Near-field study of oxy-methane non-premixed jet flame at elevated pressures

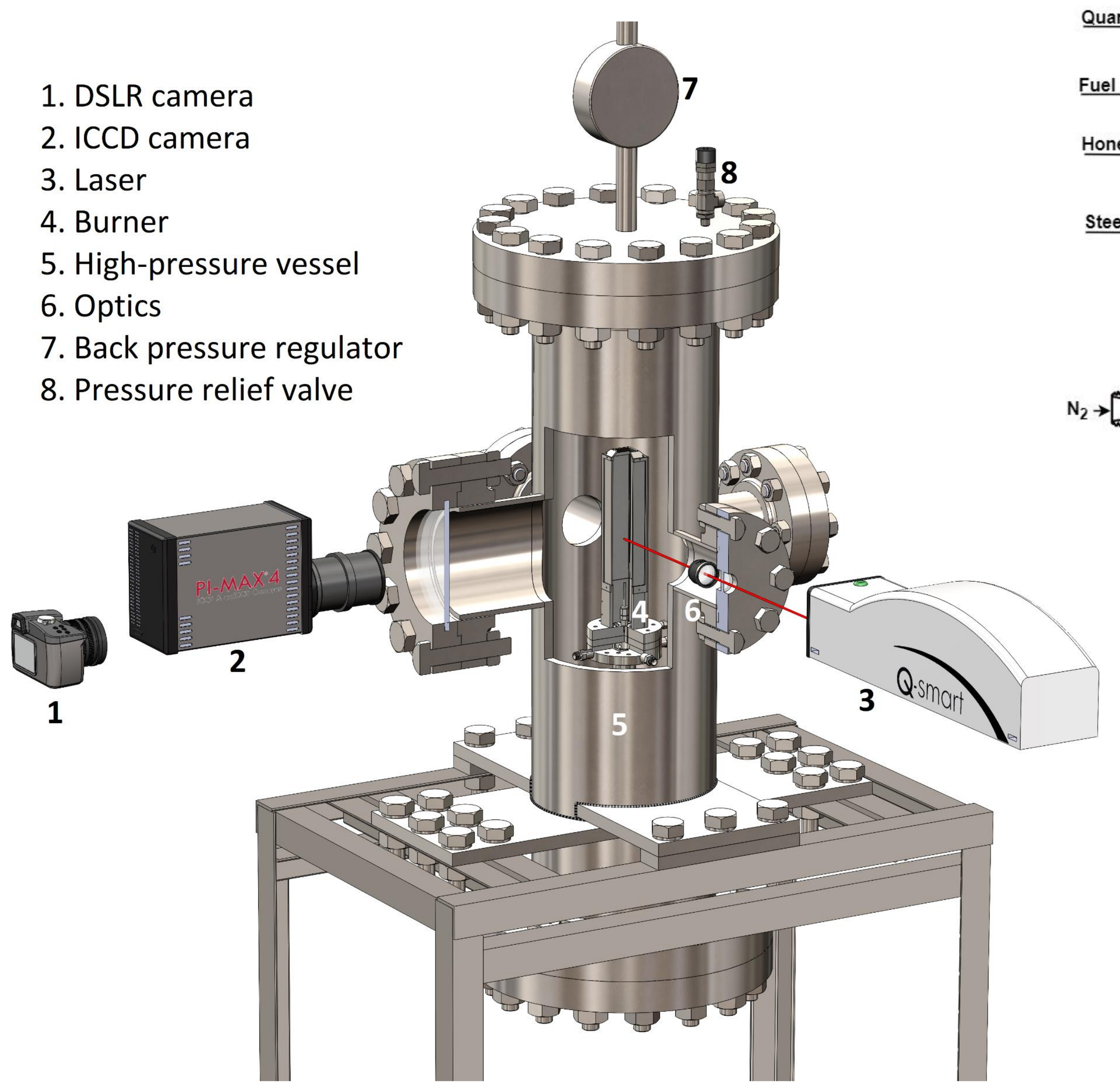
Suman Basnet, Muhammad Bukar, Bin Wu, Gaetano Magnotti
CCRC, KAUST, Thuwal, Saudi Arabia

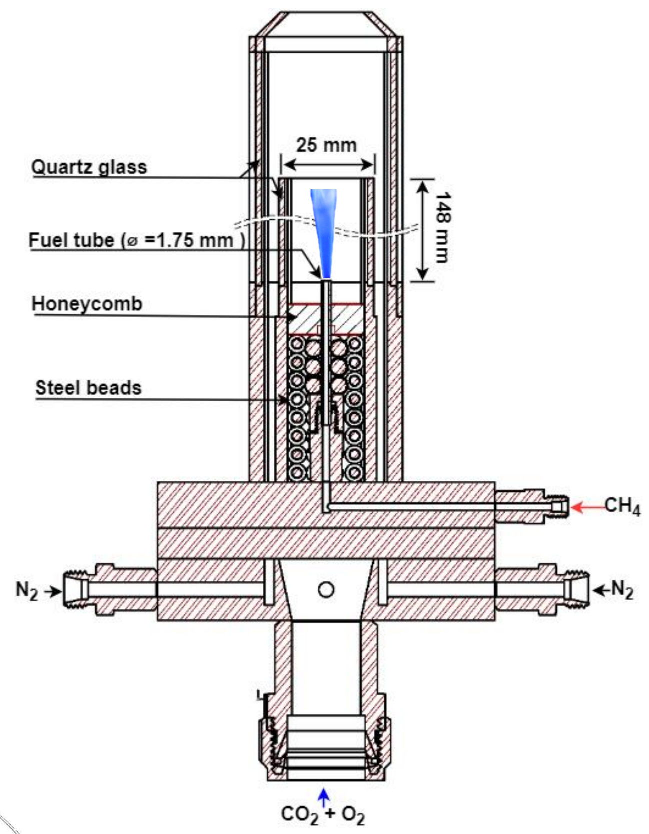
Introduction

- Among promising Carbon Capture and Storage (CCS) technologies, the novel industrial thermodynamic cycles such as the Allam cycle [1] and the semi-closed oxy-fuel combined cycle (SCOF-SS) [2] involve high-pressure oxy-fuel combustion, drawing attention from a practical point of view for more fundamental studies.
- CH* is one of the most studied short-lived species to characterize the flame, producing the strongest chemiluminescence peak at 431 nm ($A^2\Delta - X^2\Pi$).
- The jet-in-coflow burner is used as a canonical configuration to investigate oxy-fuel combustion in a high-pressure setting.
- For this study, the peak intensity of CH* radicals, which are generated in the reaction region, is considered a flame front. CH* chemiluminescence signal of CO_2 diluted oxy-methane flame is obtained in the near-field region of the flame for different fuel jet velocity and pressure levels.

Experimental setup and method

- The jet-in-coflow burner is placed inside the high-pressure vessel capable of operating at a maximum pressure of 40 bar. The ignition is achieved with a Q-smart pulse laser source with maximum energy of ~850 mJ. Flame images from DSLR and ICCD (PI-MAX4) cameras are used to characterize the near-field of the flame.
- The ICCD camera is mounted with f = 105 mm UV lens (with a resolution of 0.029 mm/pixel) and a narrow band-pass filter (430 ± 10 nm) to capture CH* signals at 431 nm. The gate width and gain are kept at 3 ms and 70 respectively. It is worth mentioning that, the obtained CH* signal also includes the contribution from CO_2^* background emission which isn't corrected for in this study and will be included in future work.
- The obtained line-of-sight integrated images from the ICCD camera are subjected to the Abel deconvolution [3] method to obtain the two-dimensional spatial distribution of the CH* chemiluminescence intensity about the center axis.





Experimental condition

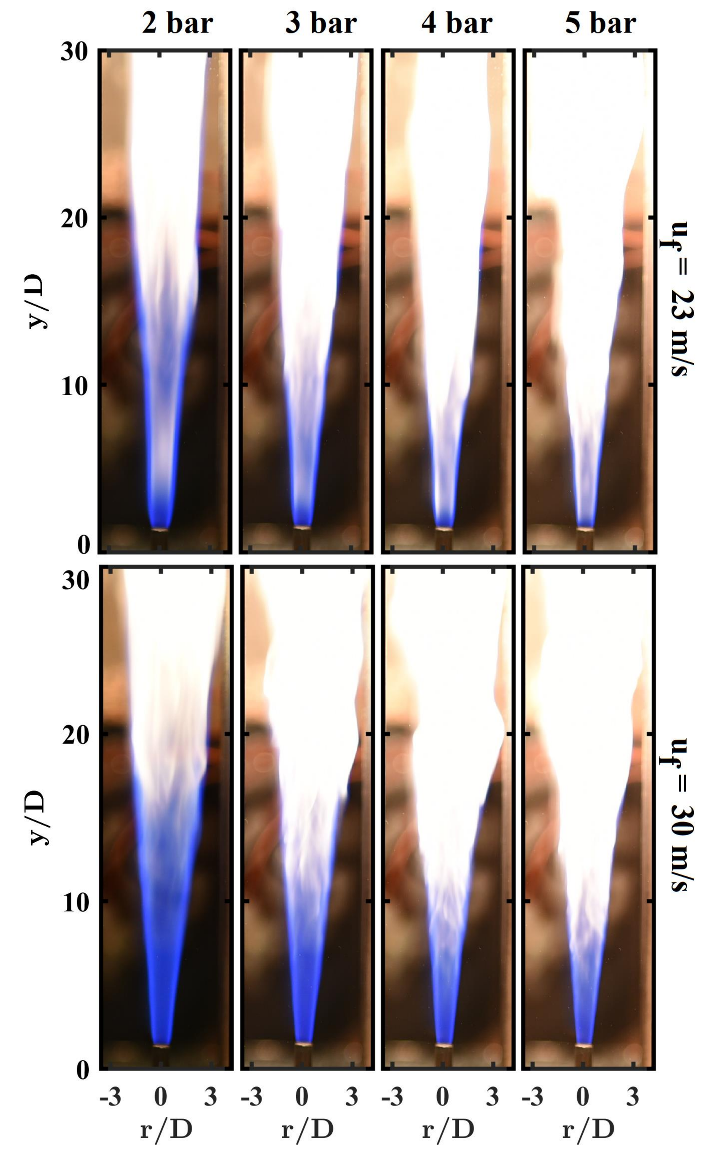
- Two series of experiments are carried out, one at constant fuel velocity and another at constant fuel Reynolds number, both as a function of increasing pressure up to 5 bar. O_2/CO_2 composition in the co-flow is 40/60 for both series.
- Increasing pressure from 2 bar to 5 bar caused the flame stability to reduce by ~7 %. Thus, the fuel velocities in constant velocity series are chosen to achieve stable turbulent flames for all pressures considered in the experiment.

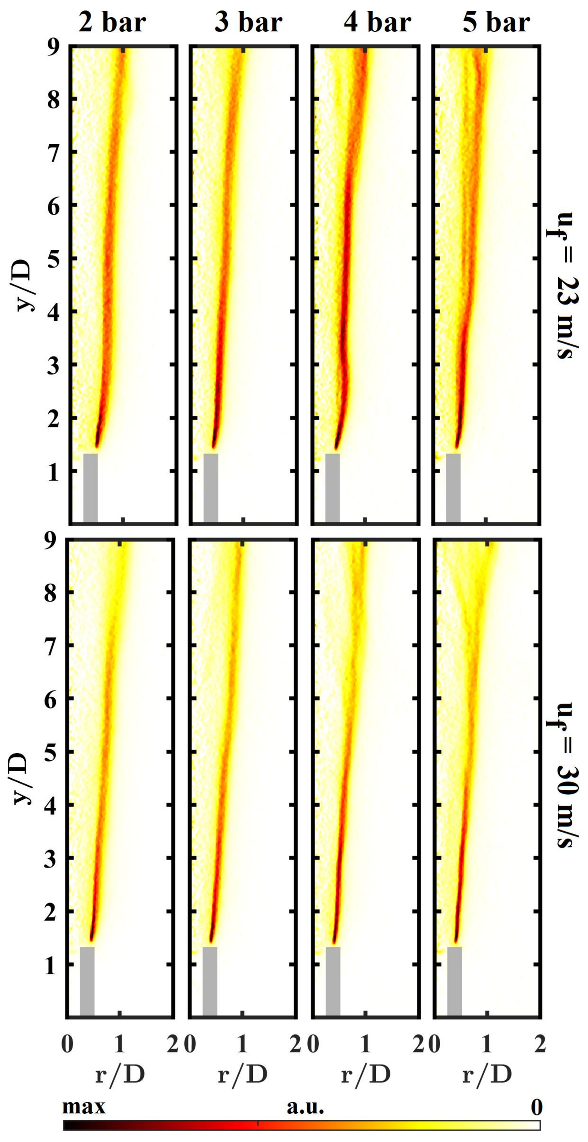
P [bar]	Constant Velocity								Constant Re				
	u_{cf} [m/s]	u_f = 23 [m/s]				u_f = 30 [m/s]			u_f [m/s]	Re_f	u_{cf} [m/s]	P [kW]	ϕ
		Re_f	P [kW]	ϕ		Re_f	P [kW]	ϕ					
2	0.35	4600	6.5	1.3	. . .	6000	8.5	1.7	37.5	7500	0.87	10.62	0.9
3		6900	9.7			9100	12.7		25.0		0.58		
4		9300	13.0			12100	17.0		18.7		0.44		
5		11600	16.3			15100	21.2		15.0		0.35		

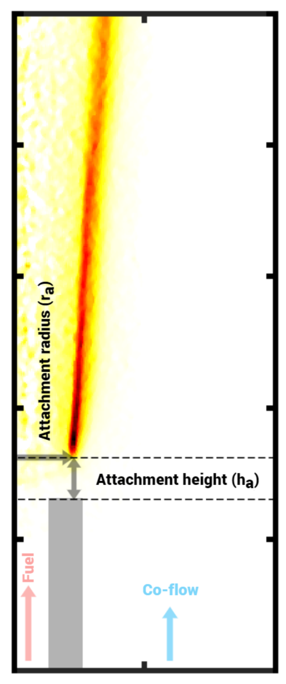
Results

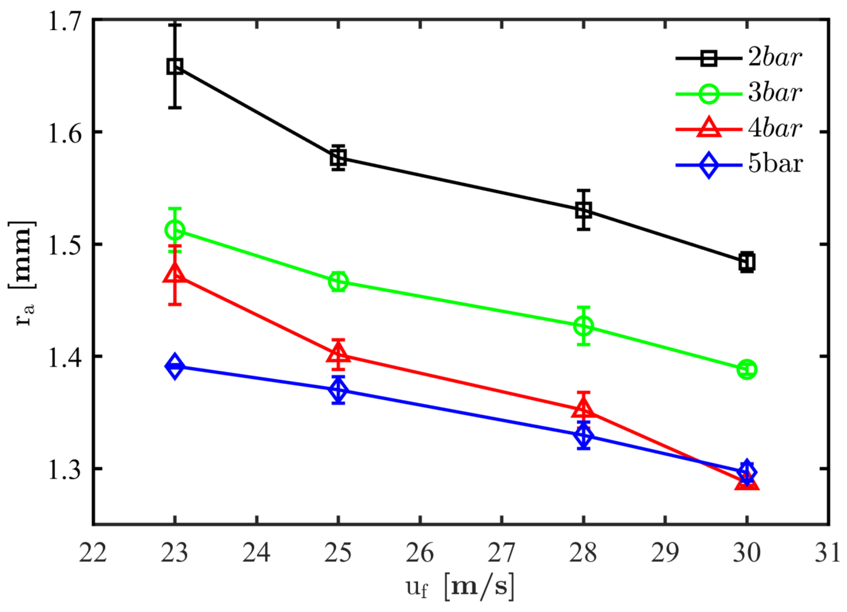
Constant Velocity:

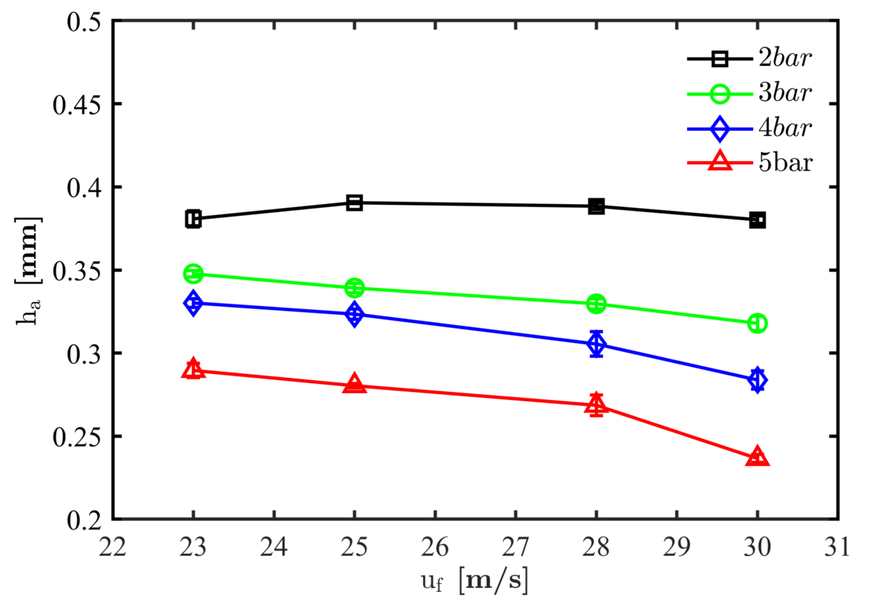
- Sooting propensity increases with increasing pressure. Increased mixing due to an increase in the fuel velocity caused the soot to be more localized in the downstream region of the flame.
- As pressure increases, the flame is stabilized closer to (both axial and radial) the location of the fuel tube.





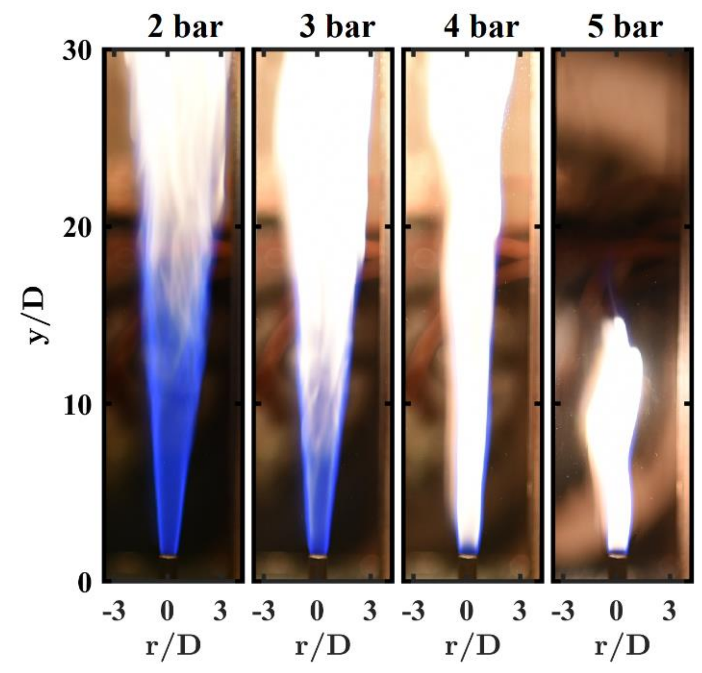


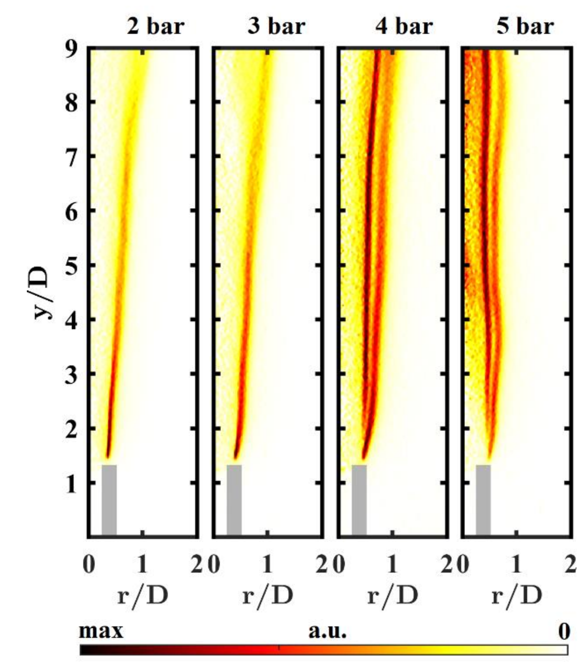


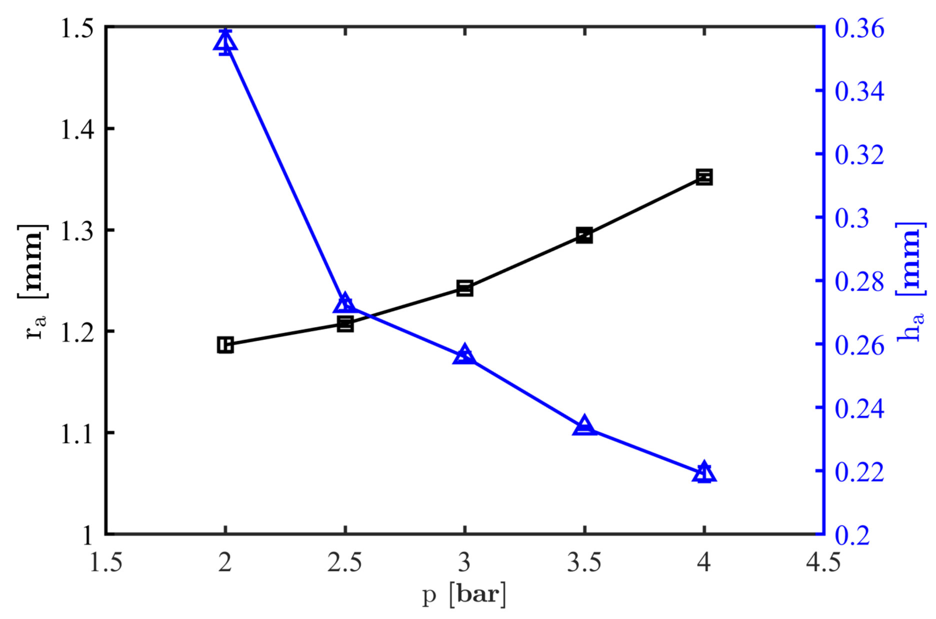


Constant Reynolds number:

- Soot level tend to increase more rapidly with pressure while also causing the flame to be more buoyancy driven.
- As pressure increases, the flame is stabilized closer in axial location but farther away in radial location from the fuel tube.







Future work

- Correction technique to subtract CO_2^* from CH* signal will be employed.
- Laser-Induced Incandescence (LII) will be used to quantify the soot volume fraction at elevated pressures.

References

- Rodney Allam, et al., Energy Procedia (2017) 5948-5966.
- Hanne M. Kvamsdal, et al., Energy (2007) 0360-5442.
- J. Canny, IEEE Trans. on pattern analysis and MI (1986) 8-679.

Acknowledgement

This work is supported by funding from the King Abdullah University of Science and Technology (KAUST).