TNF target flame: Lean premixed turbulent H_2/air jet flames at atmospheric pressure

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Introduction

The piloted jet flames are designed to provide insights into macroscopic and microscopic flame structures of hydrogen/air combustion under fuel lean conditions at atmospheric pressure. The equivalence ratio of the pilot and jet flow are identical to have purely premixed conditions avoiding fuel stratification. Secondary air mixes into the flow downstream of *x*/D = 20. For this reason, the measurements are focusing on axial positions below *x*/D = 14. Macroscopic flame properties include information on the flow field, and the flame topology, as measured by PIV and OH-PLIF. Microscopic flame properties include information on thermochemical states (temperature and main species) and local flame topology, measured simultaneously by 1D Raman/Rayleigh and 2D Rayleigh scattering. The operational conditions include a wide range of Reynolds numbers (jet exit) from 28,000 to 55,000 and Karlovitz numbers from 100 to 7,600 (at flame position). Dependent on the equivalence ratio, effective Lewis numbers were 0.356, 0.372, and 0.370. The study provides quantitative information on how flame structures are influenced by competing effects of turbulence and molecular transport.

Experimental setup and geometry

Figure 1 shows a schematic of the piloted turbulent jet burner, which is based on the McKenna burner. The burner consists of a concentric jet nozzle with an inner diameter of *D* = 4.5 mm, a concentric central porous sintered stainless steel pilot plate (outer diameter 60.5 mm), and an outer porous sintered bronze coflow annulus. The pilot and coflow areas have a porosity of approximately 0.4. The pilot porous block was water cooled for homogeneous inflow temperature conditions. Nitrogen was used as a shielding coflow to minimize cold air entrainment.

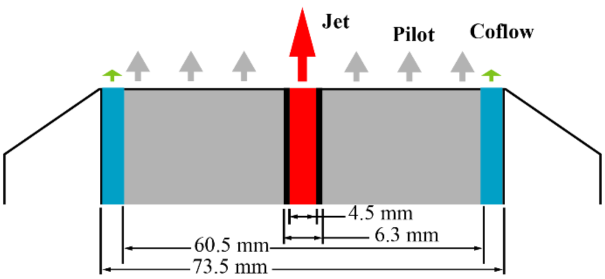

Figure 1 Schematic of the piloted turbulent jet burner

Operation conditions

Premixed fuel lean jet flames have been investigated for a wide range of Reynolds and Karlovitz numbers. For this purpose, the equivalence ratio and the jet bulk velocity have been varied. Table 1 provides an overview of the operational conditions.

Table 1. Flow configuration and properties of lean premixed H_2/air turbulent flames.

Case	ϕ_{global} (-)	U_0 (m/s)	x/D	U_{pilot} (m/s)	Le	T_{ad} (K)	S_L (m/s)	l_F (mm)	U'_C (m/s)	U'_F (m/s)	l (mm)	Ka_C	Ka_F	$Re_{T,F}$	Re
H100P040U050	0.4	50	7	2.5	0.372	1427	0.24	0.6	2.4	5.9	4.4	10	50	70	13820
H100P040U100	0.4	100	7	2.5	0.372	1427	0.24	0.6	5.1	17.4	3.7	40	260	130	27640
H100P040U150	0.4	150	7	2.5	0.372	1427	0.24	0.6	8.1	28.1	3.6	85	545	200	41460
H100P030U100	0.3	100	7	2	0.356	1188	0.04	2.2	6.0	17.6	3.2	1530	7690	220	28060
H100P045U100	0.45	100	7	2.5	0.379	1538	0.39	0.5	5.4	17.1	3.9	20	100	115	27435
H100P040U200	0.4	200	3.5	2.5	0.372	1427	0.24	0.6	7.0	30.3	2.9	75	680	140	55280
	0.4	200	7	2.5	0.372	1427	0.24	0.6	9.3	33.9	3.5	105	730	230	55280
	0.4	200	10.5	2.5	0.372	1427	0.24	0.6	10.8	36.9	4.0	125	775	300	55280
	0.4	200	14	2.5	0.372	1427	0.24	0.6	12.5	35.8	4.6	140	690	400	55280

Diagnostics

Macroscopic flame properties were measured by simultaneous 2C-PIV and OH-PLIF imaging at 10 Hz, following a standard approach as detailed in [1,2]. For OH-PLIF, OH radicals were excited in the linear regime at 283.01 nm using the $Q_1(6.5)$ line of the A-X(1-0) transition. The laser sheet was 25 mm high and 120 µm thick. The field of view spanned 24 × 32mm^2 with a projected pixel resolution of 23 µm. OH-PLIF images were shot-by-shot corrected for spatial inhomogeneities of the laser profile. For PIV measurements, the center jet was seeded with submicrons aluminum oxide tracer particles. The projected pixel size was approximately 16 µm. Simultaneous PIV and OH-LIF data were recorded at different downstream locations by step-wise moving the burner.

Microscopic flame properties were measured by simultaneous one dimensionally resolved Raman/Rayleigh spectroscopy combined with 2D Rayleigh scattering. Along a 6 mm long line, temperature and main species concentrations were measured quantitatively and the 2D Ryleigh provided quasi-simultaneously information on the local flame topology such as flame curvature. Detailed information on the experimental setup is provided in refs. [1,2]. Data evaluation is based on the hybrid matrix inversion method [3]. Experimental uncertainties are summarized in Table 2.

Table 2. Estimated precision and accuracy in temperature and mole fractions at representative flame conditions.

Scalar	Precision (%)	Accuracy (%)	Equivalence ratio ϕ (–)
T	1.3	2.0	1.0
ϕ	7.4	2.6	1.0
H_2	9.6	8.4	1.3
H_2O	3.0	2.0	1.0
N2	3.0	1.0	1.0

Exemplary results

Figure 2 shows time averaged chemiluminescence images of selected operational conditions. Horizontal lines highlight axial positions of the 1D Raman/Rayleigh measurements.

Figure 3 shows a side-by-side comparison of ensemble-averaged (left-hand-side half) and instantaneous (right-hand-side half) OH-LIF image pairs of lean premixed H_2/air turbulent flames at a constant global equivalence ratio ϕ_{global} of 0.4 and increasing bulk velocity U_0 from 50m/s to 200 m/s.

Figure 4 exemplifies insights into the microscopic flame structure showing conditional mean and rms values of the mole fractions of H_2 and H_2O and the equivalence ratio as function of the temperature.

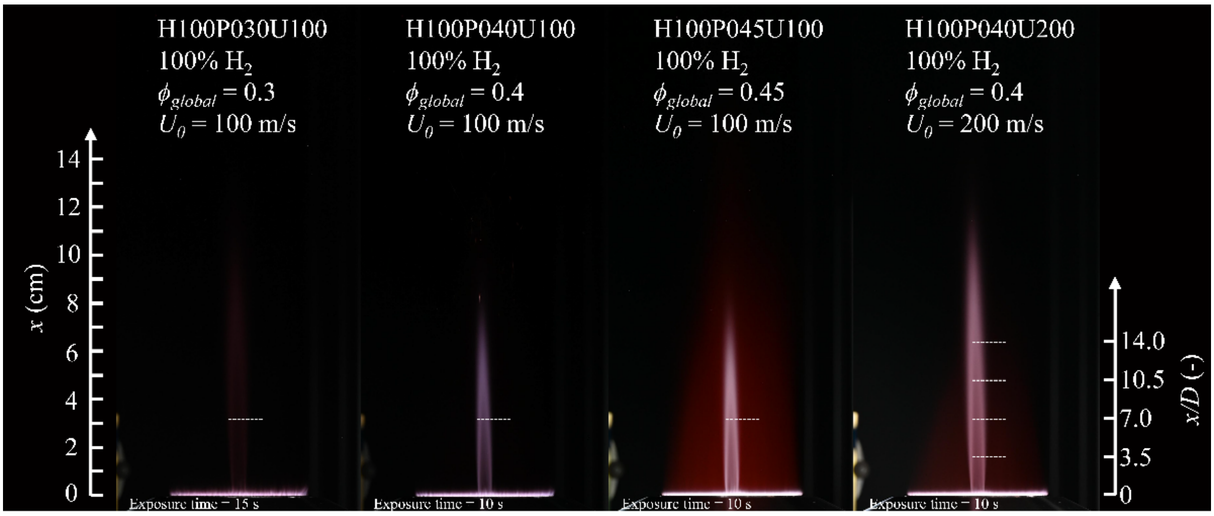

Figure 2 Chemiluminescence images of selected lean premixed H_2/air flames listed in Table 1

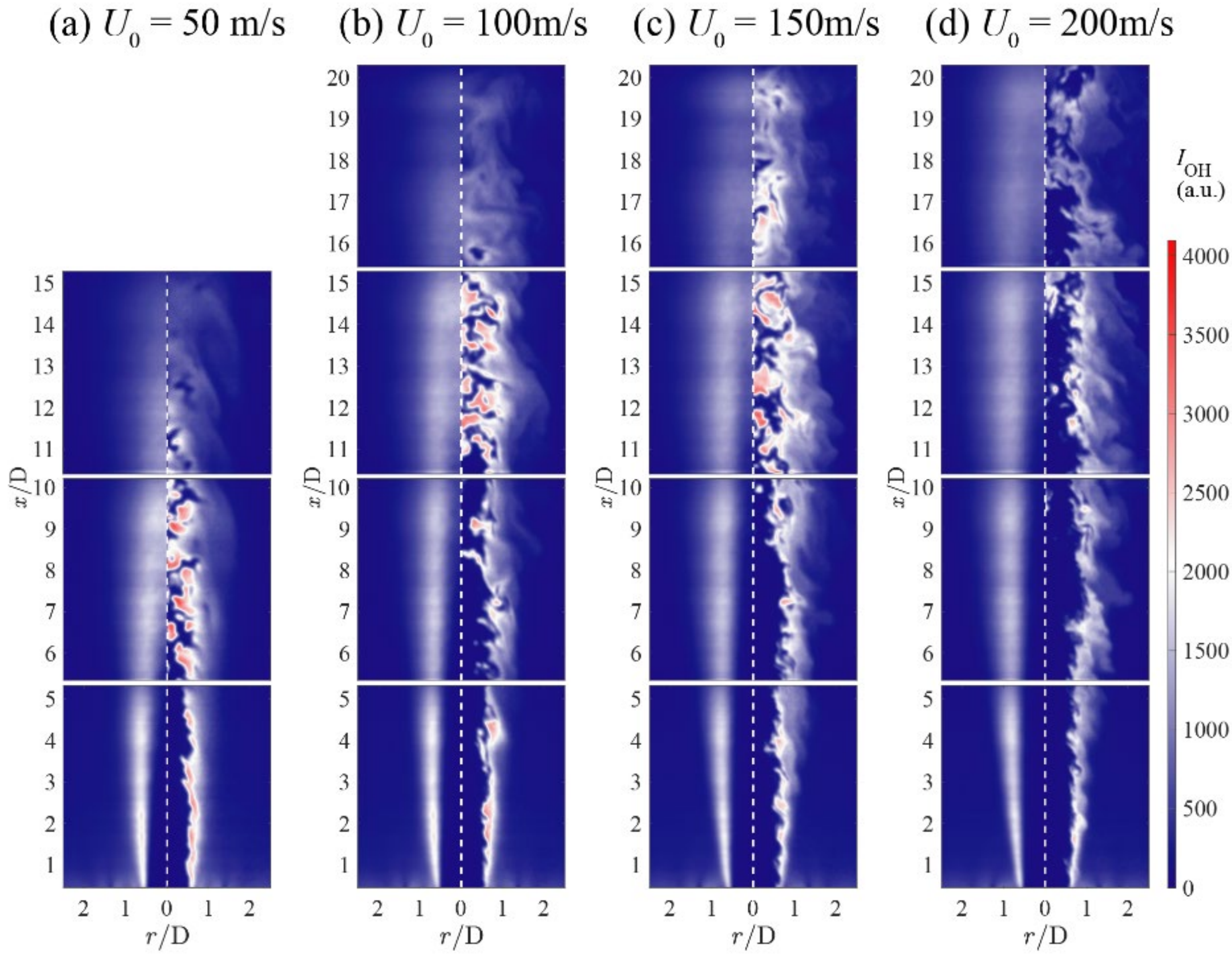

Figure 3 Side-by-side comparison of ensemble-averaged (left-hand-side half) and instantaneous (right-hand-side half) OH-PLIF image pairs of lean premixed H_2/air turbulent flames. Note that the OH-LIF intensity in (a) is doubled for a better visualization.

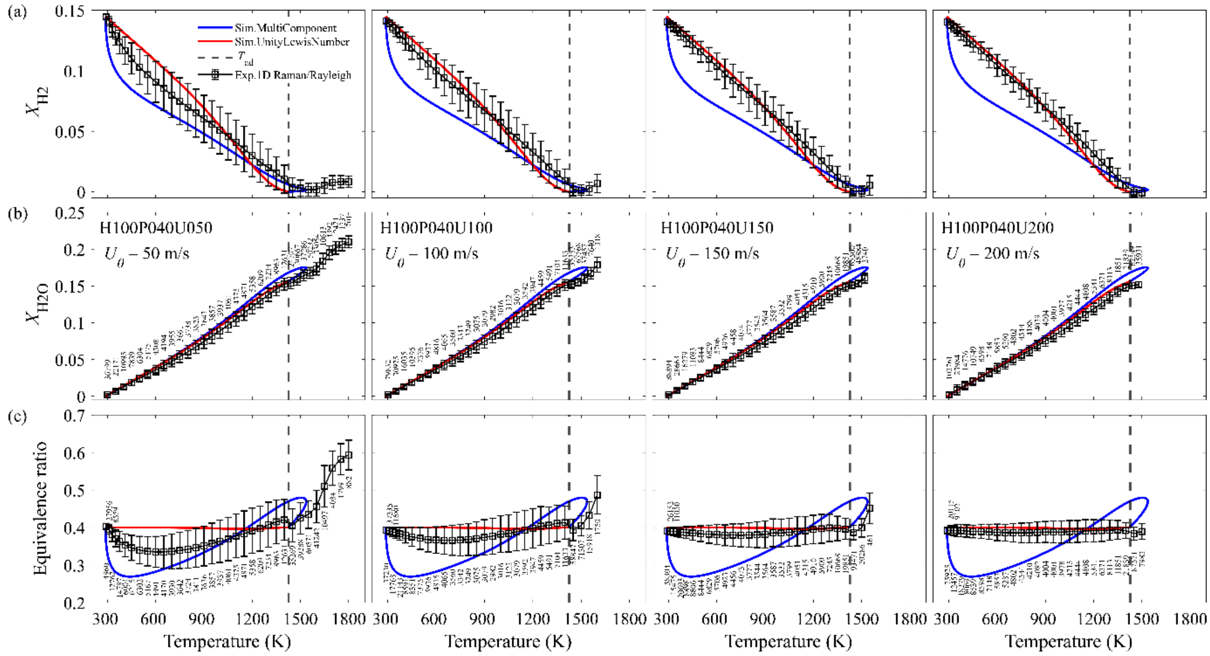

Figure 4 Conditional mean of H_2 mole fraction (a), H_2O mole fraction (b) and equivalence ratio (c) as function of temperature in lean premixed H_2/air turbulent flames with bulk velocities varying from 50 to 200 m/s. Numbers indicate the number of sample points in each temperature bin. Blue and red solid lines represent results from 1D flame simulations with detailed chemistry, but different transport models as indicated in the insert.

How to get access to the data

Upon request. Contact Dr. Tao Li (tao.li@rsm.tu-darmstadt.de) or Prof. Andreas Dreizler (dreizler@rsm.tu-darmstadt.de).

References

[1] S. Shi, R. Schultheis, R.S. Barlow, D. Geyer, A. Dreizler, T. Li, R. Schultheis, Assessing turbulence-flame interaction of thermo-diffusive lean premixed H_2/air flames towards distributed burning regime, Combust. Flame 269 (2024) 113699.

[2] S. Shi, R. Schultheis, R.S. Barlow, D. Geyer, A. Dreizler, T. Li, Internal flame structures of thermo-diffusive lean premixed H_2/air flames with increasing turbulence, Proceedings of the Combustion Institute 40 (2024) 105225.

[3] Frederik Fuest, 1D Raman/Rayleigh-scattering and CO-LIF measurements in laminar and turbulent jet flames of dimethyl ether using a hybrid data reduction strategy, Darmstadt, 2011.