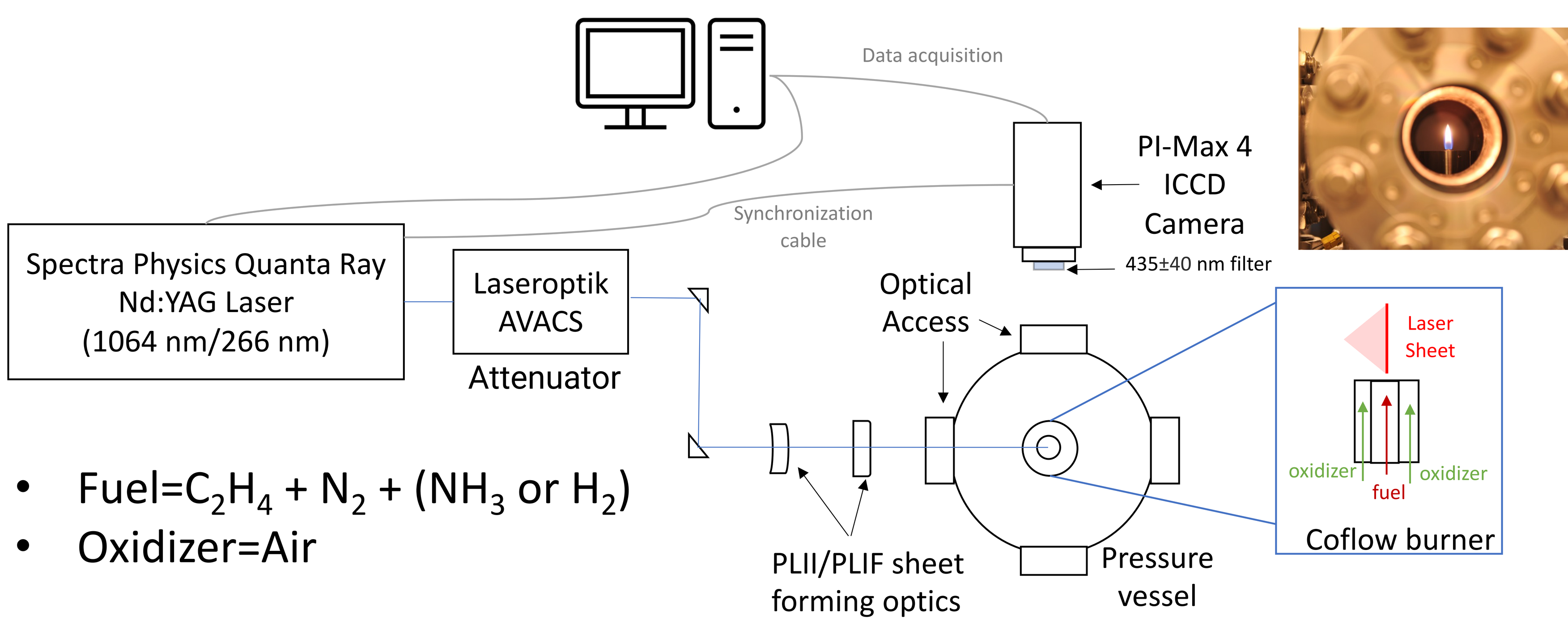
INVESTIGATION OF THE INFLUENCE OF AMMONIA AND HYDROGEN ADDITION ON SOOT FORMATION IN CO-FLOW LAMINAR DIFFUSION FLAMES

Faruk Y. Aydin, Yujia Wu, Peng Liu, Carson Chu, William L. Roberts
Clean Combustion Research Center, King Abdullah University of Science and Technology (KAUST), Saudi Arabia
Contact: ***faruk.aydin@kaust.edu.sa***

MOTIVATION

- Ammonia and hydrogen are promising carbon free fuels that can be produced by using renewable energy sources in the future. Ammonia has higher volumetric energy density than liquid hydrogen. Ammonia is also easier to store and transport. Infrastructure is well established. Poor combustion characteristics limit ammonia use as a fuel.
- Co-firing ammonia with hydrocarbon fuels could enable wider use in combustion applications and help lower CO_2 emissions. When co-firing, soot production must also be considered as soot is a harmful pollutant. Experiments can help validate mechanisms and soot formation models.
- In this study, we will provide a comparison between ammonia and hydrogen addition to ethylene–air diffusion flame to investigate the effects on soot formation .

METHODS



- Fuel=$C_2H_4 + N_2 + (NH_3 \text{ or } H_2)$
- Oxidizer=Air

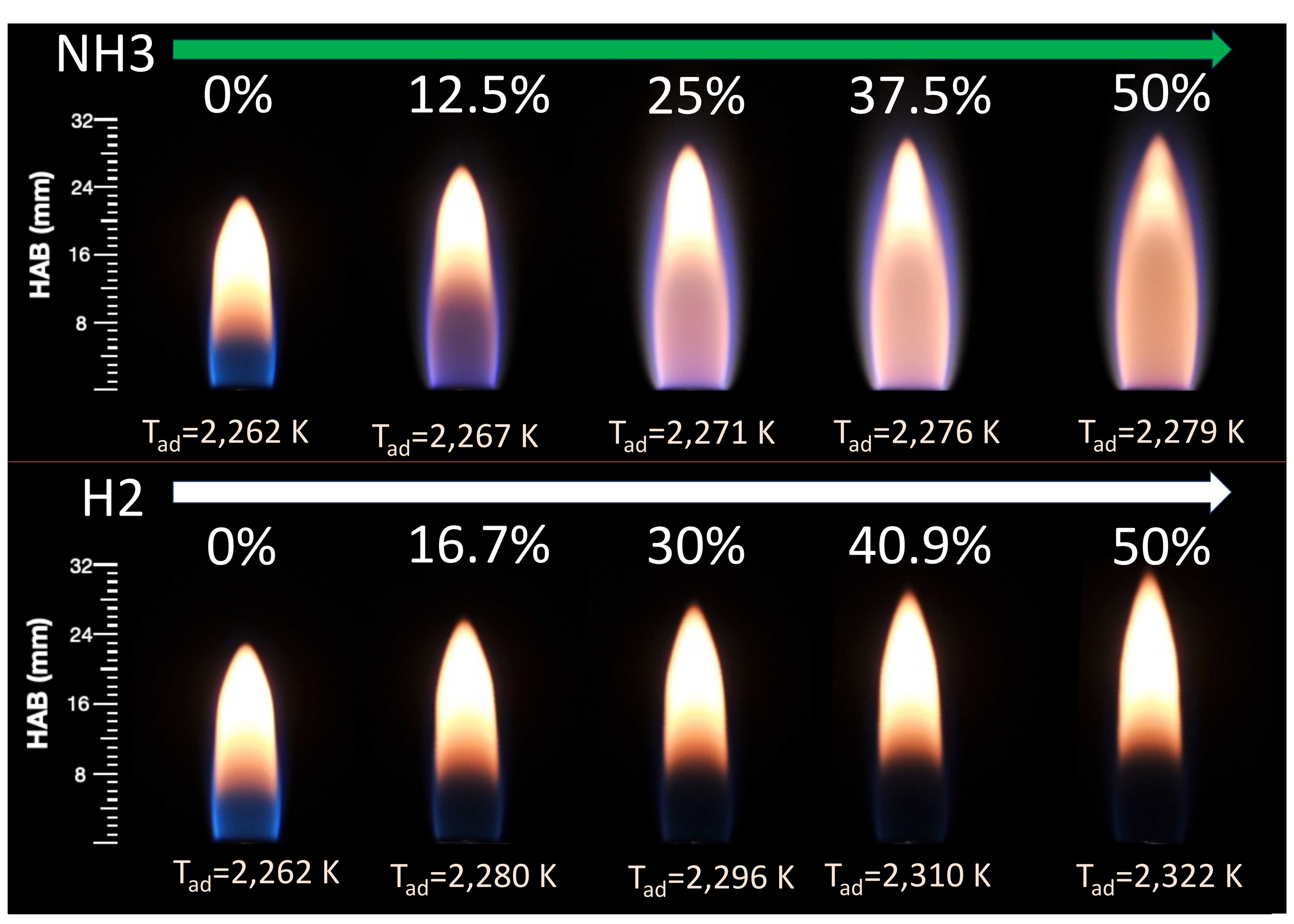
Laser measurement setup for co-flow burner inside the pressure vessel

Temperature: Type S thermocouple (PtRh-10%/Pt) is inserted into the flame at different locations. Temperature is averaged over 20 s at each location. Temperature profiles help reveal soot deposition zones [1].

Qualitative PAH: Planar LIF technique captures signal from excited PAHs in the flame using a lower energy 266nm laser ~3.5 mJ. Fluorescence signals from 3-4 ring PAHs and larger PAHs were captured using 400,450 and 500 nm bandpass filters respectively [2,3].

Soot volume fraction (SVF): Planar LII is used to heat soot particles with high energy laser pulses ~25 mJ. ICCD camera with 435nm BP filter captures the incandescence signal from heated soot particles. LII is calibrated to previous 2D LOSA measurements to calculate SVF [4].

Soot Particle Size Distribution: Soot particles are sampled from the flame with a quartz probe at different locations along the centerline. After a two-stage dilution, particles are sent to the SMPS to measure size and number concentration. (work in progress)



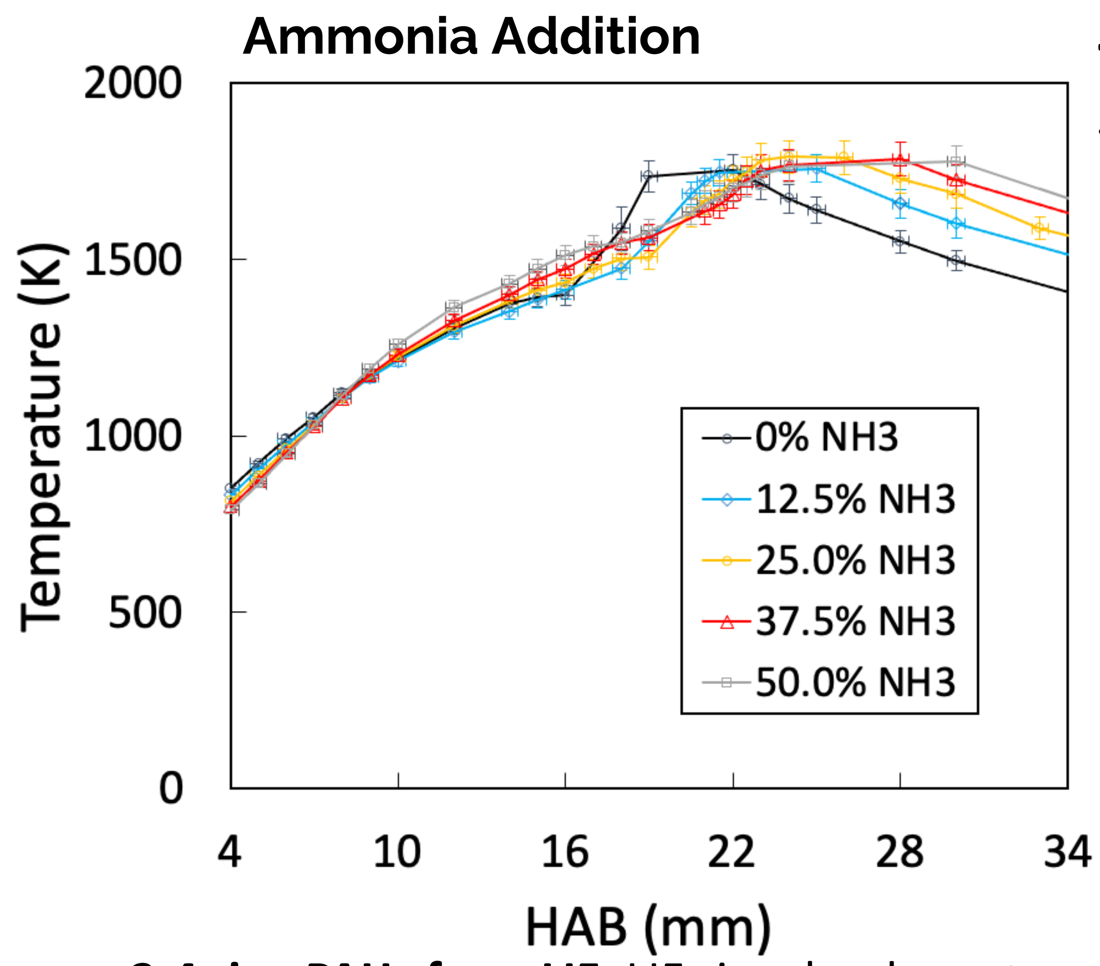
Approach for choosing the conditions: Maintain the same molar balance for carbon while varying N_2 and NH_3 or H_2 flow rates

$$Q_{fuel\ mix} = Q_{C2H4} + Q_{N2} + Q_{NH3\ or\ H2}$$

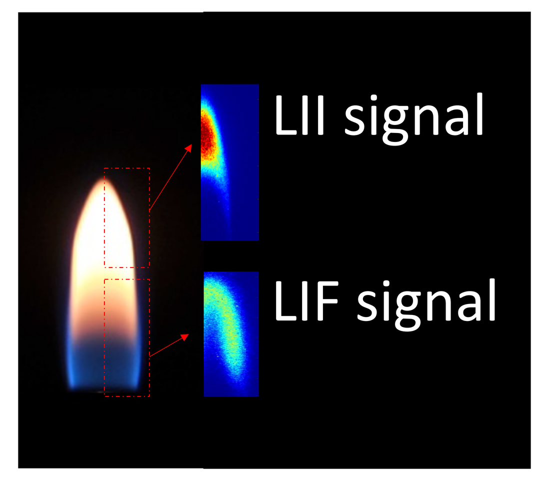
$$\frac{Q_{NH3\ or\ H2}}{Q_{fuel\ mix}}$$

Tested flame conditions for the study. Conditions are shown as a function of the fraction of added NH_3 (top) or H_2 (bottom) in the fuel flow.

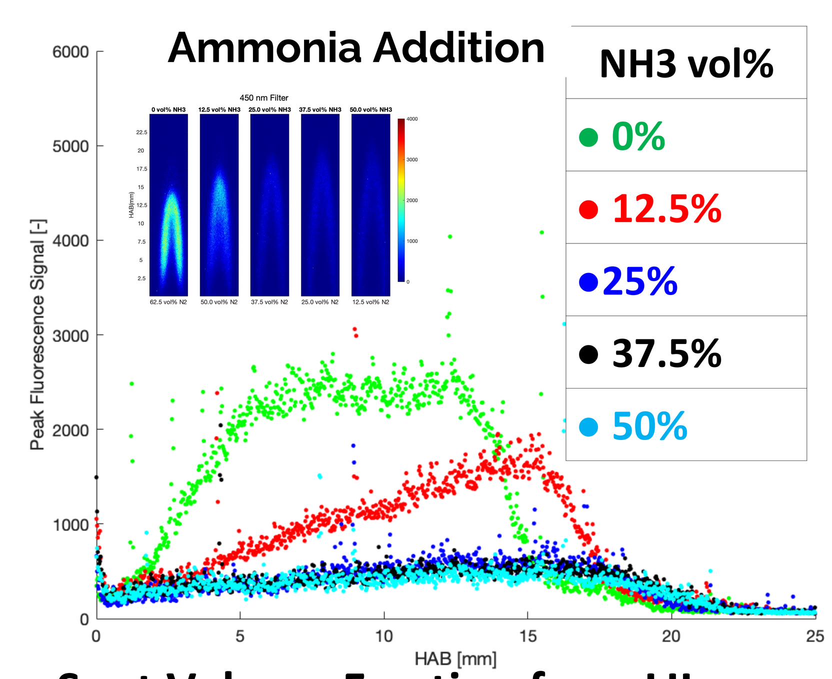
RESULTS

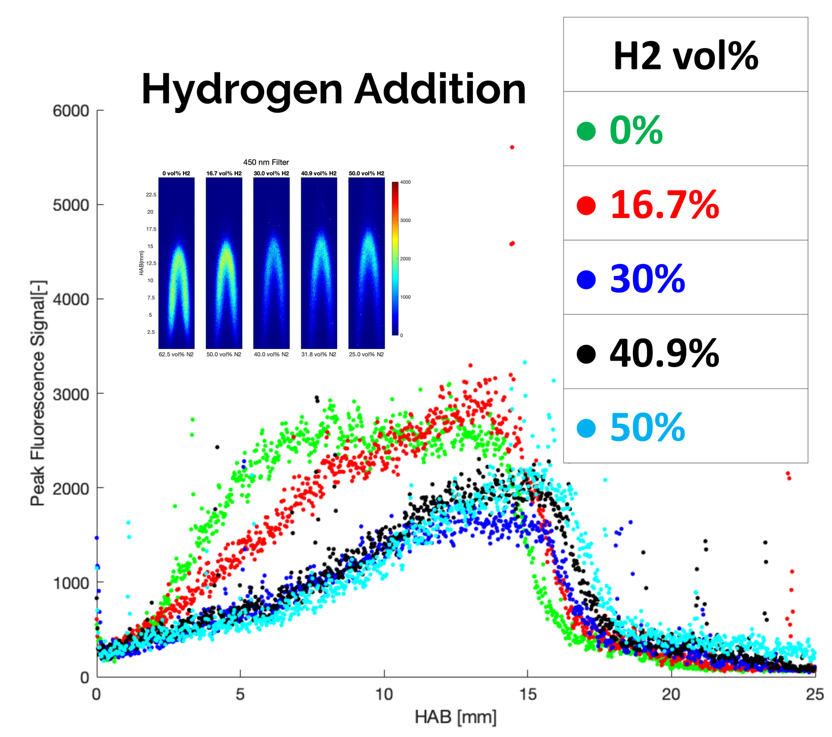


Temperature: Dips in the profile occur up to 25% NH_3. Profile gets smoother with ammonia addition.

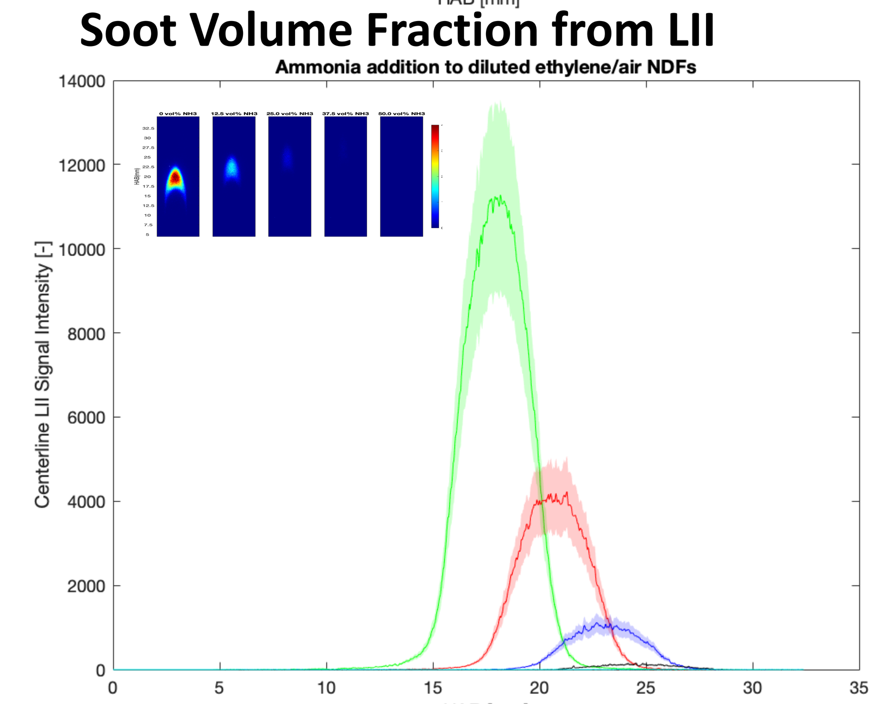


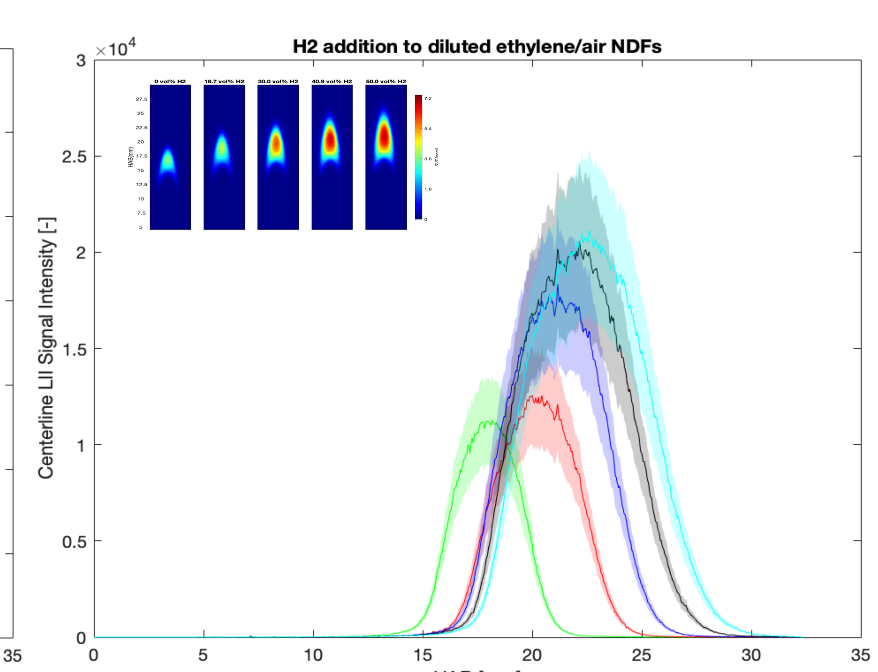
3-4 ring PAHs from LIF: LIF signal reduces to minimum levels by 25% NH_3 addition.





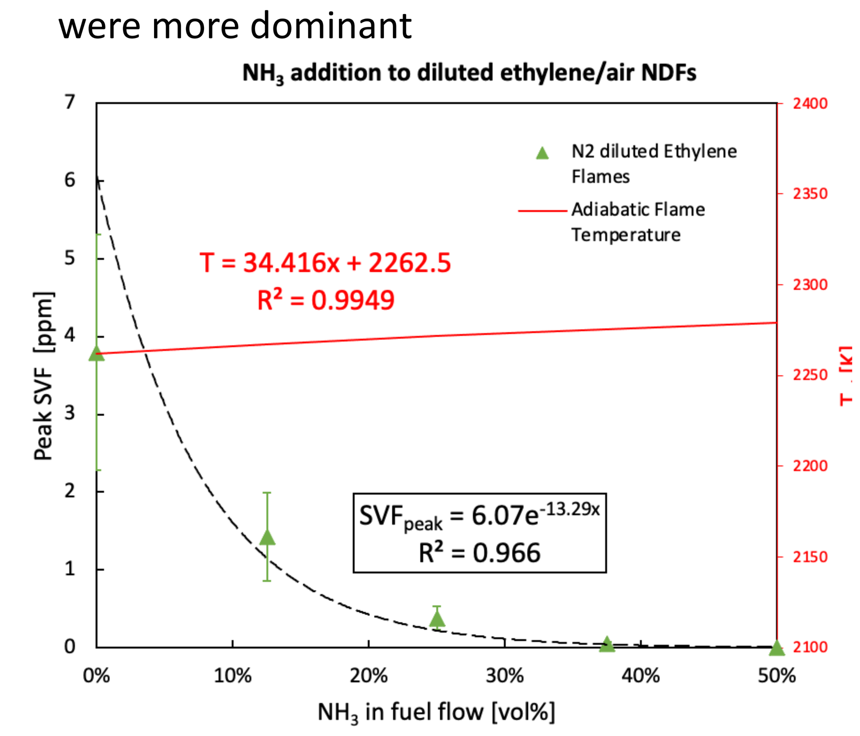
Soot Volume Fraction from LII

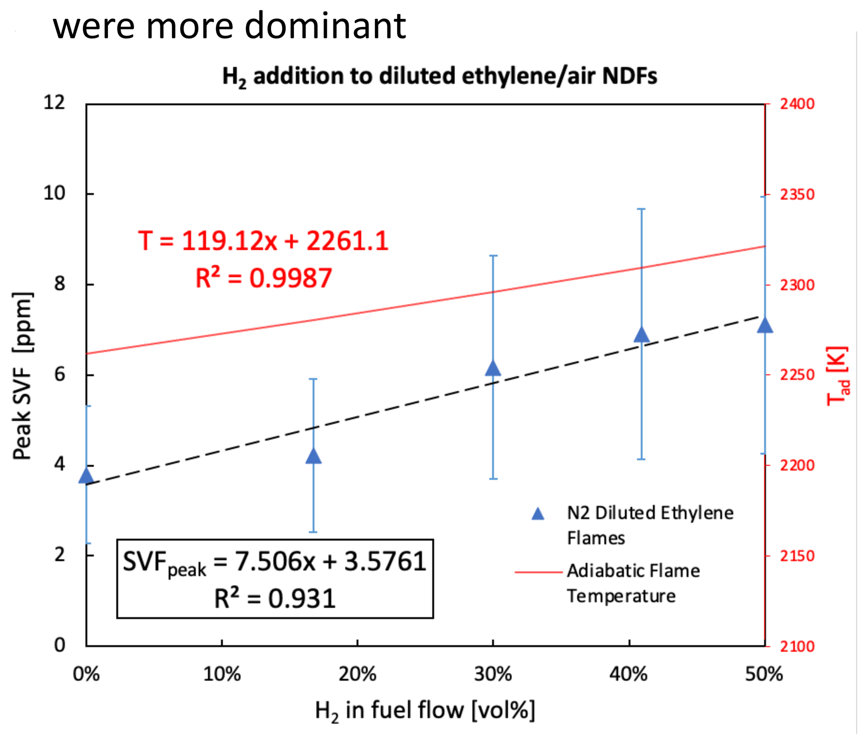




Ammonia addition: chemical effects were more dominant

Hydrogen addition: thermal effects were more dominant





CONCLUSION

- Soot volume fraction decays exponentially with ammonia vol% .
- Soot volume fraction increases linearly with hydrogen vol%.
- PAH-LIF signal reaches a minimum by 25% ammonia in fuel flow.
- PAH-LIF measurements in hydrogen addition cases were affected by quenching due to the increase in flame temperature.

REFERENCES

[1] Y.R. Tan, M. Salamanca, L. Pascazio, J. Akroyd, M. Kraft, The effect of poly(oxymethylene) dimethyl ethers (PODE3) on soot formation in ethylene/PODE3 laminar coflow diffusion flames, Fuel 283, 2021, 118769.
[2] A.M Bennett, P. Liu, Z. Li, N.M. Kharbatia, W. Boyette, A.R. Masri, W.L. Roberts, Soot formation in laminar flames of ethylene/ammonia, Combustion and Flame 220, 2020, 210-218.
[3] P. Liu, J. Guo, H.G. Im, W.L. Roberts, The effects of CO2/CH4 ratio on soot formation for autothermal reforming of methane at elevated pressure, Combustion and Flame, 2022, 112379.
[4] A.M. Bennett, H.M.F. Amin, E. Cenker, W.L. Roberts, Measurements of Pressure Effects on PAH Distribution and 2D Soot Volume Fraction Diagnostics in a Laminar Non-premixed Coflow Flame, Energy Fuels 32(10) , 2018, 10974-10983.
[5] M.J Montgomery, H. Kwon, J.A.H Dreyer, Y. Xuan, C.S McEnally, L.D Pfefferle, Effect of ammonia addition on suppressing soot formation in methane co-flow diffusion flames, Proceedings of the Combustion Institute 38(2), 2021, 2497-2505.

Acknowledgements: This work is supported by KAUST Competitive Research Grants (URF/1/4688-01-01)