Laser Doppler Velocimetry Measurements in Turbulent Non Premixed Hydrogen/Helium Flames

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1 Abstract

Laser Doppler Velocimetry (LDV) measurements (including the Reynolds Stress tensor) were conducted in a turbulent non premixed hydrogen flame. The hydrogen was diluted with 0%, 20% and 40% helium. The burner was a straight tube (inner diameter 3.75 mm) centered in a coflowing air stream. The flames were similar to the ones investigated by R.S. Barlow and C.D. Carter with Raman/Rayleigh/LIF at Sandia National Laboratories (Barlow and Carter, 1994).
Additionally simple heat flux measurements were performed and for illustration purposes integral video pictures were taken.

2 Boundary Conditions

Geometry The nozzle was a straight, 0.55 m long tube with an inner diameter of 3.75 mm and an outer diameter of 5 mm. It was centered in a vertical wind tunnel with a hexagonal base which had a diameter of 0.6 m. Two of the six tunnel walls were made of glass (Figure 1). To investigate the influence of the slightly different experimental setup of the ETHZ and Sandia, the geometry of the Sandia tunnel (fixed measurement volume, moveable flame and moveable wind tunnel with a square base of 0.3 m side length) was reconstucted for one measurment position. However, for the LDV measurements, no differences between the two setups were found.

Fuel The hydrogen was diluted with 0%, 20% and 40% helium. The mean exit velocities and Reynolds numbers are listed in Table 1. The fuel inlet temperature was 25 $^\circ \pm 1^\circ$ celsius.

Dilution %He	Mean velocity at the nozzle [m/s]	Reynolds number
0%	296 $\pm$ 1.5%	10'000
20%	294 $\pm$ 1.5%	10'000
40%	256 $\pm$ 1.5%	8'300

Table 1: Fuel inlet conditions

Coflow The velocity of the coflowing air at a temperature of 25 $^\circ$ celsius was 1 m/s. The turbulence intensity was about 10 %, and the mean velocity varied about 1.3 % over the radius.

3 Measurement Technique

Measurement Facility The velocity measurements were performed with a three/two dimensional Laser Doppler Velocimeter from Dantec (one channel got defective during the measurements). The LDV probes were perpendicular and a cross scattering technique was used, which reduced the measurement volume to nearly a spherical shape of 80 μm diameter. The probes were moved with a traverse of 0.05 mm repetition accuracy. Mean data rates varied from 800 Hz to 5 kHz, depending on the seeding density and the laser intensity. Temporarely the data rate raised up to several 10 kHz.
The Doppler frequency was analysed with Burst Spectrum Analyzers (BSA).

Data Analysis With a Shannon algorithm (Veynante and Candel, 1993) the non equal spaced raw data was remapped to a regularly spaced timebase. This procedure reduces LDV biases which occur due to higher measurement probabilities of faster seeding particles and due to conditional sampling. The reliability of the Shannon algorithm was shown by (Veynante and Candel, 1988) and (Flury and Schlatter, 1996). Based on the remapped data, Reynolds averaged mean, rms, and Reynolds Stress tensor components were calculated. Furthermore for the 20% dilution integral time scales were determined.

Radiation Measurements To estimate the radiative heat flux of the flame, a black plate (Figure 2) was moved along the flame at a radial distance of 0.3 m. The temperature of the plate was measured with a calibrated thermocouple. With an additional correction for the convective heat losses the emitted radiation could be determined.

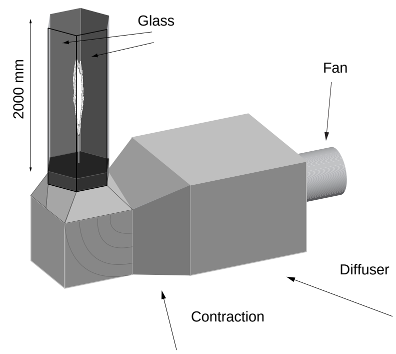

Figure 1: Sketch of the test facility

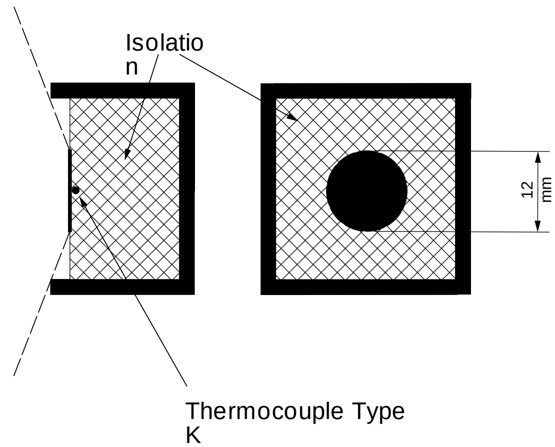

Figure 2: Sketch of the black plate sensor

4 Summary of Measurements

Radial velocity profiles were measured at different axial positions. The distances to the nozzle (Table 2) are related to the visible flame length L according to the definition of Barlow (Barlow and Carter, 1994) .

Axial Distance		0% Dilution		20% Dilution		40% Dilution	
		mm	D	mm	D	mm	D
0	L	0	*0*	0	*0*	0	*0*
1/16	L	42	*11*	35	*9*	23	*6*
1/8	L	84	*23*	70	*19*	47	*13*
1/4	L	169	*45*	141	*37*	94	*25*
3/8	L	253	*68*	211	*56*	141	*38*
1/2	L	338	*90*	281	*75*	188	*50*
5/8	L	422	*113*	351	*94*	234	*63*
3/4	L	506	*135*	422	*112*	281	*75*
1	L	675	*180*	562	*150*	375	*100*

Table 2: Downstream position of the radial profiles

5 Availability of Data

The velocity data are available over anonymous ftp from :
`camelot.ethz.ch`
or via :
`http://www.les.iet.ethz.ch/comb/nox/nox.html`.

For each flame and axial distance there is one file with the name: `sxxyy.dat`, where xx is the axial distance in L and yy is the amount of helium. The data files contain a header, describing the measured flame, the axial position and the seeding.

```
# Date         : 18-Mar-96  M.Flury ETHZ CH
# Data File    : s1420.dat
# Raw File     : 1420a
# Re           : 10 000
# Mean out.vel.[m/s]: 294
# Dilution He% : 20
# Seeding in   : fuel & coflow
# Hight [mm]   : 141
# Hight [L]    : 1/4
# Comment      : Shannon
# Variables    :
# nr x y   z     u     varu v     varv uv
  0     0 12.5  140 22.58 115.23 2.13 56.99 23.52
  2     0 8.5   140 37.2 163.11 2.67 85.04 20.98
```

The variables are:

- nr : index of the measurement point
- x : tangential position in mm
- y : radial position in mm
- z : axial position in mm
- u : axial velocity in m/s
- varu : RMS of the axial velocity in m/s
- v : radial velocity in m/s
- varv : RMS of the radial velocity in m/s
- uv : shear stress component of the Reynold Stress Tensor

The other quantities (Time Scales, Radiation data) are not available on the anonymous ftp server.

6 Existing Model Comparisons

The flames were studied numerically with a Lagrangian type combustion model (Borghi, 1988), which models a skeleton of the joint PDF between mixture fraction and a reactive species. The turbulence is modeled with the k-ϵ model, which was extended to predict the spreading rate of a round jet correctly (Pope, 1978). Details may be found in the publications below.

7 Publications

Schlatter, M. and Ferreira, J.C. and Flury, M.1996. Analysis of Turbulence-Chemistry Interaction with Respect to NO Formation in Turbulent Nonpremixed Hydrogen-Air Flames. *Twenty-Sixth Symposium (International) on Combustion*. The Combustion Institute, Pittsburgh.

Schlatter, M. and Flury, M.1995. Modelling of $\mathrm{NO_x}$ Formation in Turbulent $\mathrm{H_2}$ Diffusion Flames. *Third International Conference on Combustion Technologies for a Clean Environment, 3-6th July 1995, Lisbon, Portugal.*

References

Barlow, R. S. and Carter, C. D. 1994. Raman/Rayleigh/Lif measurements of nitric oxide formation in turbulent hydrogen jet flames. *Combust. Flame*, 97:261–280.

Borghi, R. 1988. Turbulent combustion modelling. *Prog. Energy Combust. Sci.*, 14.

Flury, M. and Schlatter, M. 1996. Influence of seeding methods on LDV measurements. In *Twenty-Sixth Symposium (International) on Combustion*. The Combustion Institute, Pittsburgh. Work in Progress Poster.

Pope, S. B. 1978. An explanation of the turbulent round jet/ plane jet anomaly. *AIAA Journal*, 16(3):279–281.

Veynante, D. and Candel, S. 1988. Application of non linear spectral analysis and signal reconstruction to ldv. *Exp.in.Fluids*, 6:534–540.

Veynante, D. and Candel, S. 1993. Data reduction methods for combustion instabilities. In *Combustion Instability Course*.