Abstract for the 6th ETH Nanoparticle Conference

Comparison of the soot formation inside the cylinder and the soot particle emission in the exhaust of a direct injection spark ignition engine

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Since 1997 Direct Injection Spark Ignition (DISI) engines are on the European Market. Their advantage is a lower specific fuel consumption and therefore a reduction of CO_2-emissions, which are mainly responsible for the greenhouse effect. But from our investigations of the combustion inside the cylinder [1], we found, that the combustion takes partly place in a diffusion flame or in a partly rich premixed flame. Both generate a higher amount of soot than usually expected from gasoline engines.

In the presentation, investigations inside the cylinder by means of the two-color-method [2] are shown. With this measurement technique, it is possible to obtain information about the soot content by looking at the value of the so called KL-factor [3]. K is an absorption coefficient, which is proprtional to the number density of soot particles, while L is a geometric thickness of the flame along the optical axis. This KL-factor is used in the empirical correlation of Hottel and Broughton and it is proportional to the soot concentration [3].

Additionally, exhaust emission investigations have been performed as there are gravimetry, coulometry, photoelectric aerosol sensor (PAS), diffusion charger (DC) and scanning mobility particle sizer (SMPS).

From all investigations, it ist clear, that stratified DISI engines emit higher soot concentrations than homogeneous charge gasoline engines, even if the last run at rich conditions. These investigations have shown that there is a correlation between the maximum and the overall soot concentration inside the cylinder on one hand and the exhaust pipe emissions as well on the other. Also, the well known relationship from Diesel engines concerning the correlation between PAS and EC appears to be valid for DISI engines.

[1] K. Schänzlin: Charakterisierung der Gemischbildung und Verbrennung in einem direkteingespritzten Ottomotor mit strahlgeführtem Brennverfahren, Dissertation ETH Zürich 2002 (eingereicht).

[2] R. Schubiger: Untersuchungen zur Russbildung und –oxidation in der dieselmotorischen Verbrennung: Thermodynamische Kenngrössen, Verbrennungsanalyse und Mehrfarbenendoskopie. Dissertation ETH Zürich Nr. 14445, 2001.

[3] H. Zhao, N. Ladomatos: Optical Diagnostics for Soot and Temperature Measurement in Diesel Engines; Prog. Energy Combust. Sci. Vol. 24 pp. 221-255, 1998.

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Motivation

- Particle-measurements on gasoline engines are seldomly reported in literature, although most of the passenger cars use gasoline engines
- Gasoline direct injection engines burn to a certain extent under locally fuel-rich conditions during stratification
- Conventional gasoline engines burn globally fuel-rich during full load driving
- It is known, that there is a certain soot level if combustion takes place with a diffusion flame or under rich premixed
- In diesel engines, most of the soot generated during combustion can be oxidized – is this also the case during stratified gasoline combustion?

Content

- Engine Specification
- Gasoline Direct Injection Strategies
- Measurement Techniques
- Results
  - Comparison Stratified Charge – Homogeneous Charge
  - Comparison In-Cylinder – Exhaust Pipe Measurements
- Conclusions and Outlook

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Engine Specification

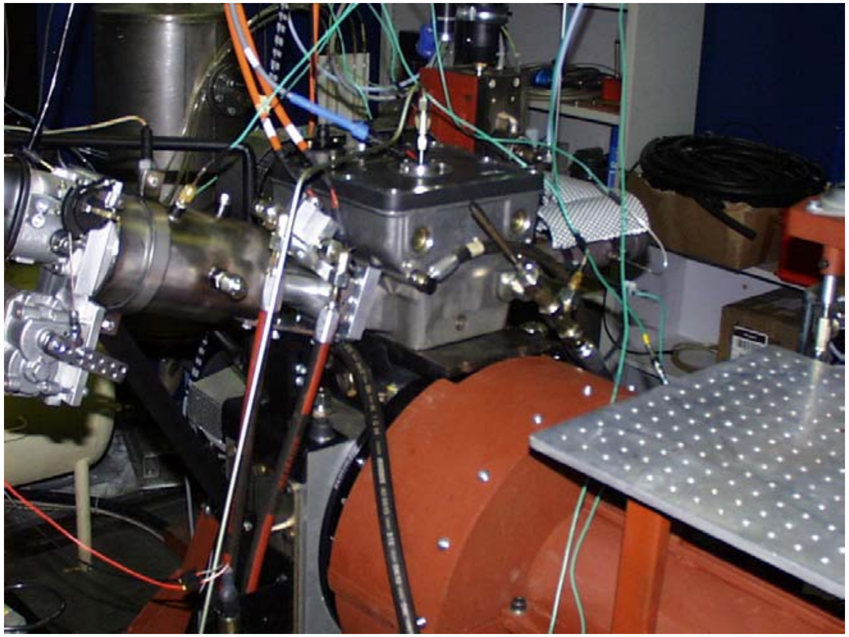
One-Cylinder Research Engine

Gasoline Direct Injection

Jet Guided Strategy

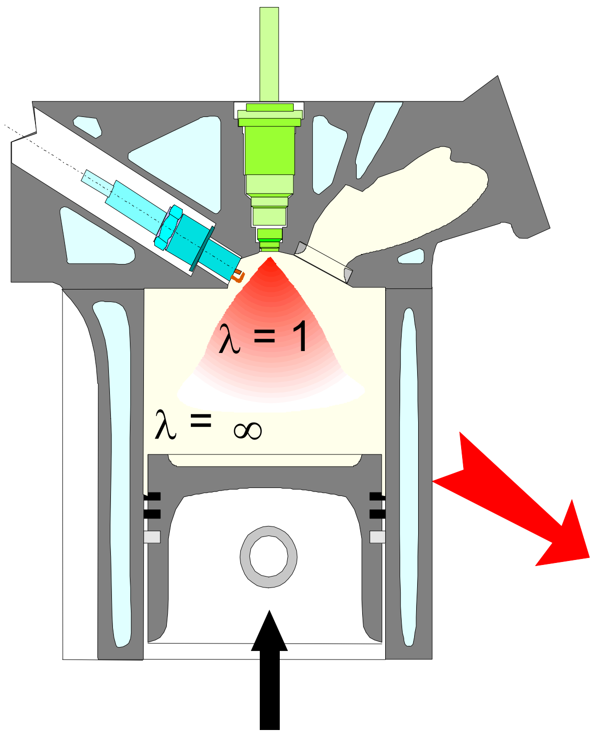
Hollow Cone Spray

Stroke: 86.6 mm
Bore: 89.9 mm
Compression Ratio: 10



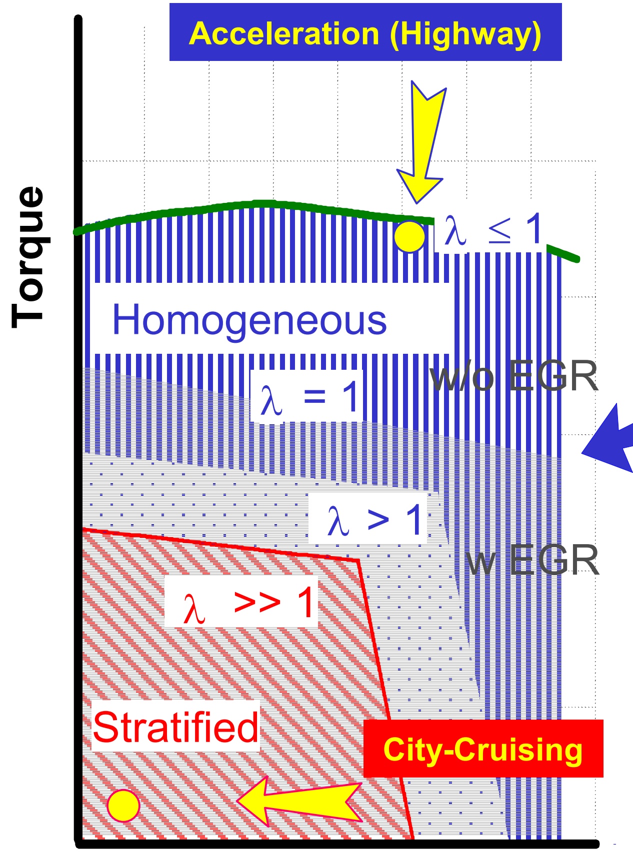
Strategies DISI – Engine (Schematical View)

Stratification

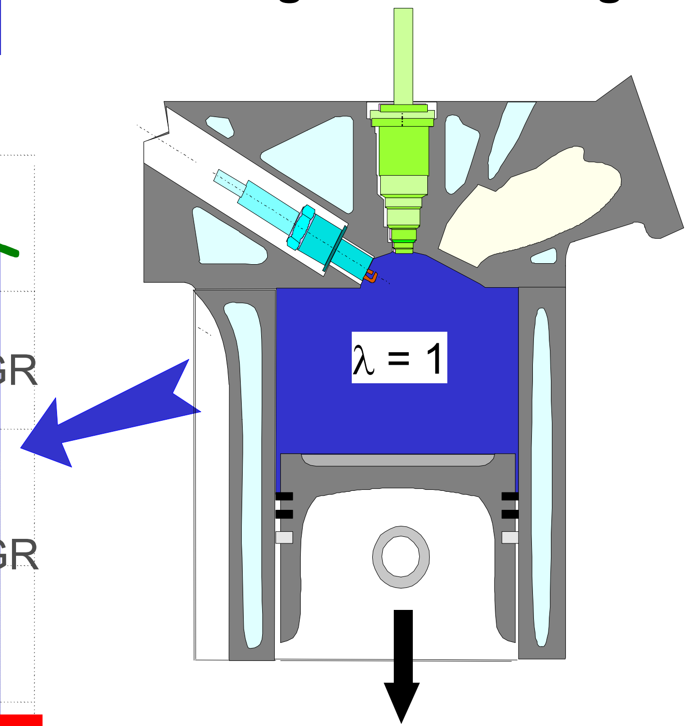


late injection during compression stroke

Performance Map



Homogeneous Charge



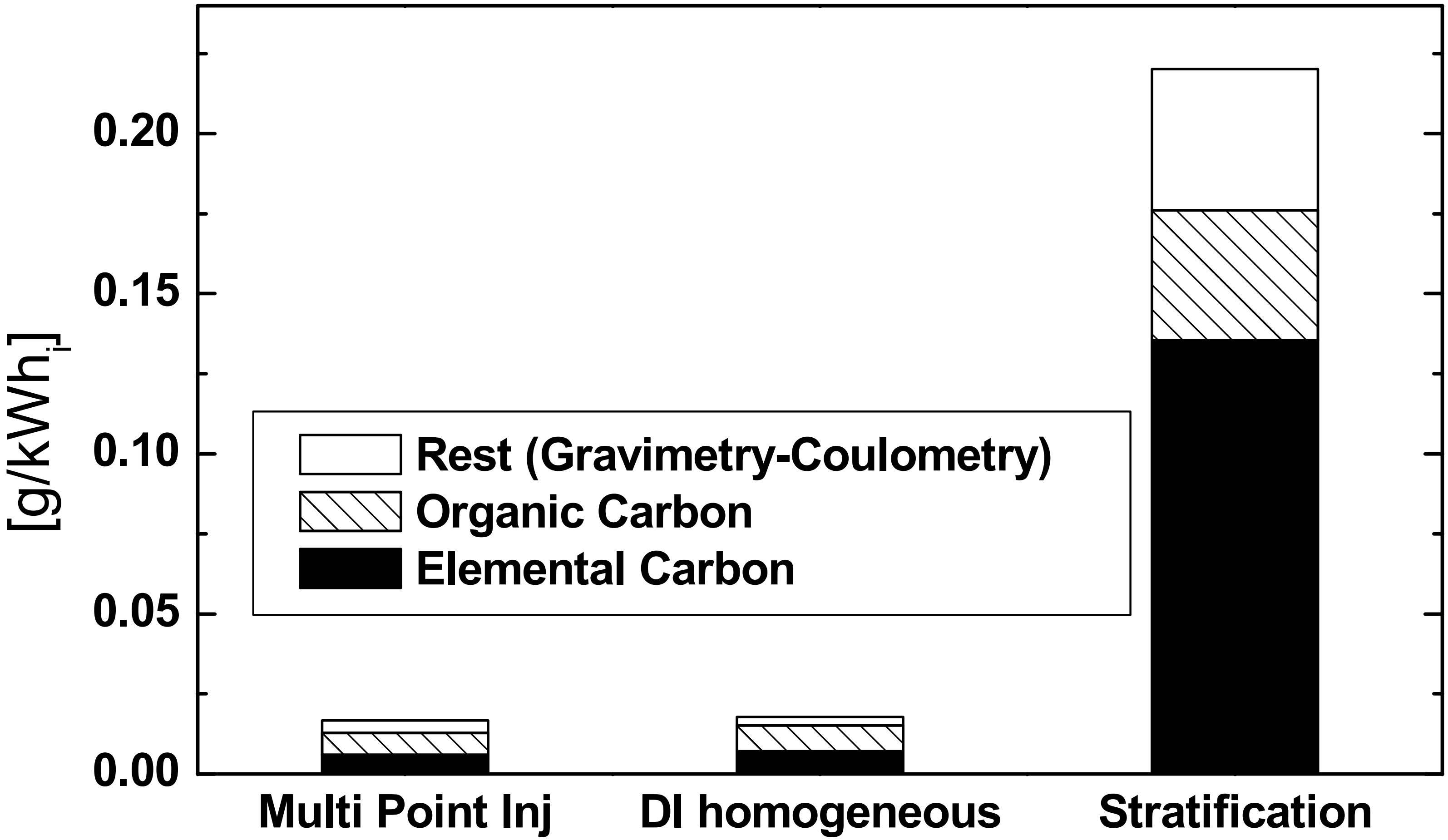
early injection during inlet stroke

Advantage stratification:
reduction of fuel-consumption between 10 to 50% in specified conditions

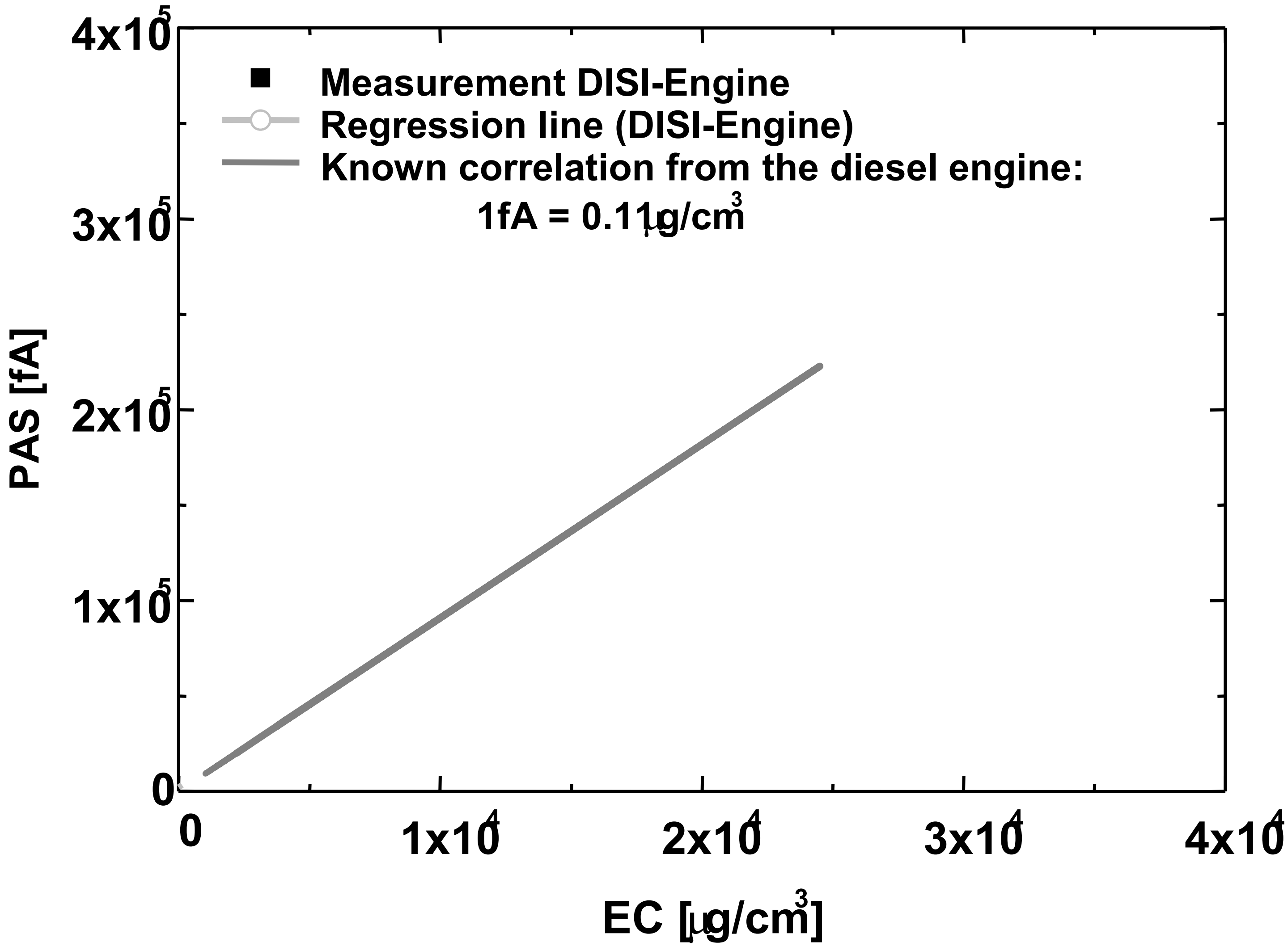
Measurement Equipment

- In-Cylinder Measurements:
  - Two-Color-Method
    - $\Rightarrow$ Radiation Temperature
    - $\Rightarrow$ KL-Factor $\propto$ Soot Concentration
- Exhaust Pipe Measurements:
  - Gravimetry
  - Coulometry
  - Photoelectric Aerosol Sensor (PAS)
  - Diffusion Charger (DC)
  - Scanning Mobility Particle Sizer (SMPS)

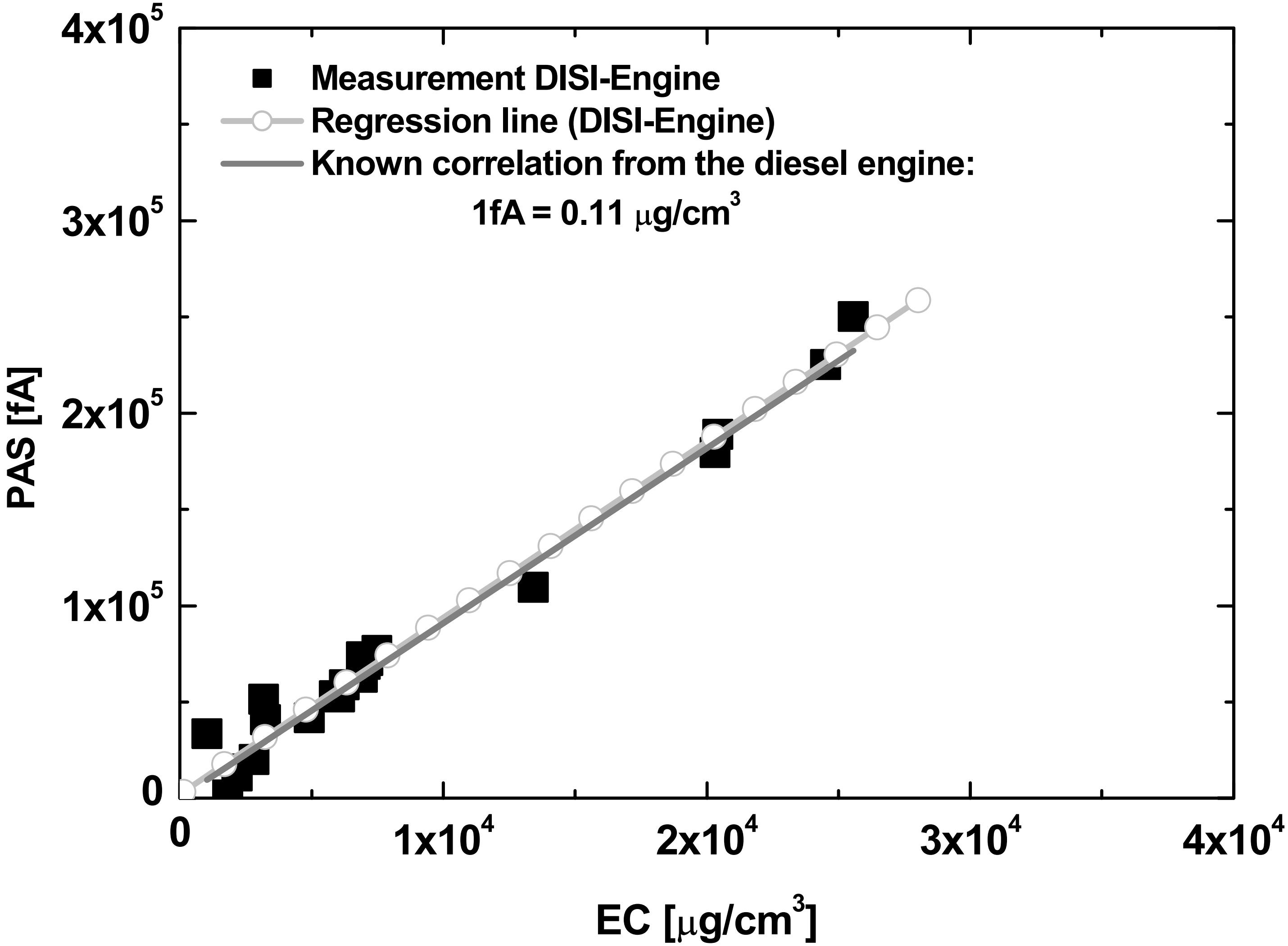
Comparison Stratified Charge – Homogeneous Charge
Gravimetry and Coulometry



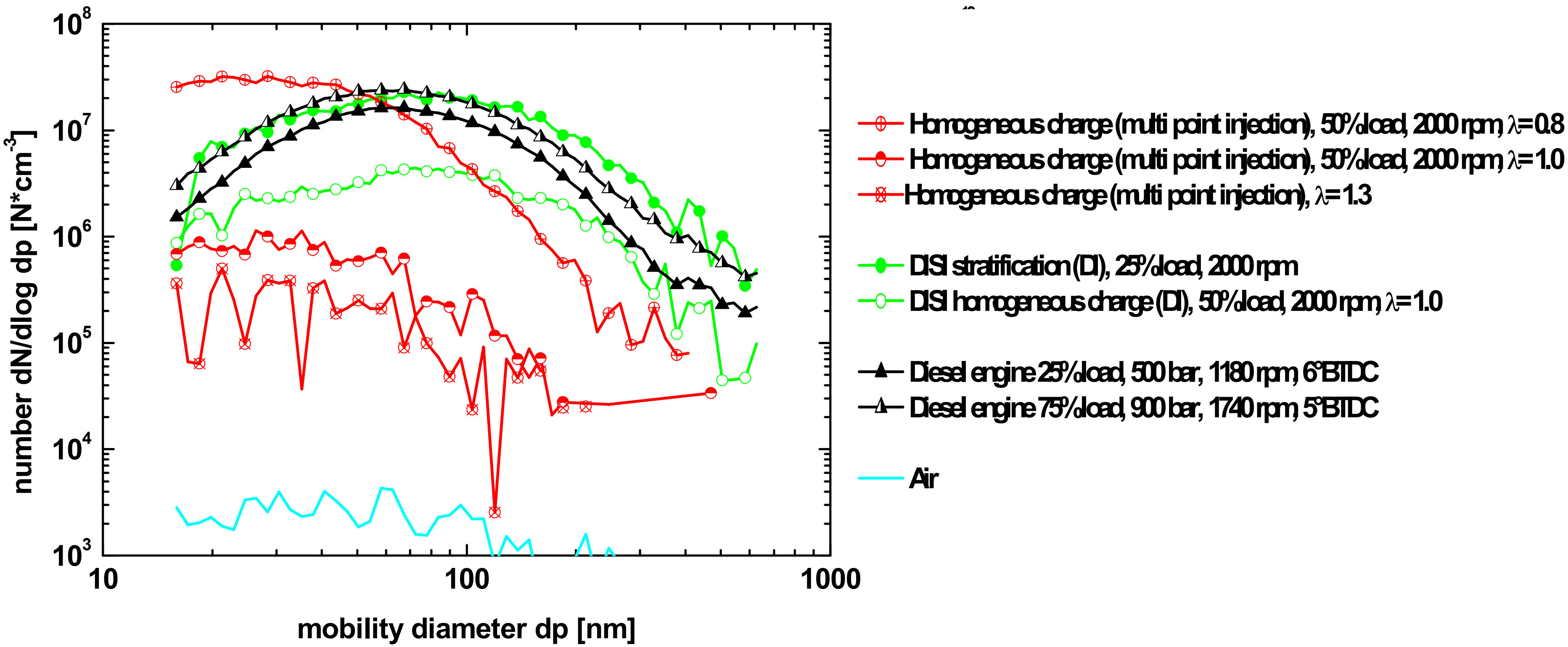
Stratification: Comparison PAS - EC



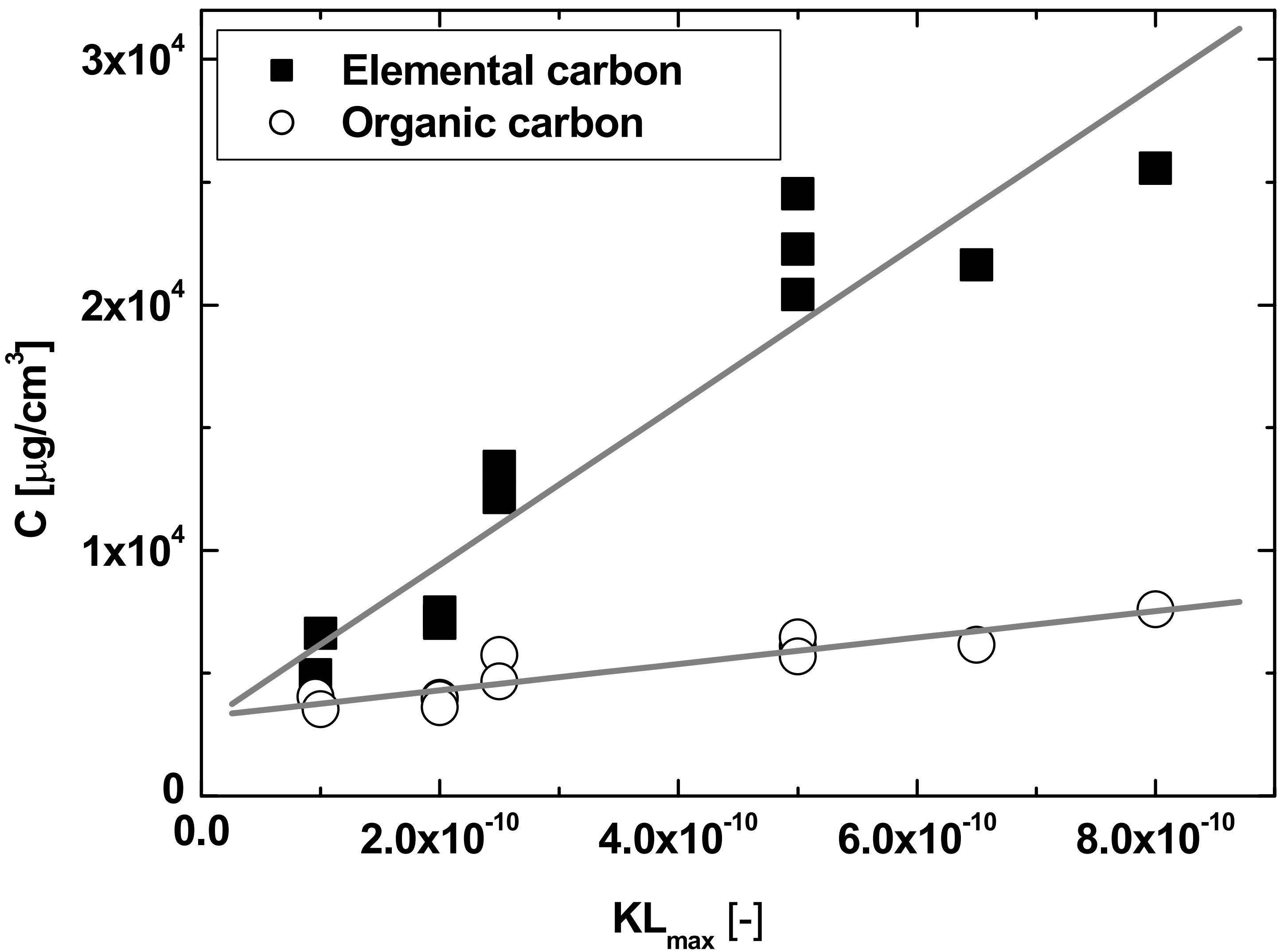
Stratification: Comparison PAS - EC



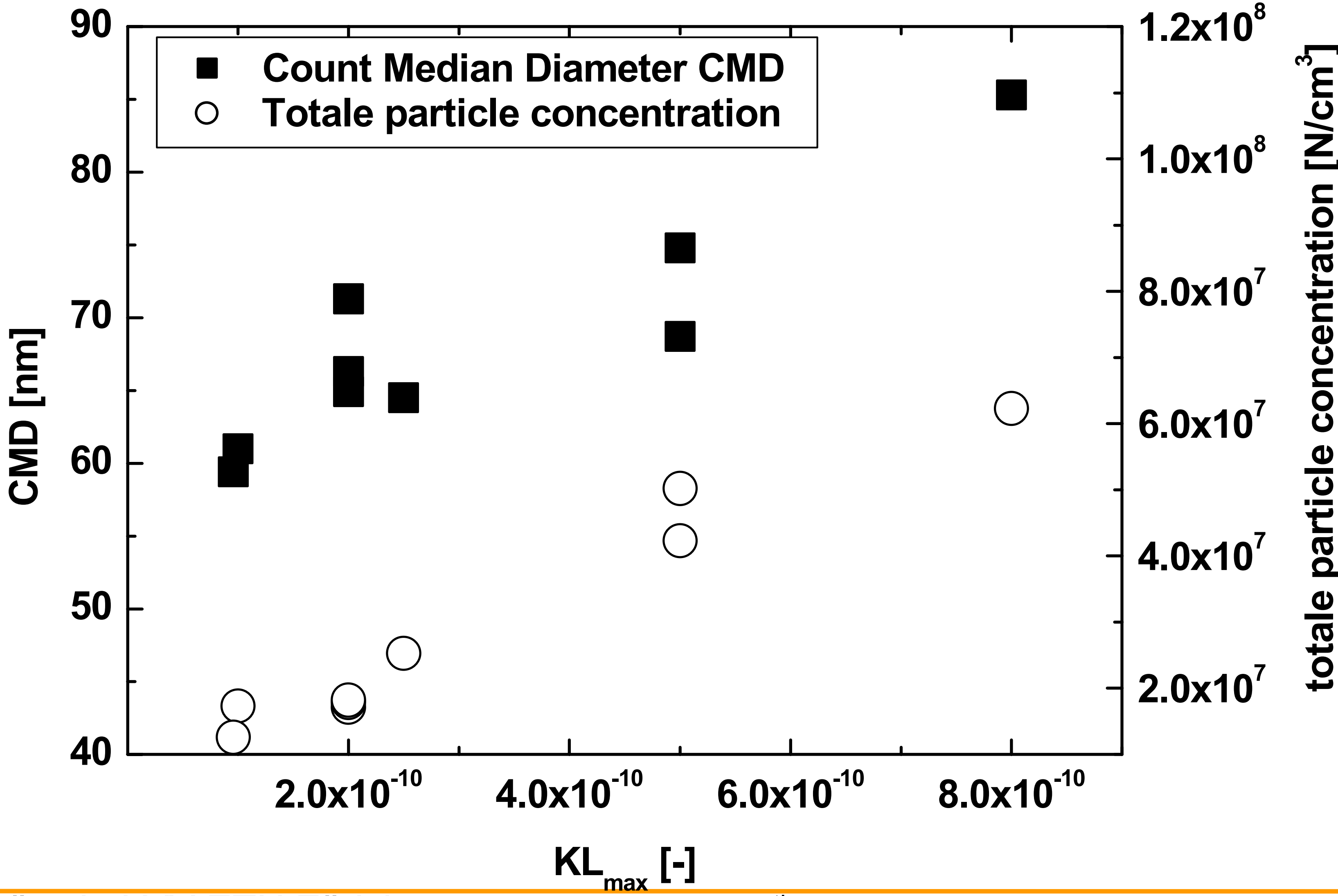
Stratified Charge vs. Homogeneous Charge: SMPS



Comparison Gravimetry with In-Cylinder-Measurements



Comparison SMPS with In-Cylinder Measurements



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Typical SMPS Results in Comparison to In-Cylinder-Results Comparison to Literature

Running condition	Totale particle con-centration [N/cm³]	Literature [N/cm³]	CMD [nm]	Literature CMD [nm]	KL_{max} [-]	∫KL [-]
Multi point injection homogen. charge	$5.65*10^5$ N/cm³	10^5 N/cm³ to 10^4 N/cm³	27.4nm	between 20nm and 38nm (dependent on load)	-	-
Direct injection homogen. charge	$2.10*10^6$ N/cm³	10^7-10^8 N/cm³	66.3nm	88nm	10^{-13} bis 10^{-14}	-
Direct injection stratification	$4.23*10^7$ N/cm³	10^8 N/cm^{-3}	68.7nm	68nm to 81nm	$4*10^{-10}$	10^{-8}
Common-rail-diesel engine	10^7 N/cm³	10^8 p/cm³ für light-duty-diesel engine w/o after treatment	55nm to 70nm	60nm to 120nm	$4*10^{-9}$	10^{-7}

Conclusions and Outlook

- During stratification, we observe a higher soot level as compared to homogeneous charge
- There is a good correlation between in-cylinder-soot measurements and exhaust pipe investigations
- In diesel engines, soot oxidation appears to be more effective than in gasoline direct injection engines
- Gasoline direct injection technique can still be seen as beeing in its infancy
  $\Rightarrow$ work has to be and can be done
  to improve soot emissions

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