ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

LAV

Soot Reduction Mechanisms Using Post-Injections under Varying EGR Conditions

18th ETH Conference on Combustion Generated Nanoparticles 23.06.2014

Dr. Christophe Barro
Laboratorium für Aerothermochemie und Verbrennungssysteme
ETH Zürich
Prof. Dr. K. Boulouchos

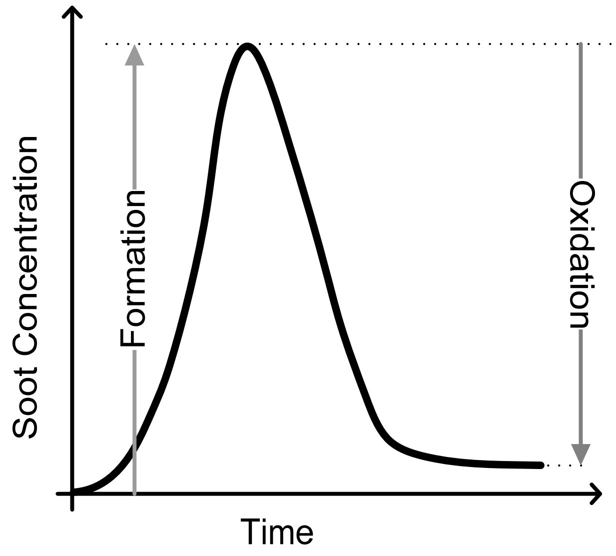
Outline

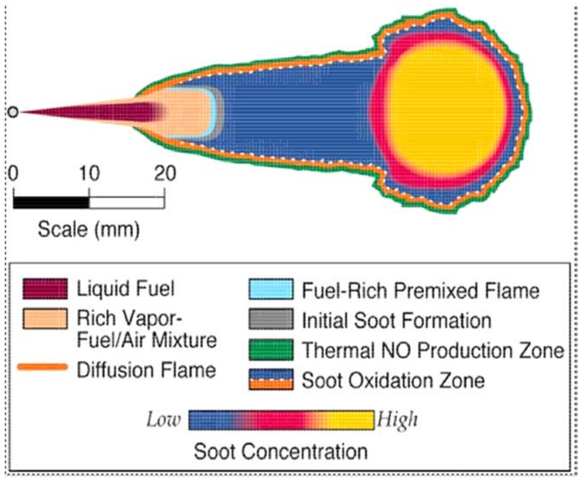
- **Introduction / Soot formation / characterization**
- **Influences of post injection on in-cylinder soot evolution**
- **Test Facility**
- **Experimental results on constant volume chamber**
  - 2D results using Post injection
- **Conclusions**

Soot Formation in Diesel Engines

- **Soot is the result of:**
  - Formation
    - *Fuel pyrolysis*
    - *Formation and growth of PAHs*
    - *Particle inception (nucleation)*
    - *Surface growth*
    - *Particle coagulation and agglomeration*
  - Oxidation
    - *Occurs concurrent to formation*
    - *Requires sufficiently high temperature and oxidant concentrations (O_2, O, OH, …)*
- **Heterogeneous environment of diesel combustion**

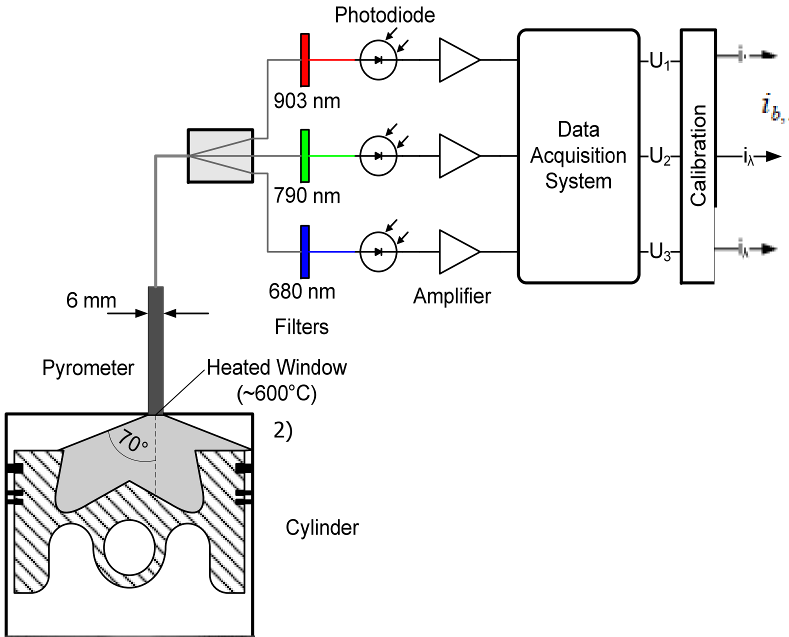
  → Formation and oxidation vary over space as they are dependent on local O_2 concentration and temperature



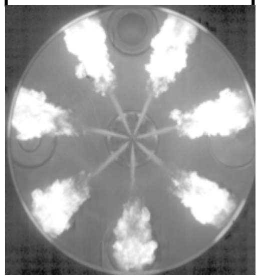


J. Dec. **SAE** 970873, 1997

Multi-Colour-Pyrometry



2)



1)

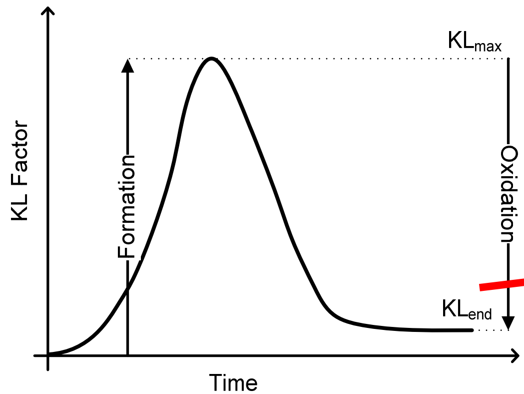
$$i_{b,\lambda}(T) = \frac{2C_1}{\lambda^5\left(e^{\frac{C_2}{\lambda T}}-1\right)}$$

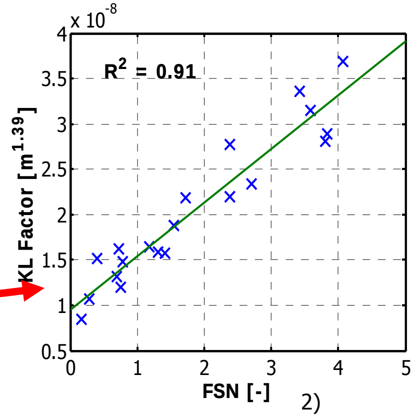
$T_{BB,1}$, $T_{BB,2}$, $T_{BB,3}$

$$\left[1-\left(\frac{e^{\frac{C_2}{\lambda_1 T_{Soot}}}-1}{e^{\frac{C_2}{\lambda_1 T_{BB,1}}}-1}\right)\right]^{\lambda_1^{\alpha}} = \left[1-\left(\frac{e^{\frac{C_2}{\lambda_2 T_{Soot}}}-1}{e^{\frac{C_2}{\lambda_2 T_{BB,2}}}-1}\right)\right]^{\lambda_2^{\alpha}}$$

T_{Soot}

$$kL = -\lambda^{\alpha}\ln\left[1-\left(\frac{e^{\frac{C_2}{\lambda T_{Soot}}}-1}{e^{\frac{C_2}{\lambda T_{BB}}}-1}\right)\right]$$





2)

1) Schneider 2003, 2) Kirchen 2008

Soot Evolutions under varying Conditions in Diesel Engines

4 engine operating points with different EGR, swirl rate and **constant fuel mass**

• Basis: λ = 1.4, 28 % EGR

•Lowered EGR: λ = 1.5, 25 % EGR

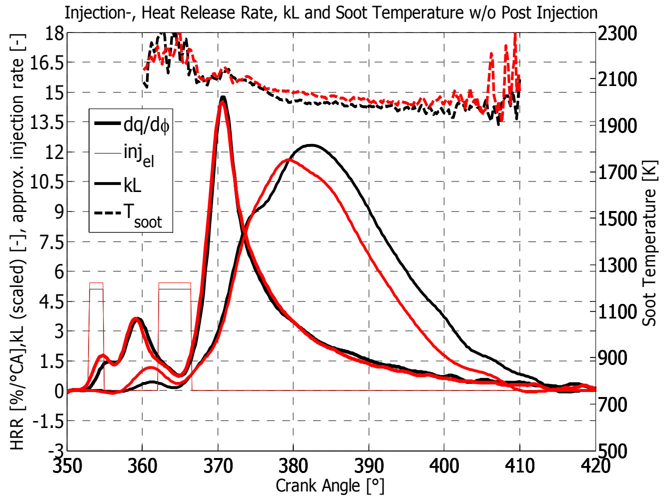
•2 Additional Operating conditions (not shown)

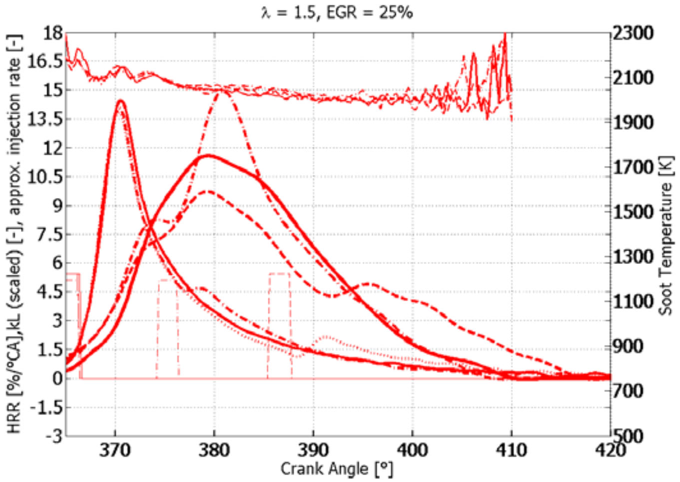
- Minor influence on heat release rate

- Post injections at 1 and 2.5 ms after end of main injection, 10% of main injection fuel mass

- Visible improvement of soot oxidation depending on soot evolution progress (interaction of the soot clouds assumed)

- Soot temperature changes are negligible





Influence of Post-Injections on Exhaust Soot

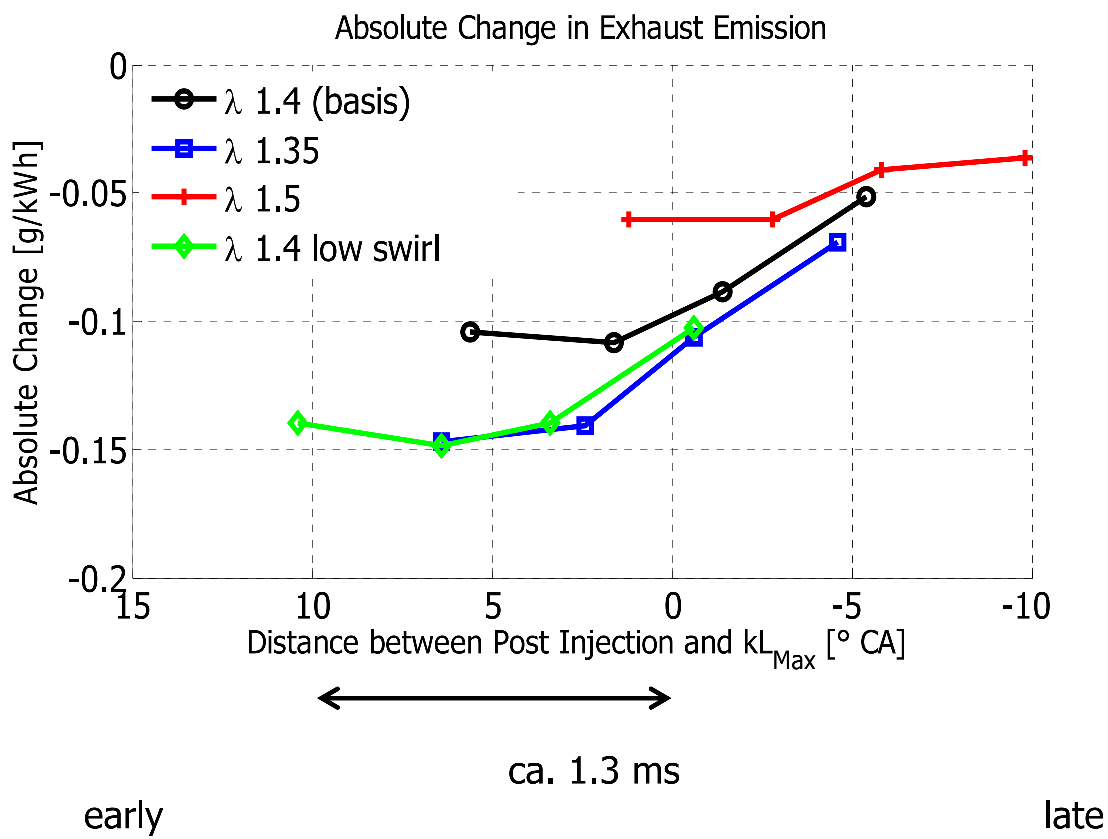
Effect on exhaust emissions depending on dwell between POI-timing and kL_{max}:

-Potential of soot reduction decreases soon as the POI occurs after the soot peak

-Goal:

-Confirmation that interaction of soot clouds is required

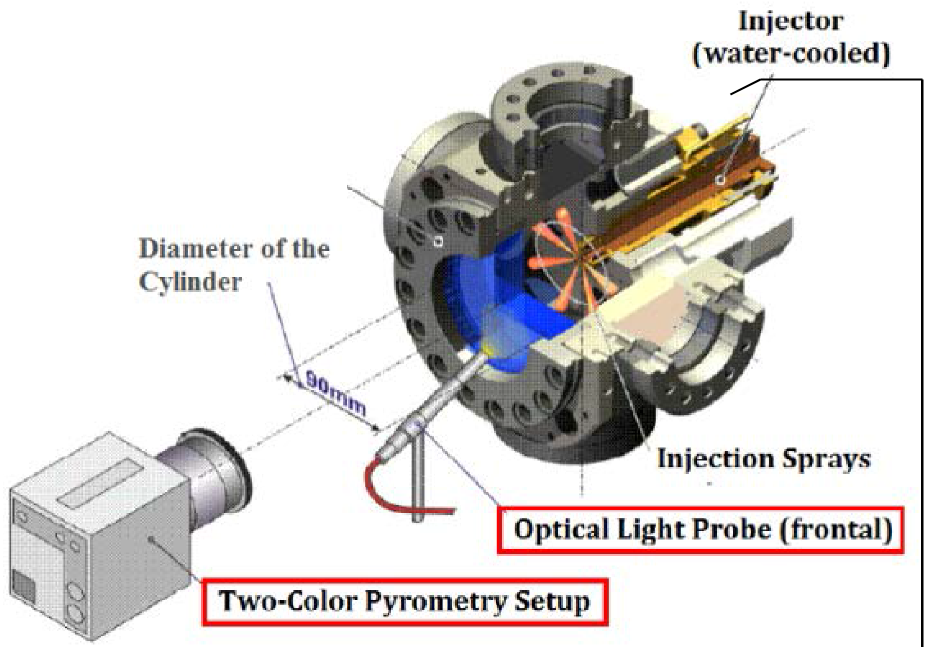
-Confirmation of negligible temperature effect



Barro C. et al. ICEF2012- 92075 Technical Conference, ASME, 2012

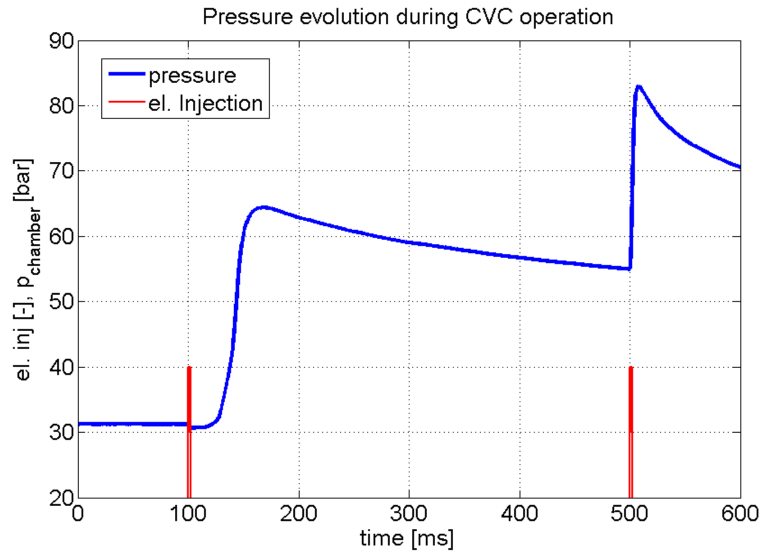
Measurement Setup

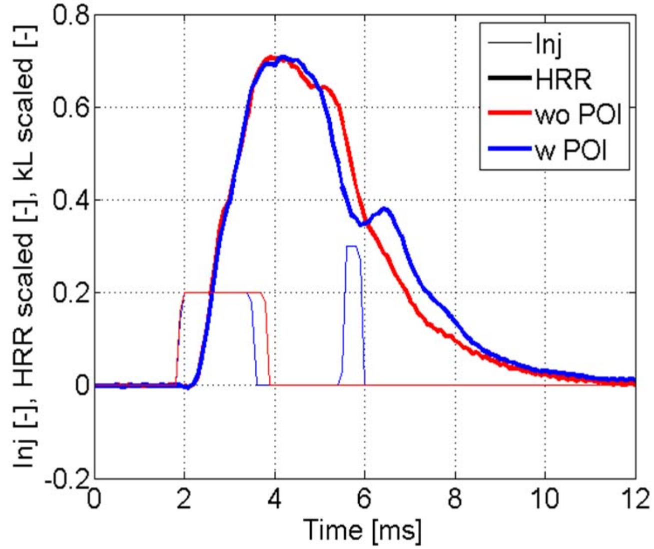
- **Cylindrical Constant Volume Chamber**
- **90 mm diameter (=Bore of passenger car diesel engine, = dia. of front window)**
- **No volume outside the visible range**
- **8-hole Piezo-injector**
- **Exhaust gas analysers**
  - Airsense (NO)
  - Cambusiton DMS 500 (Particle number & size distribustion)



Operating Conditions

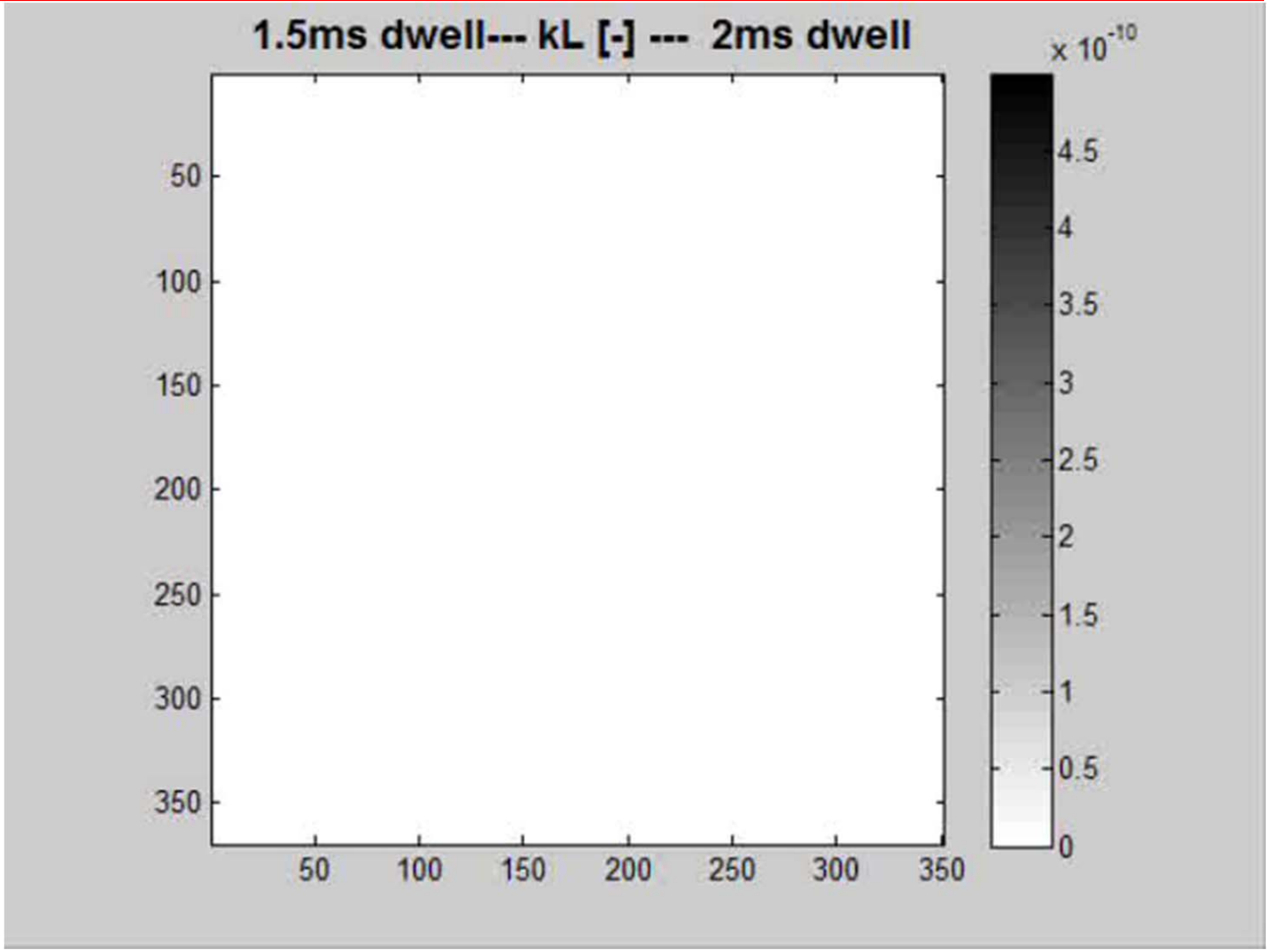
- **Fuels:**
  - Diesel, n-Heptane, n-Heptane with 30%Toluene
- **Charge**
  - Air and air $+CO_2$ (O_2 reduced to 17.8%)
- **Initial conditions**
  - 1250°K, 55 bar and 1000 bar fuel pressure (after pilot injection)
  - 106.8 mg of fuel in total (main +post)
- **Post-injections**
  - 1.5, 1.8, 2, 2.2, 2.5 and 3 ms
  - 15.5 mg of fuel.





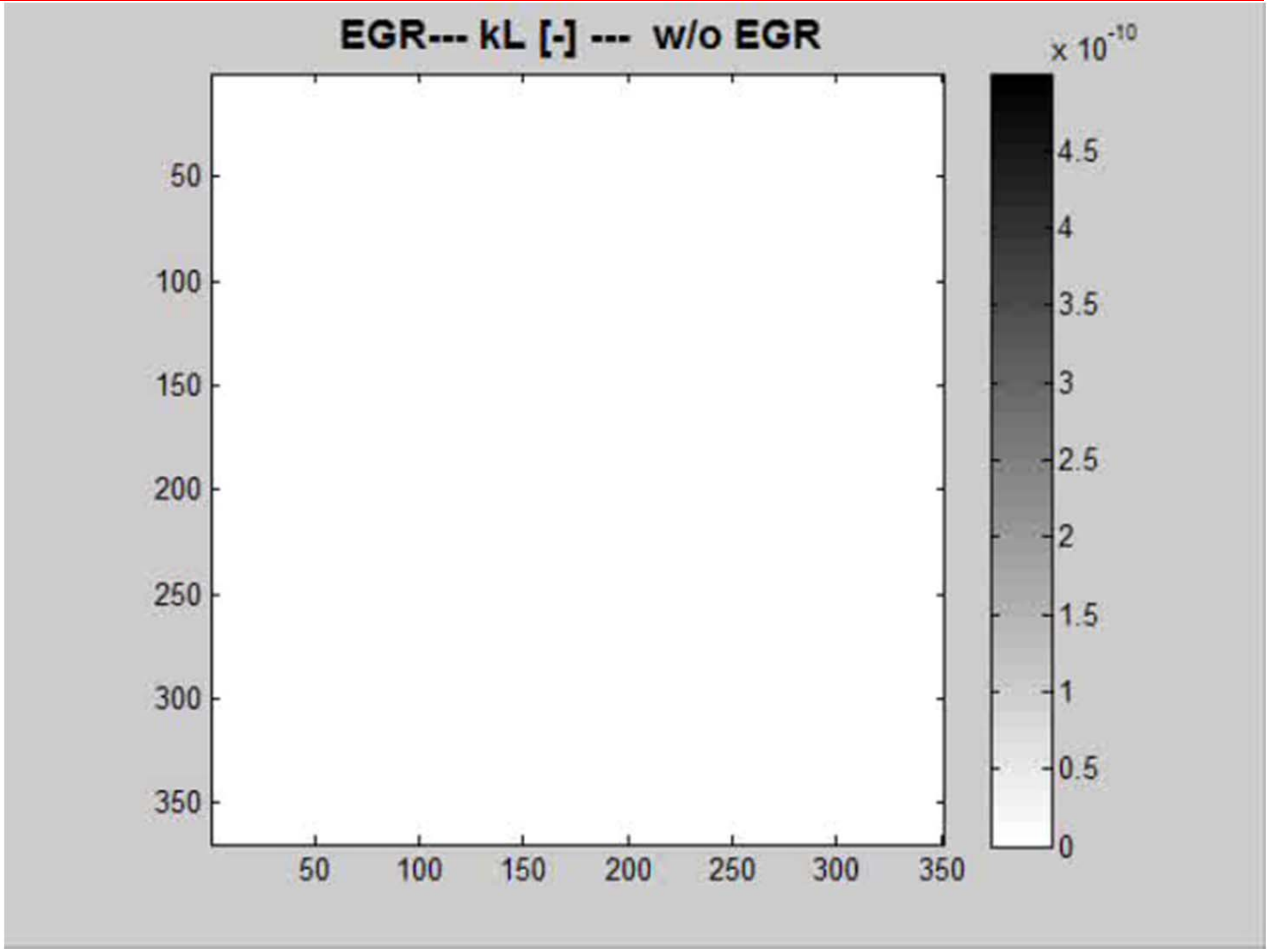
Results: Post-Injections 2D-kL and Temp.

- Post injection with 1.5 ms (left) and 2 ms dwell (right)
- Interaction between the two soot clouds for the early case
- No relevant change of temperature in case of interaction



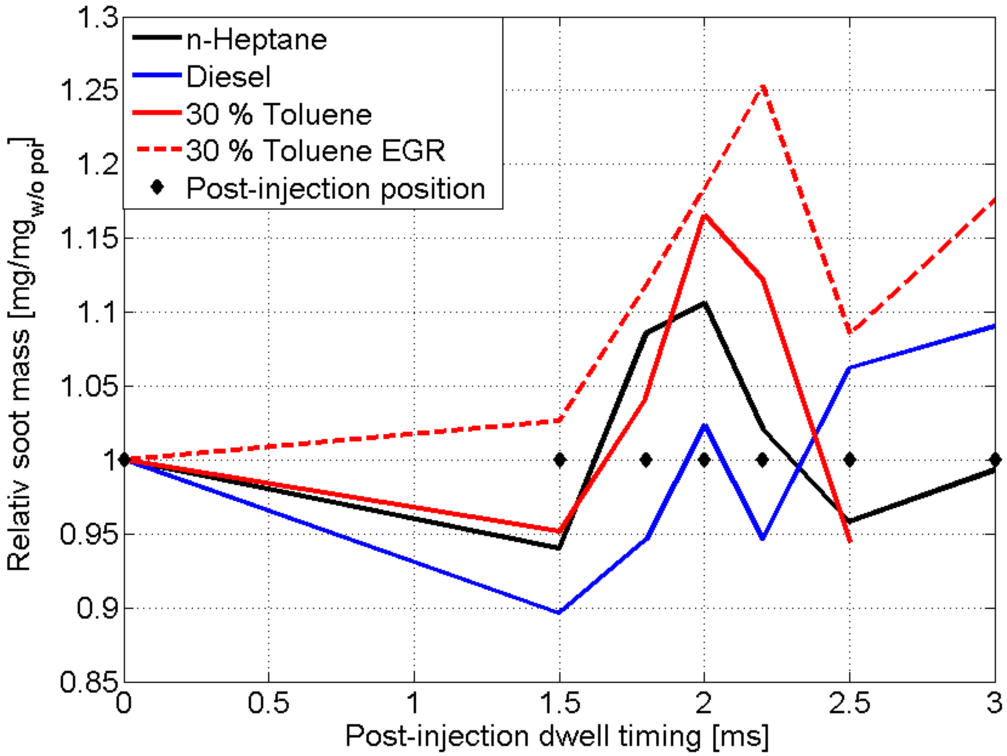
Results: Post-Injections 2D-kL and Temp.

- Post injection with 2 ms dwell and EGR (left), w/o EGR (right)
- Higher potential of interaction under presence of EGR
- No relevant change of temperature in case of interaction



Results: Post-Injections, Exhaust Emissions

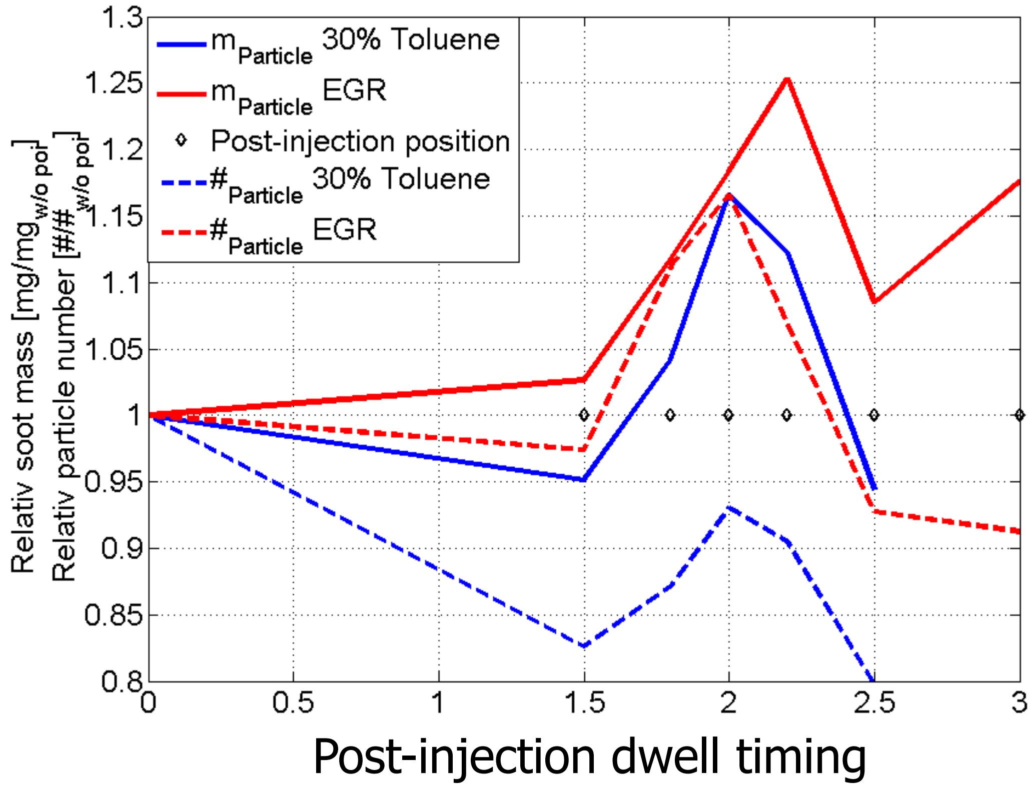
- **Reduction potential for all fuels**
  - high potential for short dwell timings
  - potential decrease rapidly
- **No decrease of exhaust soot mass using EGR**
  - prob. due to too low local oxygen availability without background turbulence



Barro C. et al. SAE 2014, under review

Results: Post-Injections, Exhaust Emissions

- **Reduction potential due to lower particle number**
- **Even w/o reduction of soot mass, reduced PN also in the EGR-case**



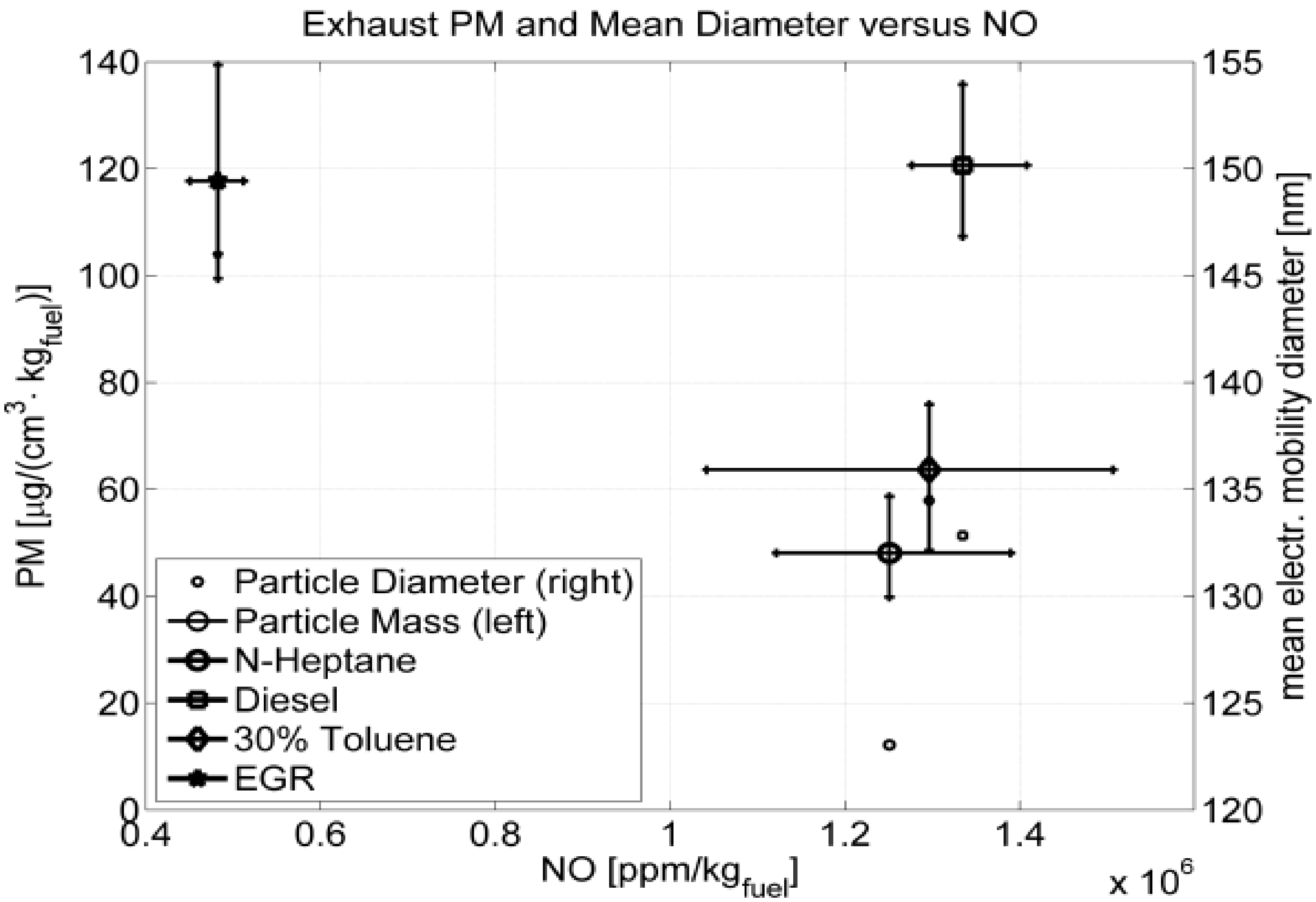
Barro C. et al. SAE 2014, under review

Summary and Conclusions

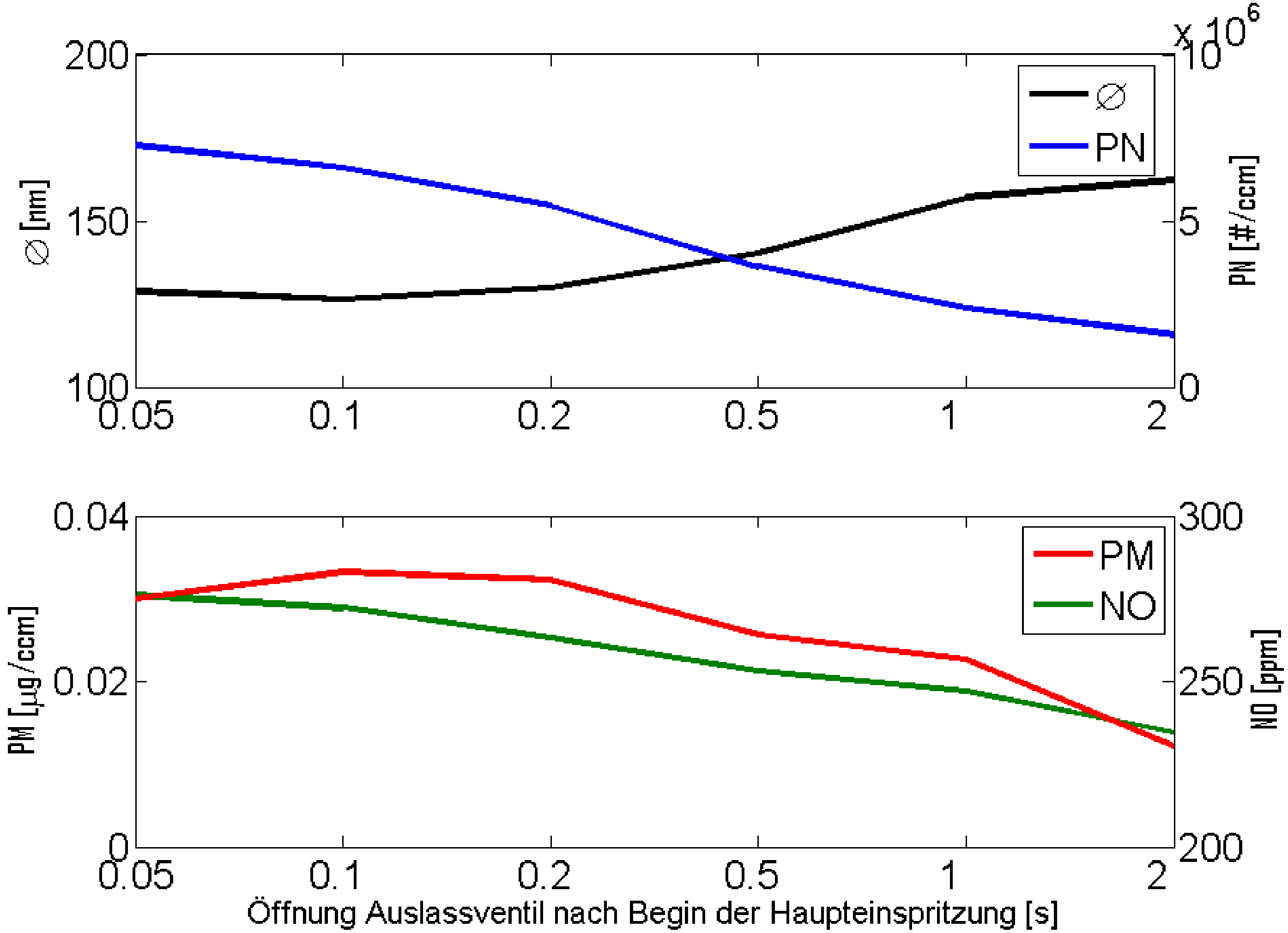
- The diesel engine combustion process has been reproduced using a cylindrical constant volume chamber with high optical access.
- The soot oxidation and formation process has been visualized using 2D-2-colour-pyrometry.
- The exhaust emission have been measured.
- The measurements showed high potential for exhaust soot reduction if interaction between the soot clouds occur.
- The temperature of the merged soot clouds remains constant.
- Even with higher potential of interaction, the EGR-case does not show exhaust soot reduction. The reason might be too low local oxygen availability caused by the lack of background turbulence.
- PM reduction due to PN reduction

Thank you for your attention

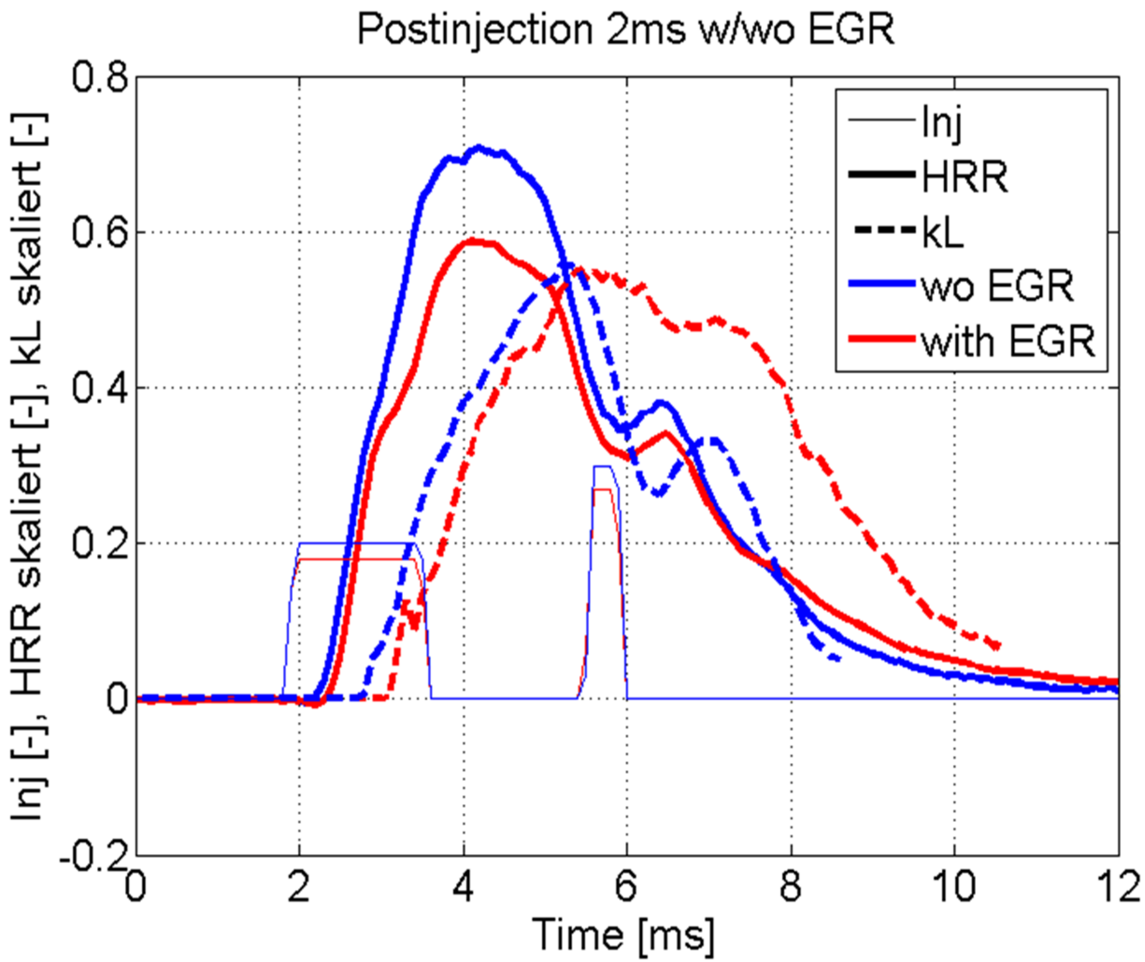
Exhaust Emissions



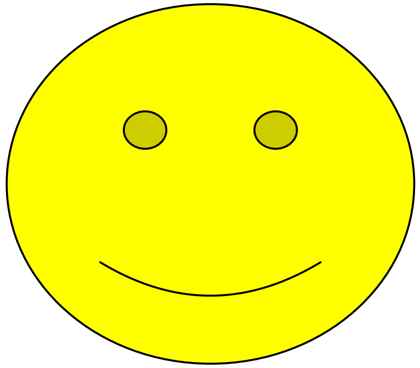
Exhaust Emission



Reserve 1


Postinjection 2ms w/wo EGR
Inj [-], HRR skaliert [-], kL skaliert [-]
0.8
0.6
0.4
0.2
0
-0.2
0
2
4
6
8
10
12
Time [ms]
Inj
HRR
kL
wo EGR
with EGR

Index



Contents