# SOOT FORMATION IN OSCILLATING AND STEADY DIFFUSION FLAMES UNDER ELEVATED PRESSURE

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**Project B1 of the Collaborative Research Center 606 "Instationary Combustion"**
**Soot formation in non-stationary diffusion flames**

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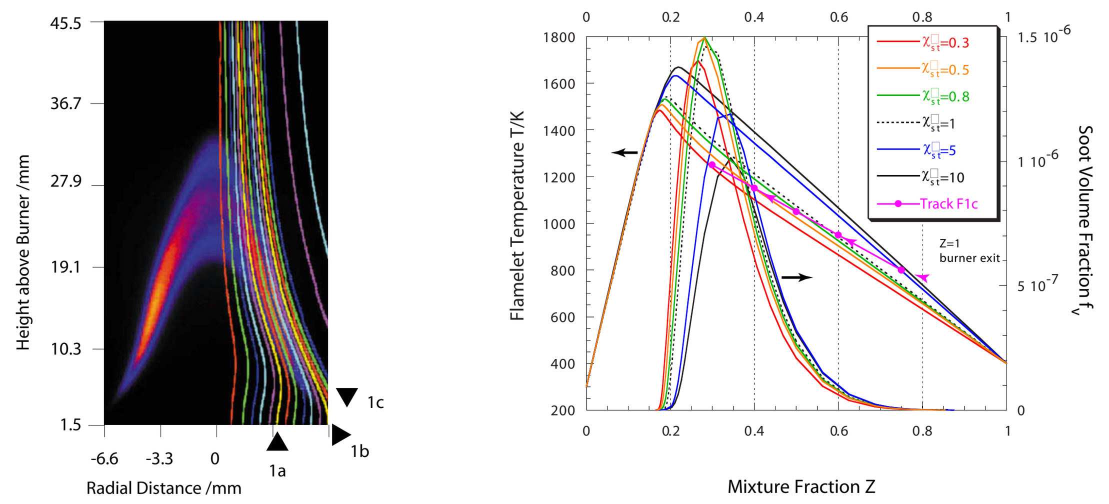
## Previous Work

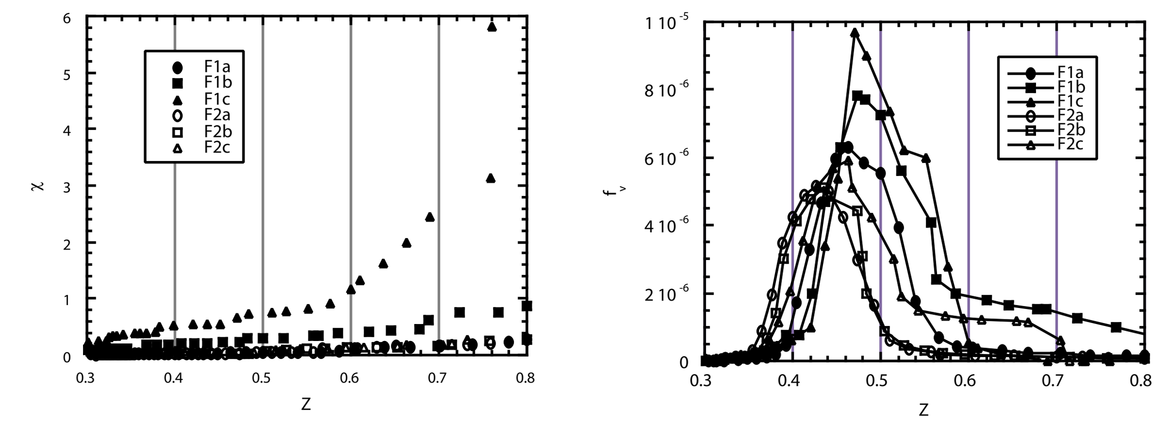
*Soot formation in a steady acetylene/air diffusion flame at ambient pressure* [1,2]

Soot particles pass through regions of different mixture fraction and scalar dissipation rates on their way through the flame. Along different tracks soot experiences different scalar dissipation rates.
How does soot adapt to these different conditions?

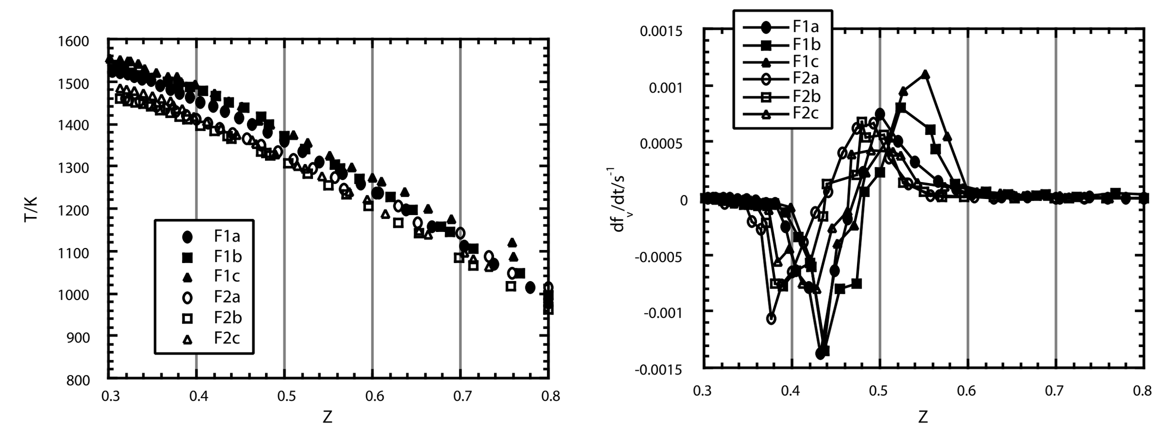
| Flame | $O_2$ coflow | $N_2$ coflow | $C_2H_2$ core flow | $N_2$ core flow |
|---|---|---|---|---|
| F1 | 2 | 8 | 0.1 | 0.25 |
| F2 | 1.75 | 8.25 | 0.1 | 0.25 |



Development of soot volume fractions along the tracks from fuel rich to fuel lean conditions for two steady acetylene air diffusion flames



For steady diffusion flames soot adapts to the different conditions.
Soot volume fraction is shifted in the mixture fraction space due to different scalar dissipation rates on different tracks



Temperature along the tracks as a function of mixture fraction.
Soot formation in F2 occurs in an oxygen depleted atmosphere.

The scalar dissipation rate is important for the formation of soot in flames.
Oxidation of soot seems to be dominated by temperature effects.

## Motivation

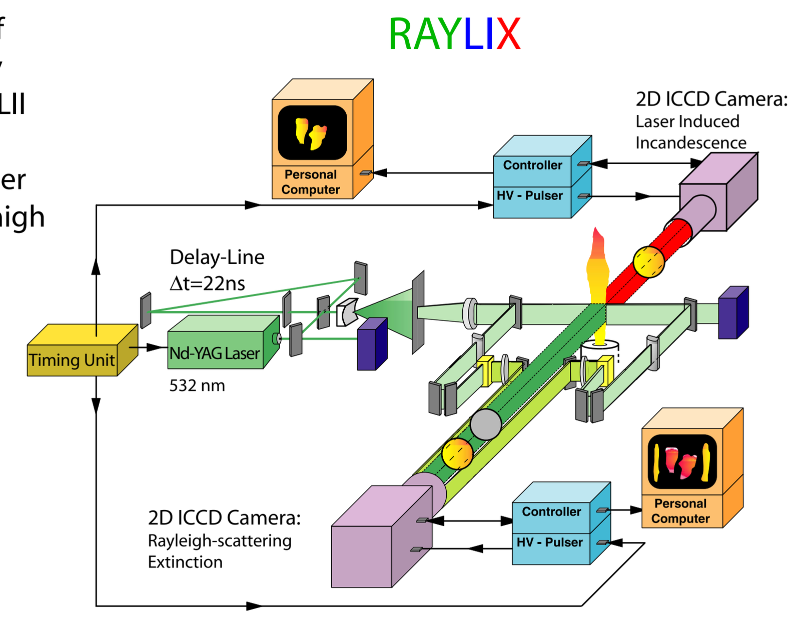
- Soot formation and oxidation in diffusion flames is affected by mixture fraction, scalar dissipation rate and temperature.
- How do these non-linear effects combine in unsteady combustion (diffusion flames)?
- For experimental approach to these effects pulsating flames give access to a broader range of scalar dissipation rates.
- Combustion in engines occurs under non-adiabatic conditions. By this temperature varies independently from mixture fraction and scalar dissipation rate.
- Independent variation of temperature can be realised by tuning heat loss by radiation to the cold walls.

## Experimental Setup

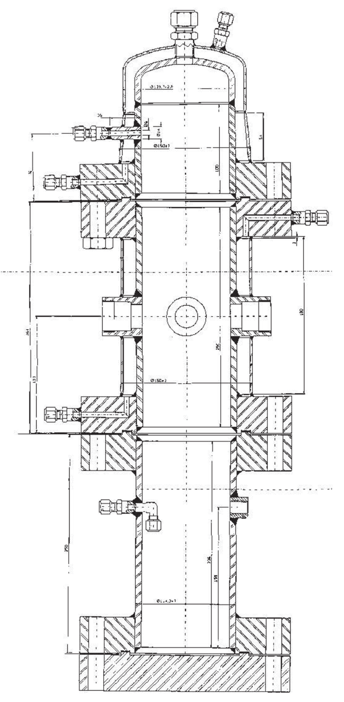
### *Laser Diagnostics*

Simultaneous Measurement of Rayleigh-scattering, LII and Extinction

Near-isochronous (Δt=20 ns) aquisition of signals outruns flow speed and chemistry
Independent measurements of Rayleigh, LII and extinction result in 2D-fields of soot volume fraction ($f_v$), mean particle diameter ($r_m$) and particle number density $N_t$ with high temporal and spatial resolution



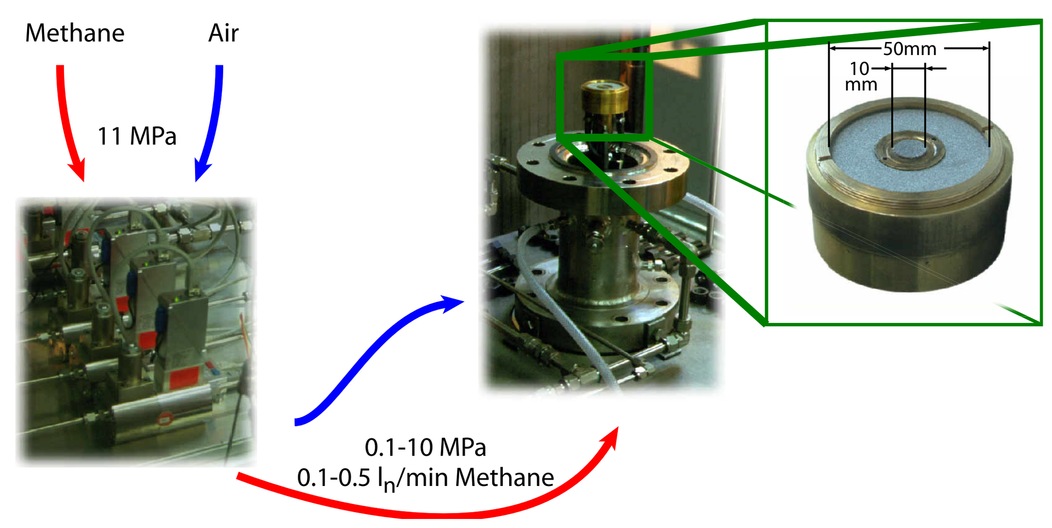

### *Burner Setup*

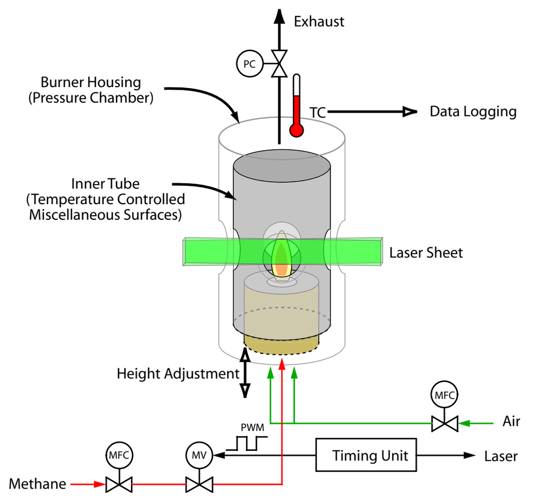


The housing consists of 3 parts

- exhaust gas cooling and leveling
- burner and flame / window unit
- burner adjustment and gas supply

The burner is surrounded by a tube that is independently temperature controlled and can have polished or mattfinished black surfaces



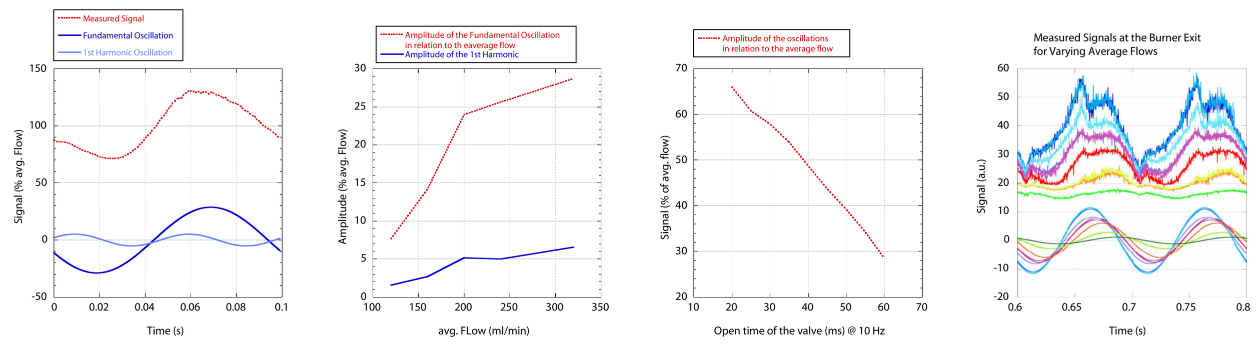




The inner tube can be equipped with different inner surfaces (polished metal, black matted) to set different boundary conditions for non-adiabatic flames.

The temperature of the inner wall is controlled by a cooling coil.

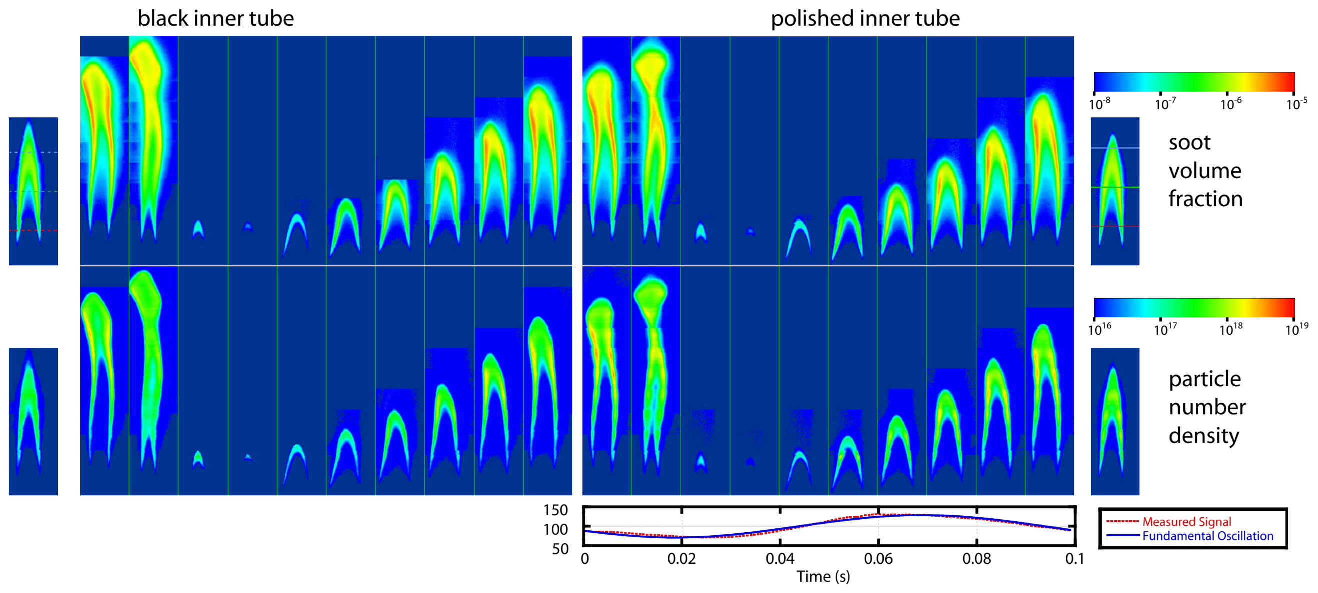
The methane flow is pulse width modulated to induce the pulsation of the flame

CTA measurements at the burner outlet show that the pulse width modulation of the gas feed further upstream results in a function that can be fitted as the sinusoidal oscillation and its harmonics.
Their amplitudes and phases depend on the pulse width and average flow.

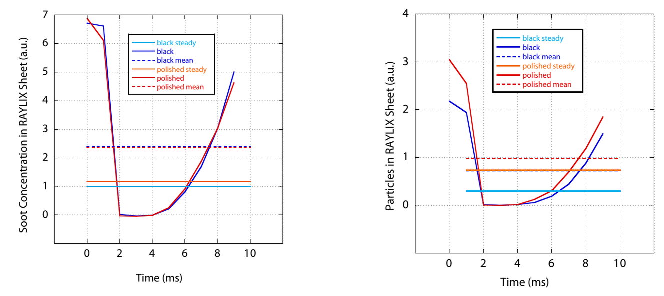


## Results

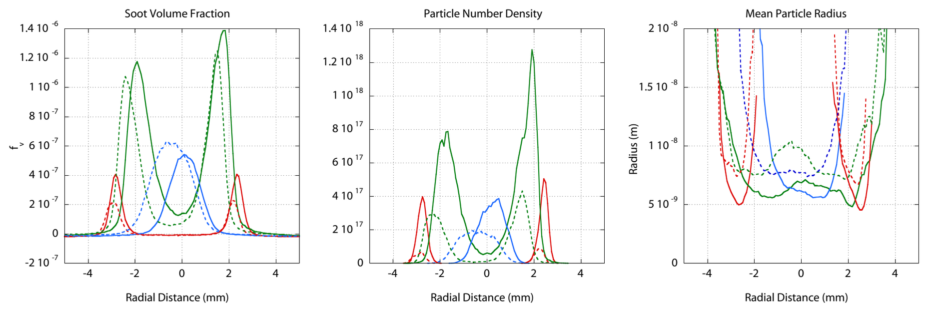
All results shown on this poster are taken from a flame at 0.25 MPa, temperature of the inner tube 293K, air flow 12 l/min, methane flow 200ml/min




Images from RAYLIX measurements taken at different phases of the oscillation. The phase locked images can be mapped to the outlet gas flow as measured by the CTA.



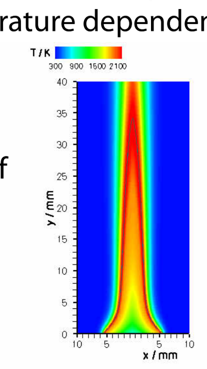
Soot volume fraction in the steady flame is smaller than the phase averaged soot volume fraction in the oscillating flame. The properties of the walls affect mainly the particle numbers and not the soot volume fraction.



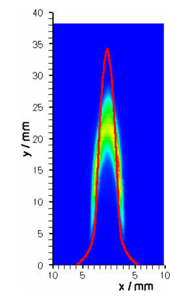

Profiles of the particle parameters taken from the two steady flames at the lines indicated in the pictures above.

*Numerical Calculations:*
In order to map the soot volume fraction to the mixture fraction, temperature and scalar dissipation rates, computations of these flames are being performed.
*ANSYS Tascflow 2.12:* Reaction rates: adaptive tables with data from 2-domain-1-step kinetics, adiabatic calculation temperature dependent diffusion coefficients

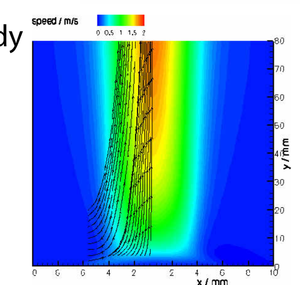
Temperatures and stoichiometric line from the computational simulation of the steady flame.

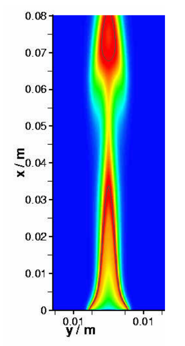


Stoichiometric line (red) from simulation superimposed on the experimentally obtained soot volume fraction field.



Flow field of the steady flame
The core flow is accelerated by buoyancy, entraining the co-flow





The numerical simulation of the pulsated flames shows a behaviour similar to the flames in the experiment
The picture shows the temperature field with the stoichiometric line. Chunks separate from the flame while it is collapsing

## Conclusions

- Soot formation in unsteady flames is enhanced compared to the corresponding steady flames
- Variation of soot formation in unsteady flames is caused by a complex interaction of temperature, scalar dissipation rate and mixing

*upcoming tasks:*

- quantitative correlation of soot formation rates to flow field (temperature, mixture fraction, scalar dissipation rates)
- Exact prediction of radiation properties.

## Literature

[1] A. Schön, T. Streibel, R. Suntz, H. Bockhorn: Numerical and experimental analysis of soot formation in laminar diffusion flames along selected particle tracks. Proceedings of the Combustion Institute (2002), 29(Pt.2), 2399-2405.
[2] T. Streibel, Ph.D.-Thesis (2002), University of Karlsruhe
[3] C. Shaddix, K. Smyth: Laser-induced incandescence measurements of soot production in steady and flickering methane, propane, and ethylene diffusion flames. Combustion and Flame (1996), 107(4), 418-452.