TNF target flame: Multi-regime turbulent H_2/air flames at atmospheric pressure

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Introduction

The Darmstadt H2-Multi-Regime Burner (H2-MRB) is designed to study multi-regime combustion of hydrogen and ammonia, where both premixed and non-premixed reaction zones coexist. This burner offers well-defined inlet mixture composition and thermal boundary conditions while enabling excellent optical access for advanced laser diagnostics. The MRB allows the study of fundamental combustion phenomena, including flame stabilization, turbulence-chemistry interactions, and the transition between combustion regimes. Recent modifications have extended its capabilities to hydrogen and hydrogen-methane mixtures, allowing for the study of practical challenges present in Rich-Quench-Lean combustors such as high burning velocities, flame flashback, and thermodiffusive instabilities [1–3]. Here we present experimental insights into both macroscopic and reaction zone structures of three different fuel-rich multi-regime flames. Macroscopic flame properties include data on the flow field and flame topology, as measured by PIV and OH-PLIF. Reaction zone properties include data of thermochemical states (temperature and main species) and local flame topology, measured simultaneously by 1D Raman/Rayleigh and 2D Rayleigh scattering.

Experimental setup and geometry

Figure 1 shows a schematic of the H_2 multi-regime burner (H2-MRB). The H2-MRB concept comprises a high-velocity fuel-rich or partially premixed jet with a 3 mm inner diameter (ID, denoted as D), surrounded by a first concentric annular slot (slot 1) featuring a 3.3 mm ID and a 7 mm outer diameter (OD). An inclined bluff body, angled at 26°, separates slot 1 from the second concentric annular slot (slot 2), delivering a lean air/fuel mixture. The inclination of the bluff body enables unhindered optical access close to the burner nozzle [1]. Note that the present design retains the jet and slot 1 dimensions of the original MRB [2] but reduces the dimensions of the bluff body and slot 2. The bluff body is kept at a constant temperature of 80°C by circulation of heated oil to provide well-defined boundary conditions. Air was used as a shielding coflow to minimize cold air entrainment.

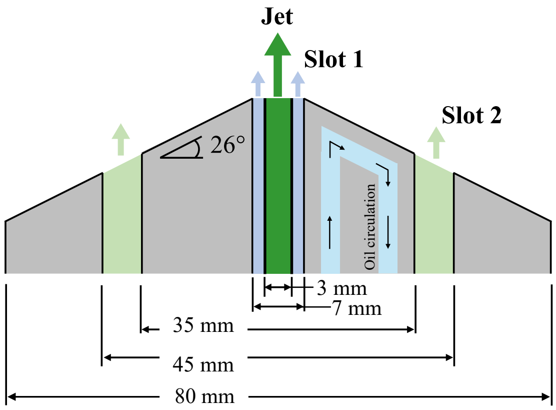

Figure 1 Schematic of the H_2-multi-regime burner. Rich/partially premixed H2/air jet, air in slot 1, lean premixed H2/air mixture in slot 2.

Operation conditions

Fuel-rich partially-premixed multi-regime flames were studied for a wide range of jet equivalence ratios ϕ_{jet} and slot 1 airflow velocities U_{slot1}. Table 1 provides an overview of the operating conditions and the respective measurement data available for each case. The general notation of the flames is defined as $H\alpha - \beta - \gamma - a/b$, where α represents the H_2 percentage in the fuel, β denotes ϕ_{jet}, and γ represents the equivalence ratio of slot 2 (ϕ_{slot2}). The suffix -a or -b denotes two different bulk velocities of slot 1, 7.5 m/s and 12.5 m/s, respectively [1]. In addition, the suffix -n indicates that, beyond the reactive cases, additional non-reactive cases were measured. In the non-reactive cases, the air mass flow in slot 1 and slot 2 has been replaced by nitrogen.

Table 1. Flow configuration of multi regime H_2/air turbulent flames.

Case	X_{H2} (-)	ϕ_{jet} (-)	U_{jet} (m/s)	ϕ_{slot1} (-)	U_{slot1} (m/s)	ϕ_{slot2} (-)	U_{slot2} (m/s)	OH-LIF	PIV	Raman/ Rayleigh
H100-140-026-a	100	1.4	105	0	7.5	0.26	20	X	X	X
H100-220-026-a	100	2.2	105	0	7.5	0.26	20	X	X	X
H100-350-026-a	100	3.5	105	0	7.5	0.26	20	X	X	X
H100-350-026-b	100	3.5	105	0	12.5	0.26	20	-	-	X
H100-900-026-b	100	9.0	105	0	12.5	0.26	20	-	-	X
H100-350-026-a-n	100	3.5	105	0	7.5	0.26	20	-	-	X
H100-350-026-b-n	100	3.5	105	0	12.5	0.26	20	-	-	X
H100-900-026-b-n	100	9.0	105	0	12.5	0.26	20	-	-	X

Diagnostics

The flow field and overall flame properties were measured by simultaneous 2C-PIV and OH-PLIF measurements at 10 Hz, following a standard approach as detailed in [4,5]. 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 burner (jet, slot 1 and slot 2) was seeded with aluminum oxide tracer particles with a diameter of 1-1.7 µm. The projected pixel size was approximately 16 µm. Simultaneous PIV and OH-LIF data were recorded at three different downstream locations by stepwise moving the burner vertically.

The scalar structure of the flame was measured by simultaneous one dimensionally resolved Raman/Rayleigh spectroscopy combined with 2D Rayleigh scattering. Along a 6 mm long focused laser beam, temperature and main species concentrations were measured quantitatively and the 2D Rayleigh provided quasi-simultaneous information on the local flame topology such as flame front curvature. Detailed information on the experimental setup is provided in refs. [4,5]. Raman/Rayleigh data evaluation is based on the hybrid matrix inversion method [6]. 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 dotted lines highlight axial positions of the 1D Raman/Rayleigh measurements.

Figure 3 shows the mean OH-PLIF images and flow streamlines of six different flame structures, allowing a side-by-side comparison of methane (left) and hydrogen (right) flame structures for three different jet equivalence ratios.

Figure 4 provides insight into the macroscopic flame structure by showing the radial profiles of temperature, the mole fractions of H_2, H_2O and O_2 and the local equivalence ratio along the spatial axis above the burner for different heights (x/D).

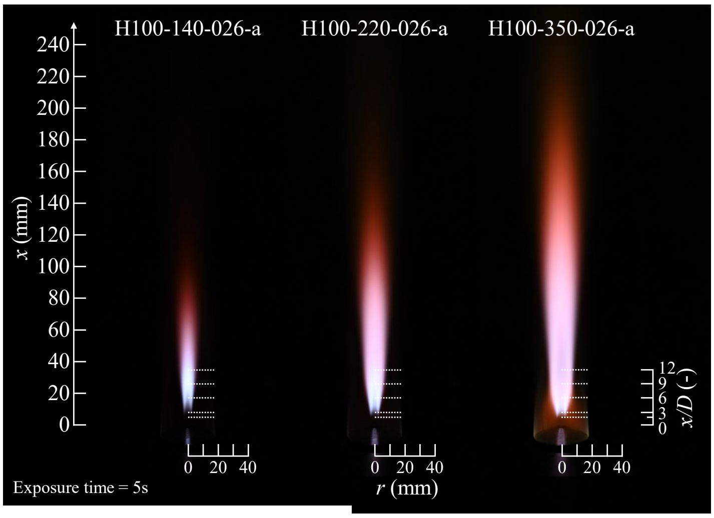

Figure 2 Chemiluminescence images of selected rich multi-regime H_2/air flames listed in Table 1

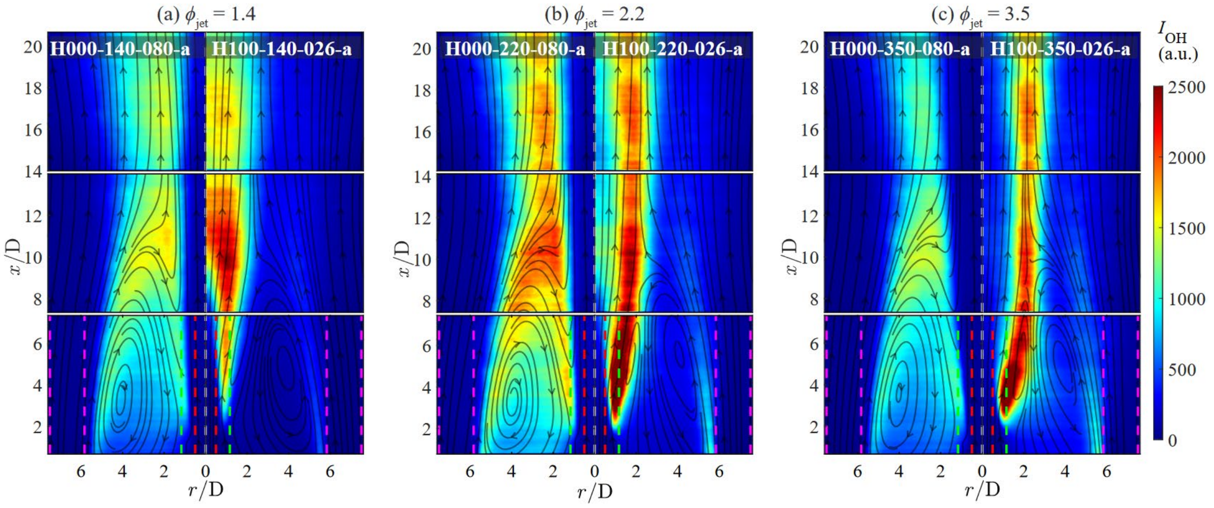

Figure 3 Side-by-side comparison of methane (left) and hydrogen (right) flame structures with increasing ϕ_{jet} of (a) 1.4, (b) 2.2, and (c) 3.5, superposed with flow streamlines.

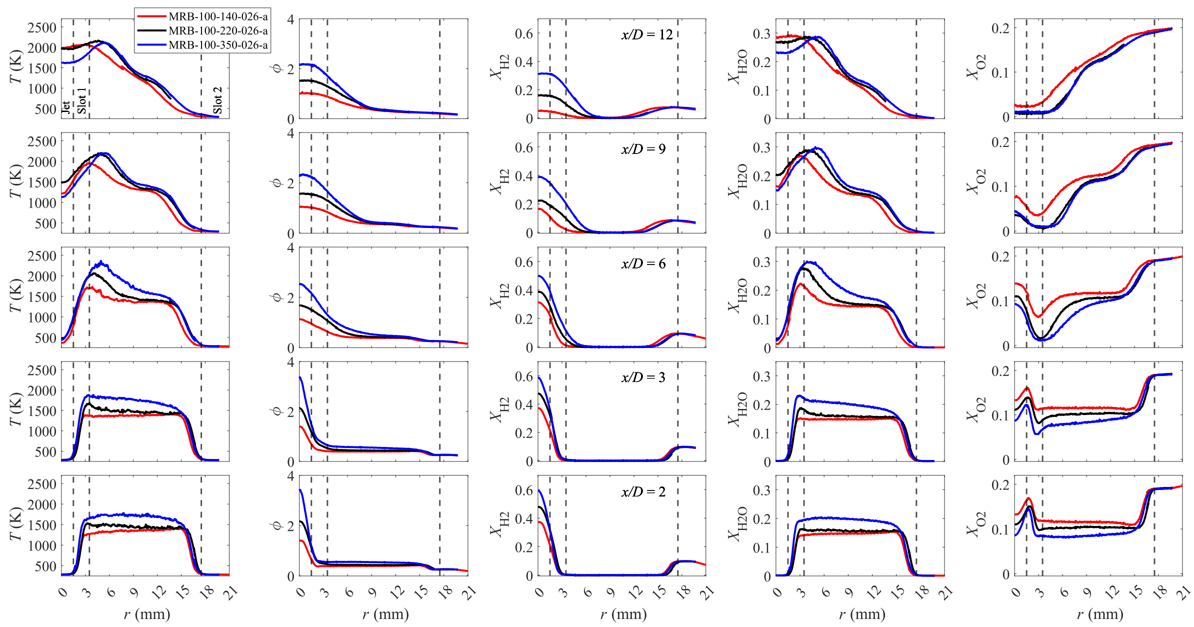

Figure 4 Mean of temperature, equivalence ratio, H_2 mole fraction, H_2O mole fraction and O_2 mole fraction along the spatial axis over the burner of selected rich multi-regime H_2/air flames with increasing height above burner from x/D=2 to x/D=12.

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).

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