_x emissions



Aims and objectives

- To develop detailed and comparative numerical combustion and plasma chemical kinetic mechanisms to analyze the combustion of alternative fuels (Ammonia, Hydrogen, etc.).
- Experimental Validation of newly developed mechanisms.
- Parametric study of different parameters to obtain the optimum conditions for flame speed, ignition delay time, flam stability and pollutant emission.
- Perform the experiments with and without plasma to investigate the effect of key parameters (Temperature, pressure, reduced electric field, equivalence ratio, etc.) on ammonia and hydrogen fuels combustion.

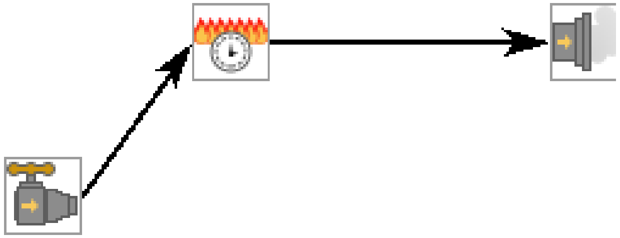
Plasma Assisted Combustion– Methodology



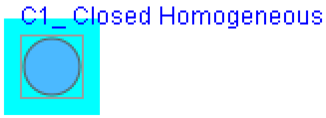
A detailed sketch of the numerical coupling of ZDPlaskin and CHEMKIN.

Plasma and Combustion Kinetic mechanism Details

- The new kinetic reaction mechanism used for the combustion simulation in CHEMKIN is developed.

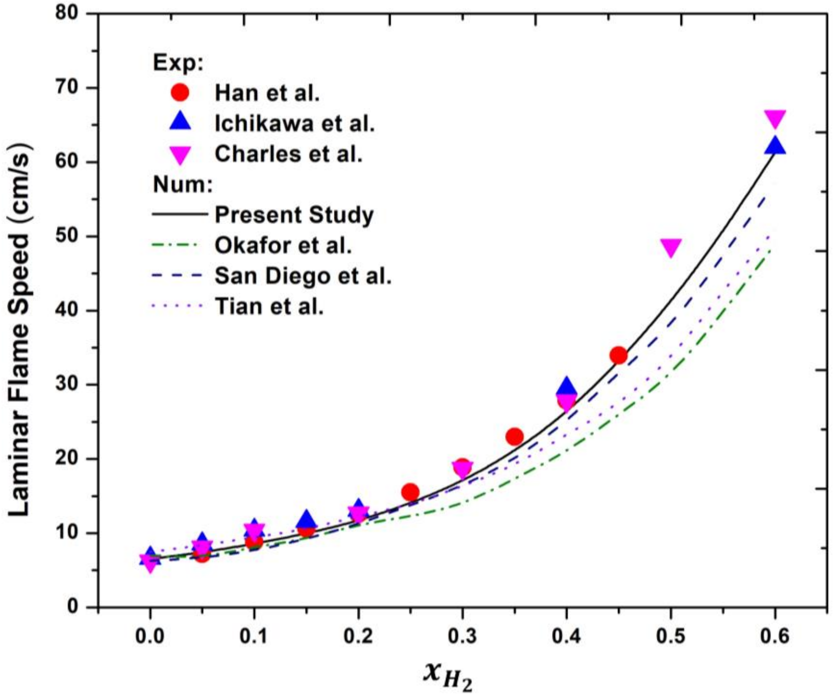


- For the modeling of laminar flame speed (LFS) and ignition delay time (IDT), premixed laminar flame speed reactor (PLFSR) and 0D Close Homogeneous Batch Reactor (CHBR), respectively were used.

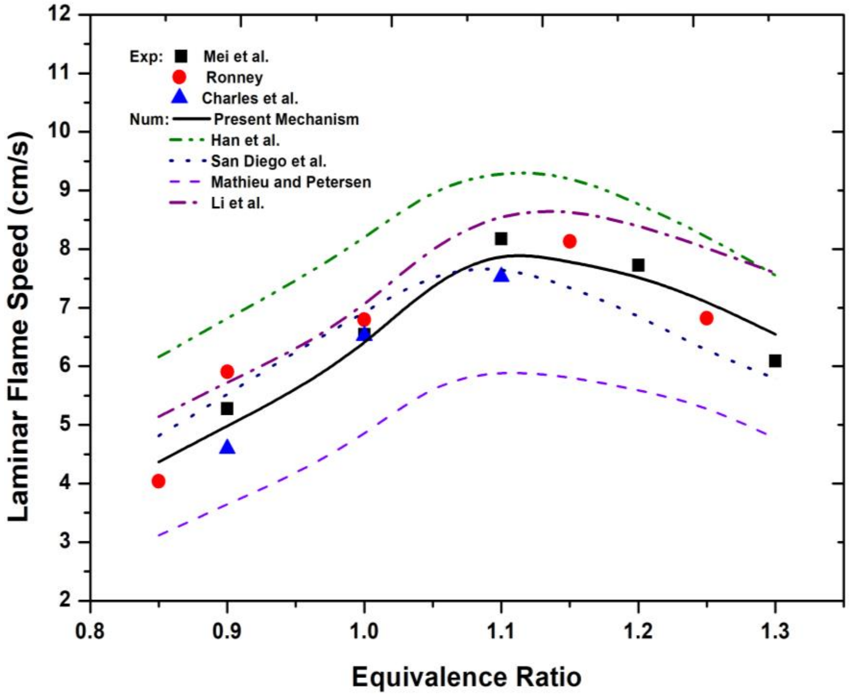


Combustion Kinetic mechanism Validation

❖ Kinetic Mechanism Validation

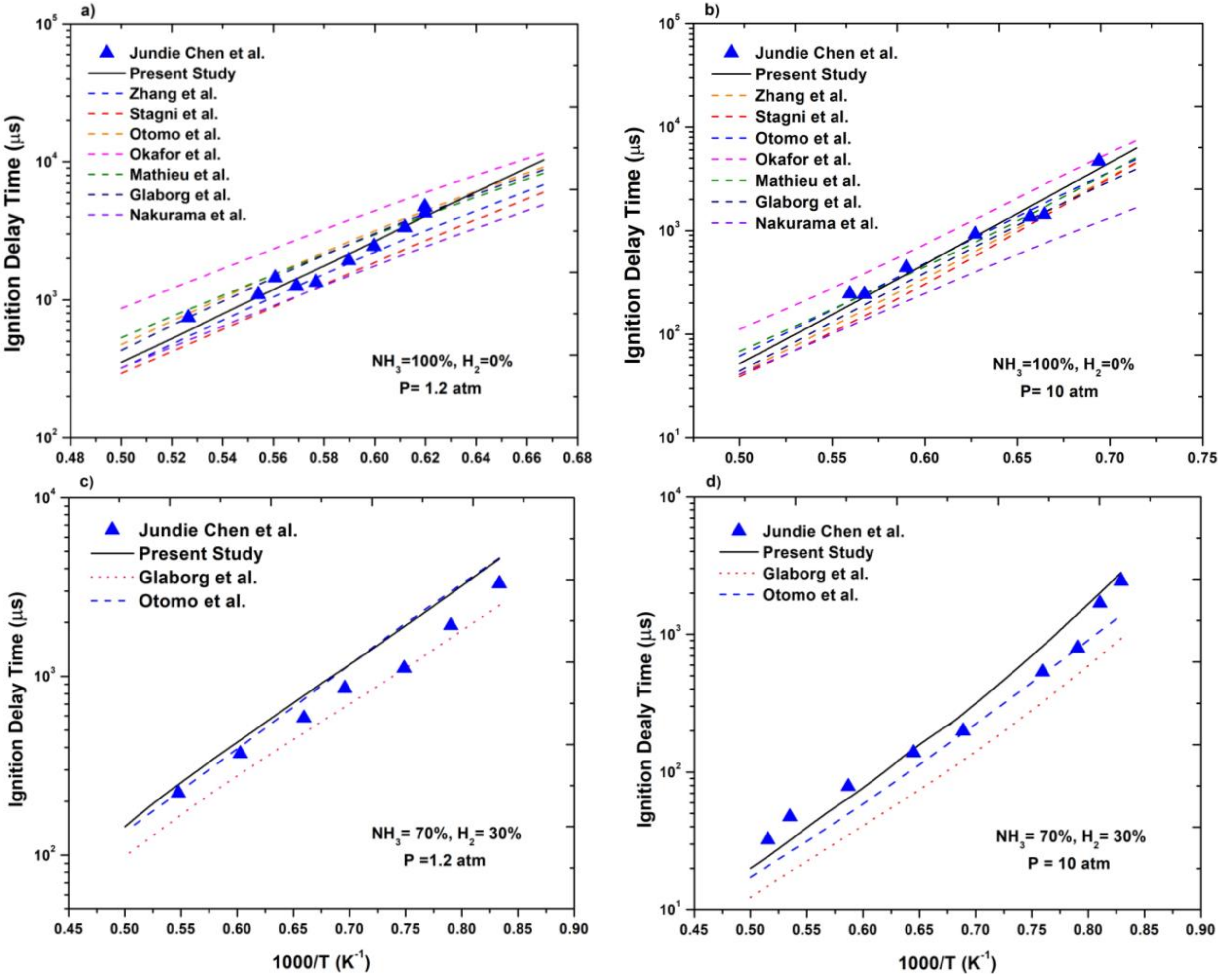


LFS of stoichiometric NH_3/H_2/air mixtures, as a function of x_{H_2}, Symbols signify the experiment data, whereas lines show the simulated findings of the current model and prior models at P=1atm and T=298K.



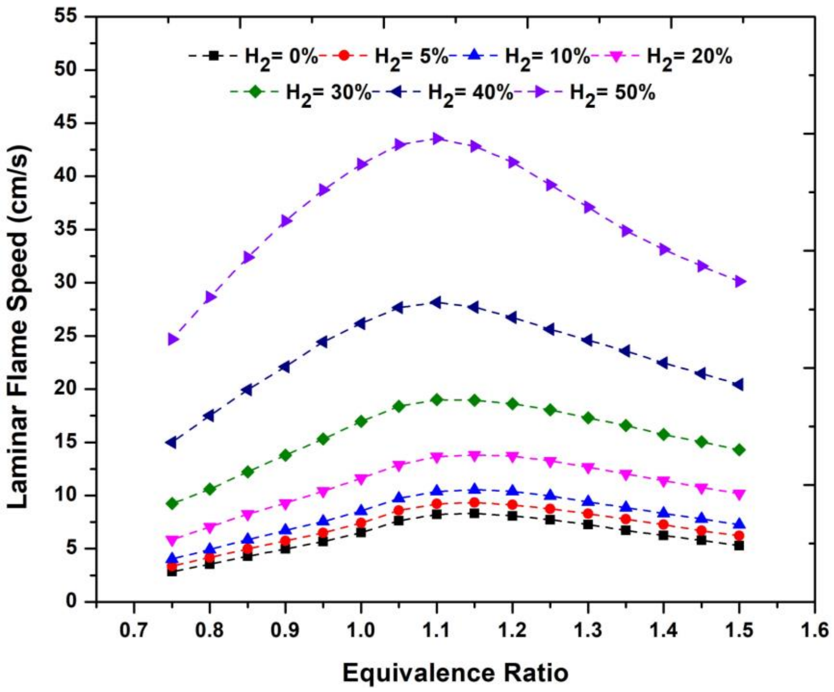
LFS of NH_3/air flame at standard conditions. Symbols signify the experiment data and lines show the simulated findings of the current model and prior models.

Combustion Kinetic mechanism Validation

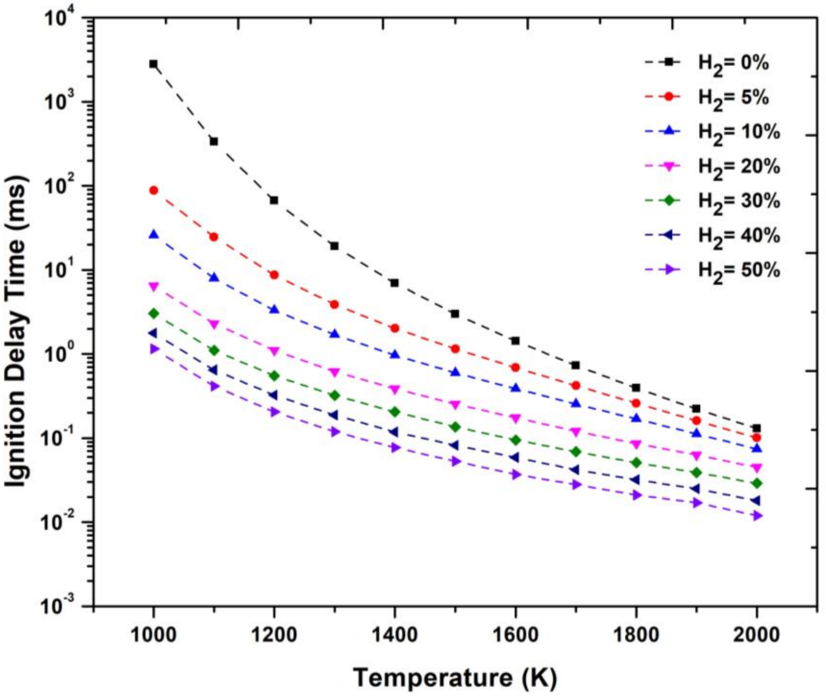


Results and Discussion

❖ Effect of Hydrogen Enrichment in the NH_3/Air Mixture on LFS & IDT



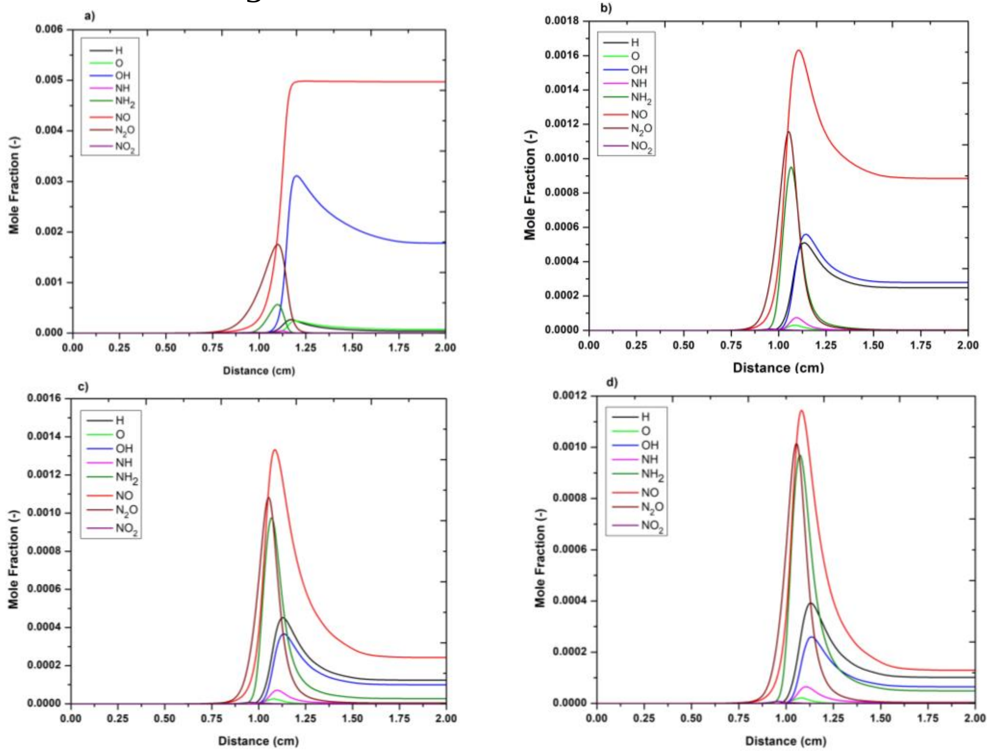
Effect of hydrogen enrichment and equivalence ratio of NH_3/air mixtures on the LFS at P = 1 atm and T = 298K



Effect of Hydrogen enrichment of NH_3/air mixtures on IDT at Φ =1, P= 1atm.

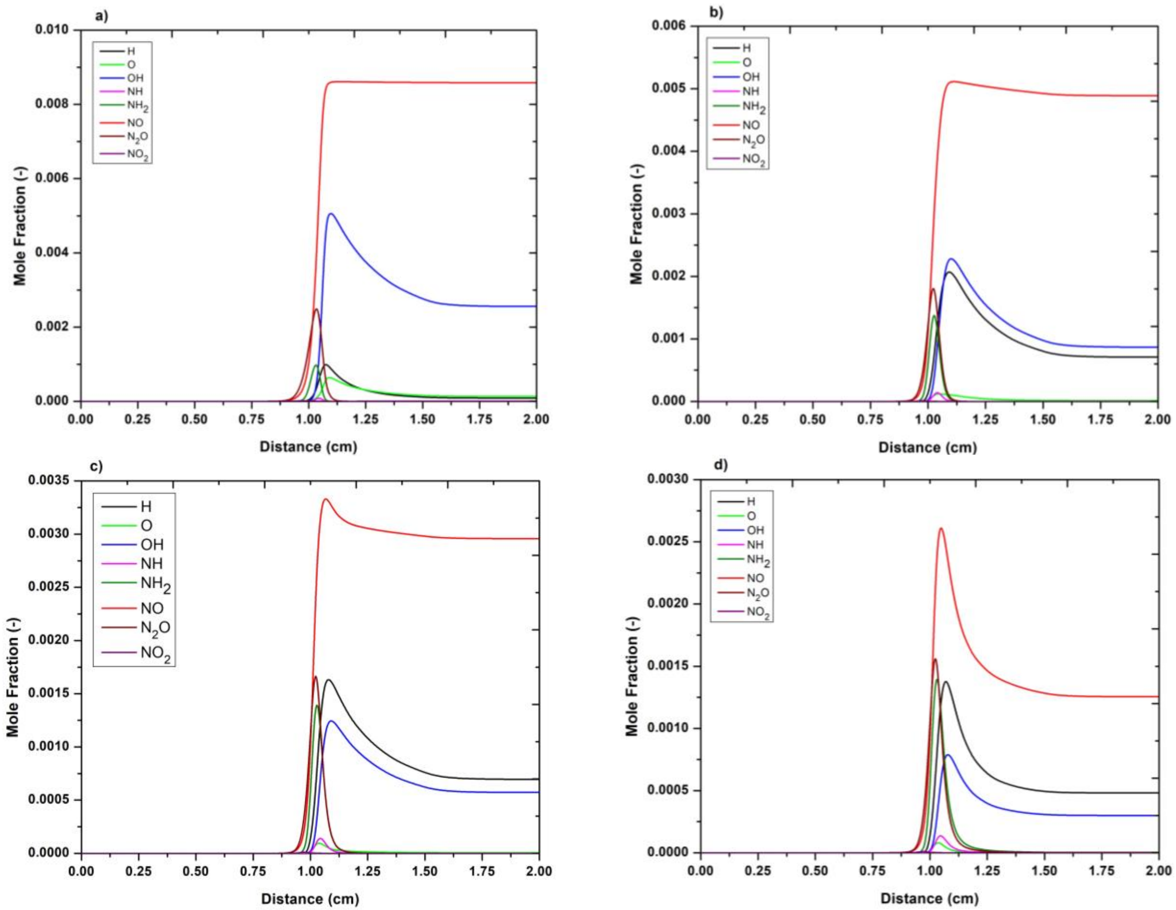
Results and Discussion

- The effect of blending hydrogen and equivalence ratio on the mole fraction profiles species of NH_3 /air mixture



Mole fraction profiles of H, O, OH, NH_2, NH, NO, N_2O & NO_2 of NH_3/air mixtures at different equivalence ratios a) $\Phi = 0.9$ b) $\Phi = 1.1$ c) $\Phi = 1.15$ d) $\Phi = 1.2$, and P= 1 atm and T=298K

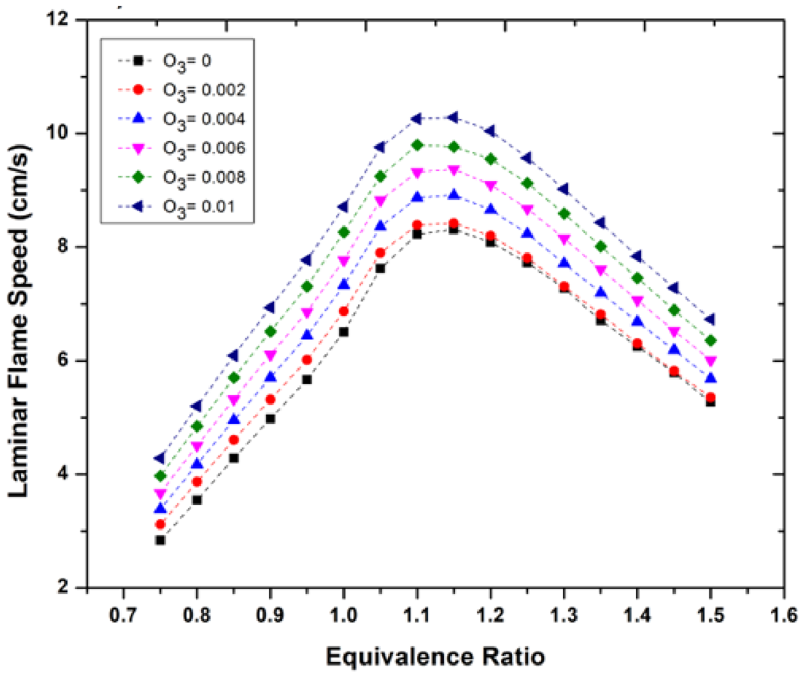
Results and Discussion

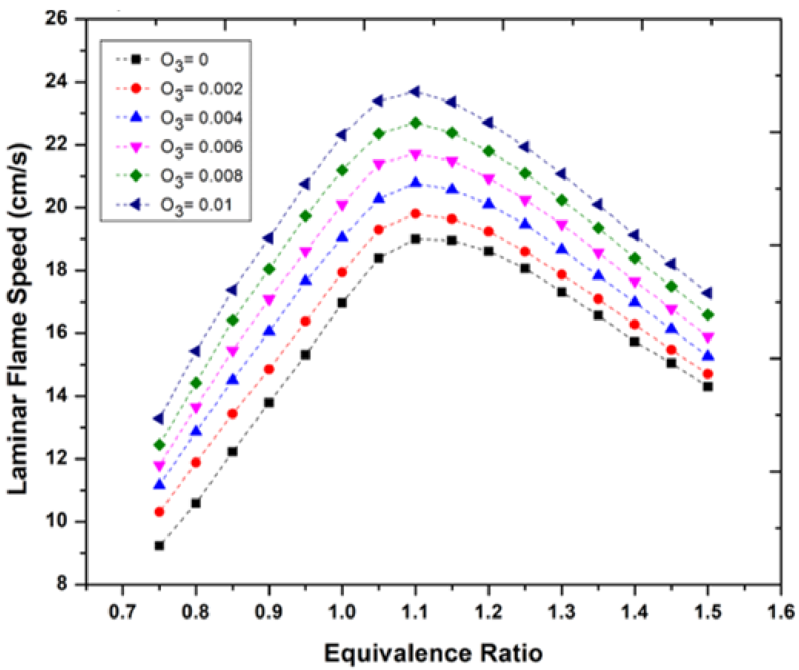


Mole fraction profiles of H, O, OH, NH_2, NH, NO, N_2O & NO_2, H_2 added 30% NH_3/air mixtures at different equivalence ratios a) $\Phi = 0.9$ b) $\Phi = 1.1$ c) $\Phi = 1.15$ d) $\Phi = 1.2$ and P=1 atm T=298K

Results and Discussion

❖ Effect of Ozone Enrichment in the NH_3/H_2/Air Mixtures on LFS



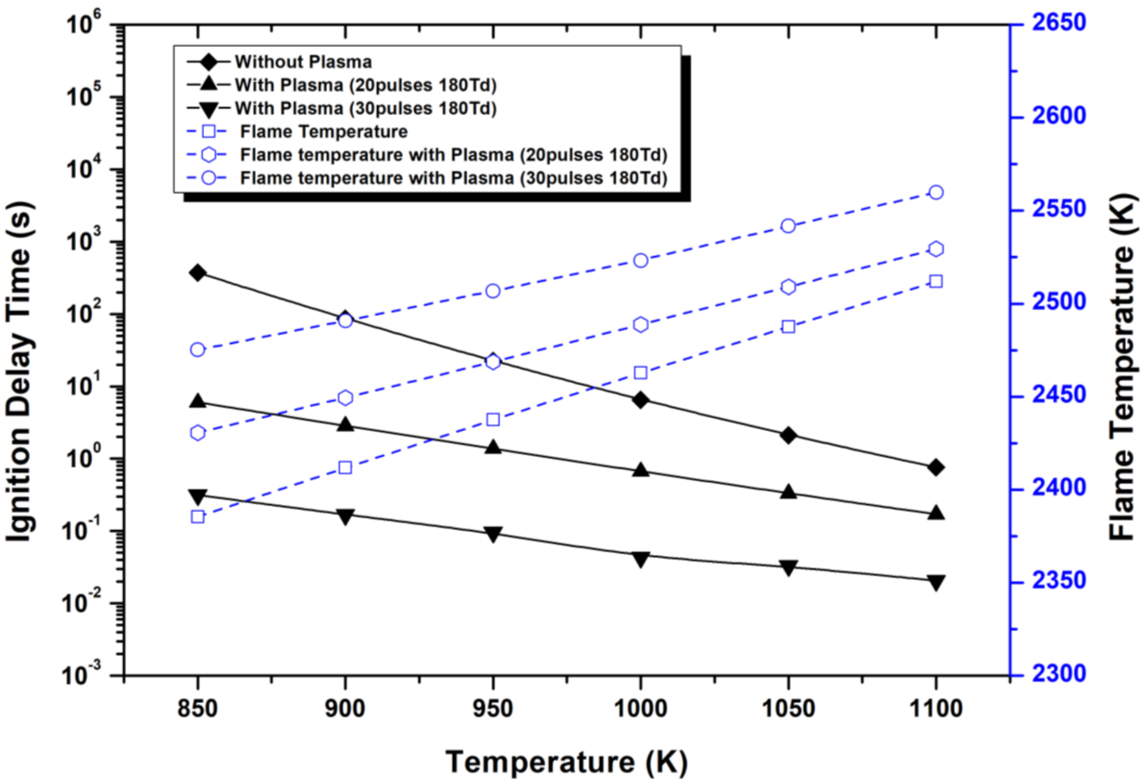


The effect of O_3 on LFS of NH_3/H_2/air mixtures under the normal condition at

H_2 = 0% and H_2 = 30%

Results and Discussion

❖ Effect of temperature and plasma on IDT and flame temperature



IDT and flame temperature without and with 20 and 30 sequential pulses of plasma discharge in NH_3/air mixture at φ = 1.0 with PRF = 50 kHz.

Conclusion

- Laminar Flame speed increased as H_2 concentration increased, and IDT is reduced with an increased concentration of H_2, and initial temperature.

- The optimized equivalence ratio exists in the range of 1.10–1.15 to achieve steady and efficient combustion as well as reduced NOx emissions.

- The ignition delay time of the combustion under the plasma case is significantly shorter and the flame temperature higher than that of the without plasma case. The findings suggest that plasma excitation accelerate reactions and introduces new pathways, which improves low-temperature NH_3 ignition.

- Adding ozone in the oxidizer also can improves the LFS of the NH_3/H_2/air mixture at normal conditions.

Publications

1. **Zubair Ali Shah**, G. Mehdi, P.M. Congedo, D. Mazzeo, M.G. De Giorgi. A review of recent studies and emerging trends in plasma-assisted combustion of ammonia as an effective hydrogen carrier. **International Journal of Hydrogen Energy** (2023) https://doi.org/10.1016/j.ijhydene.2023.05.222
2. **Zubair Ali Shah**, G. Marseglia, Maria Grazia De Giorgi. Predictive Models of Laminar Flame Speed in $NH_3/H_2/O_3$/Air Mixtures Using Multi-Gene Genetic Programming Under Varied Fuelling Conditions**. Fuel** (2023) **(Under review).**
3. **Zubair Ali Shah**, Mingming Zhu, Ghazanfar Mehdi, Maria Grazia De Giorgi. Refined Kinetic Mechanism for Modeling Improved Ignition Delay Time in Ammonia/Air Mixture through Nanosecond Plasma Discharge. The Combustion Institute's **40th International Symposium** - Emphasizing Energy Transition **(Under review).**
4. Ghazanfar Mehdi, Maria Grazia De Giorgi, Sara Bonuso, **Zubair Ali Shah**, Giacomo Cinieri and Antonio Ficarella. Comparative Analysis of Flame Propagation and Flammability Limits of CH4/H2/Air Mixture with or without Nanosecond Plasma Discharges. **Aerospace** 2023, 10(3), 224. https://doi.org/10.3390/aerospace10030224

Publications

5. Giacomo Cinieri, **Zubair Ali Shah**, Guido Marseglia, Maria Grazia De Giorgi. Towards Zero Carbon Emissions: Investigating the Combustion Performance of Shaped Micro-Combustors using H2/Air and NH3/Air Mixtures. Aerospace 2024, 11(1), 12; https://doi.org/10.3390/aerospace11010012
6. Sara Bonuso, Pasquale Di gloria, Guido Marseglia, Ramón A. Otón-Martínez, Ghazanfar Mehdi, **Zubair Ali Shah**, Antonio Ficarella, Maria Grazia De Giorgi. Investigation into the effect of Hydrogen-Enriched Conditions on Methane Flame Structure and Stability. Aerospace 2024, 11(1), 43; https://doi.org/10.3390/aerospace11010043
7. Sara Bonuso, Ghazanfar Mehdi, **Zubair Ali Shah**, Maria Grazia De Giorgi. Experimental Investigation of the Effect of Hydrogen Enrichment on Flame Structures: Insights into Flame Characteristics and Stability. 13th **EASN** International Conference Proceedings Issue of Journal of Physics (2023) **(Accepted).**
8. G. Cinieri, G. Marseglia, **Zubair Ali Shah**, Ghazanfar Mehdi, M.G. De Giorgi. Combustion Performance of Zero-carbon Fuels in a Shaped Micro-Combustor for Aerospace Propulsion Applications. 13th **EASN** International Conference Proceedings Issue of Journal of Physics (2023) **(Accepted).**

Thank you

For your Attention