Preparation for the Application of CARS Thermometry in LOX/CH₄-Spray-Flames

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diagnostics of CH$_4$/O$_2$-flames: roadmap (1/2)

**experimental set-ups**
- matrix burner ($P_C < 2$ MPa)
- pulsed HP burner ($P_C < 10$ MPa, high T)
- micro-combustor at the M3.1 test bench (LOX/CH$_4$ spray combustion, $P_C < 1$ MPa)
- combustor C at the P8 test bench (LOX/CH$_4$ spray combustion, $P_C < 10$ MPa)

**objectives**
- what can we learn from CH$_4$/O$_2$-flame emission spectroscopy?
- CARS adaptation at laboratory-burners
CH/OH-emission intensity ratio (1 bar)

- linear dependence of line intensity ratio on mixture ratio
- low $R_{OF}$: soot formation
at high pressure CH- or C₂ signals can't be identified in the emission spectrum
H₂, H₂O, and CH₄ CARS spectra for R_{OF}=0.7-2.4 (\Phi=1.7-5.7)

with increasing mixture ratio:

- CH₄ signal intensity vanishes
- good H₂ signal intensity for all R_{OF}
lessons learned

conclusion from laboratory experiments:

CH$_4$-CARS spectra
- observed only in rich flames for $\Phi$>2.7 ($R_{OF}$<1.5)
- in diffusion flames signals are expected only on the fuel rich side of the flame front (unburned, cold methane)

H$_2$-CARS spectra
- observed with good signal quality in the burned gas. Molecule of choice for thermometry

H$_2$O-spectra
- signal interference with non-resonant CARS

strategy for CARS in CH$_4$/O$_2$-flames:
- 2 probe molecules: CH$_4$ as reactant, H$_2$ as reaction product
- 1 probe molecule: H$_2$, due its availability in a wide region in the reactive flow.
CARS application at M3.1

measurement locations

- 50 mm downstream injector faceplate
- r = -15 ... 15 mm, Δr = 2 mm
CARS application at M3.1

optical set-up at M3 test bench

LN$_2$-cooler for LOX and H$_2$

dye-laser (Stokes)

Nd:YAG-laser (pump)
CARS application at M3.1

status

- run time of micro combustor extended to 7s
- housing of flash lamps and Nd:YAG crystal damaged
- low performance of new igniter
- no H₂ at first measurement location

- only data from one measurement location available today
- work continues
development of CARS-diagnostics for high pressure CH\textsubscript{4}/liquid oxygen spray combustion

INTAS project
partners:
- DLR Lampoldshausen
- ONERA (DMPH), Palaiseau
- General Physics Institute of the RAS (GPI)
- Central Institute of Aviation Motors (CIAM), Moscow

project structure
- upgrade of pulsed burner for CH\textsubscript{4}/O\textsubscript{2}-combustion
- CFD simulation of ignition and combustion in the pulsed burner
- CARS spectroscopy in the pulsed burner
- Simulation of CARS spectra
- Comparison of CARS codes
- CARS system for single shot thermography at high pressure
- application to high pressure CH\textsubscript{4}/liquid oxygen spray combustion
development of CARS-diagnostics for high pressure CH\textsubscript{4}/liquid oxygen spray combustion (cont.)

key idea from V. Smirnov, GPI:

- simultaneously
  - detection of H\textsubscript{2}-CARS signal and
  - determination of the H\textsubscript{2}-line width

- no need to determine the density of all eventual collision partners in a CH\textsubscript{4}/O\textsubscript{2}-flame during the measurement
- the broadening coefficients of these collision partners need not been known.

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development of CARS-diagnostics for high pressure CH$_4$/liquid oxygen spray combustion (cont.)

HIGH RESOLUTION SINGLE SHOT DBB-CARS SPECTROMETER
development of CARS-diagnostics for high pressure CH₄/liquid oxygen spray combustion (cont.)

NON-RESONANT DBB-CARS SPECTRA in gas cell

Fabry-Perot interferometer removed
development of CARS-diagnostics for high pressure CH₄/liquid oxygen spray combustion (cont.)

DBB - CARS SPECTRA OF H₂ Q-BRANCH in gas cell

Heated cell with mixture H₂ : N₂ = 1 : 10, T = 960 K, P=5 bar
Fabry-Perot interferometer removed
development of CARS-diagnostics for high pressure CH$_4$/liquid oxygen spray combustion (cont.)

DBB-CARS OF H2 Q-BRANCH
in gas cell

Image of Single shot Fabry-Perot Interferogram
development of CARS-diagnostics for high pressure CH$_4$/liquid oxygen spray combustion (cont.)

H$_2$ Q1 FITTING of the EXPERIMENTAL DATA for 10% H$_2$ + N$_2$ MIXTURE 25.7 AMAGA
T = 1050 K

Data: Q1b34Lcm_Q1
Model: Lorentz
y0 0
xc1 0.44592
w1 0.98698
A1 4857.63661
xc2 5.67762
w2 0.97868
A2 3784.85196
xc3 10.70335
w3 0.97936
A3 3122.90275
supplementary slides
CARS diagnostics

measured physical properties

- temperature
- species concentration
- progress of mixing and combustion

![Diagram showing CARS diagnostics](image)
CARS spectra from atmospheric CH₄/O₂-flame

CARS-signals from H₂, H₂O, CH₄, CO, CO₂

ROF=3.3
\( \phi = 1.2 \)
approach for tests at M3.1

set-up for CARS application at the micro combustor

constraints:

- no application of DBB-CARS approach at test facility
  - simultaneous detection of H$_2$ and CH$_4$ with one laser system demonstrated in laboratory flame with dual broadband CARS
  - adjustment of two dye lasers to unstable under test facility conditions (thermal drifts, vibrational loads)
- two CARS laser systems not available for the tests
- no subsequent CARS generation of H$_2$- and CH$_4$- signals
  - high test time requirement for mapping of temperature field in the micro-combustor:
    for one radial profile in the spray flame, spatial resolution $\Delta r=2\text{mm}$:
    15 locations x 10 tests/location = 150 tests / 8 test days / 4 test weeks

approach:

- detection of H$_2$-CARS with BB-CARS
- simultaneous detection of H$_2$O to get maximum information