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

Multi-Colour-Pyrometry

\[ i_\text{bb,1}(T) = \frac{2C_1}{\lambda^2} \left( e^{\frac{C_2}{\lambda T_{\text{soot}}}} - 1 \right) \]

\[ T_{\text{soot}} = \frac{C_2}{C_1} \ln \left( 1 - \frac{C_2}{e^{\frac{C_2}{\lambda T_{\text{BB,1}}}} - 1} \right) \]

\[ kL = -\lambda \ln \left( 1 - \frac{C_2}{e^{\frac{C_2}{\lambda T_{\text{BB,2}}}} - 1} \right) \]

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: $\lambda = 1.4$, 28 % EGR
- Lowered EGR: $\lambda = 1.5$, 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
Effect on exhaust emissions depending on dwell between POI-timing and $kL_{\text{max}}$:

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

-Gold:
  -Confirmation that interaction of soot clouds is required
  -Confirmation of negligible temperature effect

![Graph showing the absolute change in exhaust emission as a function of distance between post injection and $kL_{\text{max}}$. The graph includes lines for different air-to-fuel ratios ($\lambda$) and shows that the absolute change increases with distance from early to late injection.](image-url)
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 distribution)
Operating Conditions

- **Fuels:**
  - Diesel, n-Heptane, n-Heptane with 30% Toluene

- **Charge**
  - Air and air + CO₂ (O₂ 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
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
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 PM and Mean Diameter versus NO

PM [µg/(cm³ kg fuel)]

NO [ppm/kg fuel]

mean electr. mobility diameter [nm]

- Particle Diameter (right)
- Particle Mass (left)
- N-Heptane
- Diesel
- 30% Toluene
- EGR
Exhaust Emission

Graphs showing the relationship between different emissions and time:

1. Top graph: Plot of \( \varnothing \) (likely representing a type of exhaust emission) and \( \text{PN} \) (particulate number) against time in seconds (x-axis) and \( \times 10^6 \) (y-axis).

2. Bottom graph: Plot of PM (particulate matter) and NO (nitric oxide) against time in seconds (x-axis). PM is measured in \( \mu g/ccm \) and NO in ppm.
Reserve 1

Postinjection 2ms w/wo EGR

- Injection (Inj)
- HRR
- kL
- wo EGR
- with EGR

Time [ms]

Inj [-], HRR skaliert [-], kL skaliert [-]