Developing a national standard for soot mass concentration and opacity at PTB in Germany

Background:
The technology of diesel engines has changed during the last 20 years from naturally aspirated engines too high pressure direct injection engines, which influenced also the particulate emission of such engines to smaller aerosol particles with less mass concentration. Since the introduction of Euro 5 standard in January 2011 (date of first registration of cars), no measurement and validation of the required limits could be exactly validated in Germany. This fact requires novel diagnostic instruments (Light scattering measurement techniques) for measuring particle emissions of diesel engines. Such devices must fulfill the national verification ordinance (Eichordnung) in Germany. For this purpose, a cooperation project with PTB and ASA was initiated in June 2010.

Investigation methods

A special dilution system was developed in an internal PTB co-operation for the setup of national standard.
The dilution system's specificity is the symmetrically inclination of three pipe sockets to generate an angular-dependent counter flow through the spherical mixing chamber. For investigating the gas mixing capabilities three-dimensional CFD simulations were used for solving the Navier-Stokes equations in steady state. We estimated different mixing characteristics affected by both the incoming volume flow rate and the angle of inclination. As a result the stratified gas flow observed in the case of the Y-form is largely avoided by the counter flow configuration. The reduced layering is leading to a shorter mixing length. Additionally we predict the particle distribution. Therefore a statistically representative amount of 100.000 soot particle trajectories were calculated by means of a Lagrangian Particle Tracking multiphase model. Due to the quite low volume fraction of soot the dispersed phase doesn't influence the carrier fluid. Then the particle paths during post-processing based on the flow field are visualized. There is a good agreement of the expected behavior of the mixing capabilities for different geometries considered.

Setup of national standard:

The laboratory setup of national standard includes a HiMASS-CAST for generation of soot aerosols combine with a CVS-dilution system. This configuration is used to implement at PTB a highly stable, accurately characterized and defined variable particle generation method. Several particle diagnostic devices were integrated at the end of CVS-dilution system like reference opacimeter (AVL 439), particle mobility spectrometer (SMPS), engine exhaust condensation particle counter (EECPC, TSI) and a unit for loading of filters (gravimetrical mass). With this setup it will be possible to verify a correlation between opacity coefficient (k), mass concentration (m) and number concentration (N).

Results:

First studies were performed in several test procedure to characterize the entire setup for different k values in range of 0.01 (1 mg/m³) until 1.5 m-1 (250 mg/m³) for the new scattering light devices. The first results showed a good correlation for k values between common reference opacimeter and the novel instruments.

Outlook:

This year we will be planning further measurements to evaluate and to verify the Mira report (Report No. 1965/10, Nuneaton), especially for k values below 0,1 m^{-1} and mass concentration below 13 mg/m³. Furthermore, few more devices will be installing at current laboratory setup to get more information about correlation between mass concentration and dilution factors.

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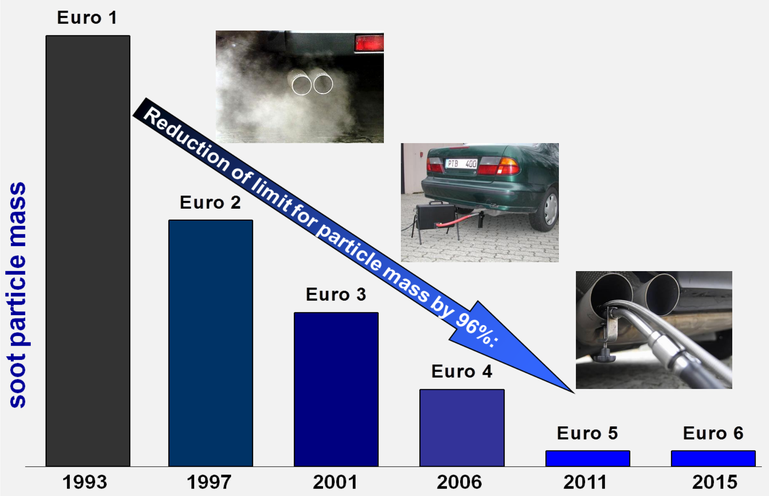
Background

➢ Technology of diesel engines has changed significantly during the last 20 years from naturally aspirated engines to high pressure direct injection engines with DPF.

➢ This new engines and also gas engines influenced the particulate emission to smaller aerosol particles with less mass per volume concentrations .

➢ Since the introduction of Euro 5 standard in January 2011 no measurement and validation of the required limits could be validated in Germany.



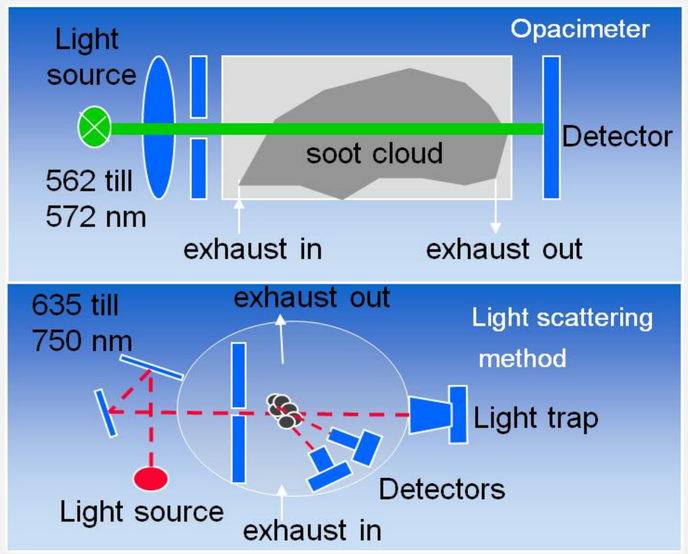
Developing of type approval limits for particulate emissions since introduction of European regulations

Motivation

➢ Novel diagnostic instruments (scattered light principle) with better sensitivity for measuring particle emissions are strongly needed.

➢ Such devices must fulfill the national verification ordinance (Eichordnung) in Germany.

➢ New correlation between mass and opacity have to determined for novel devices.



Simple schemes of common opacimeters versus novel devices based on light scatter principles

Objectives

PTB and ASA Cooperation project

➢Setup a metrological infrastructure for developing scientific fundamentals of the second generation opacimeter (scattered light principle)

➢ Determination of missing correlations between soot mass concentration (m) and transmission coefficient (k)

➢ Transfer of scientific results in the type approval procedures for the new devices

Ongoing development towards particle counting at PTB for automotive industry (VW, BMW…)

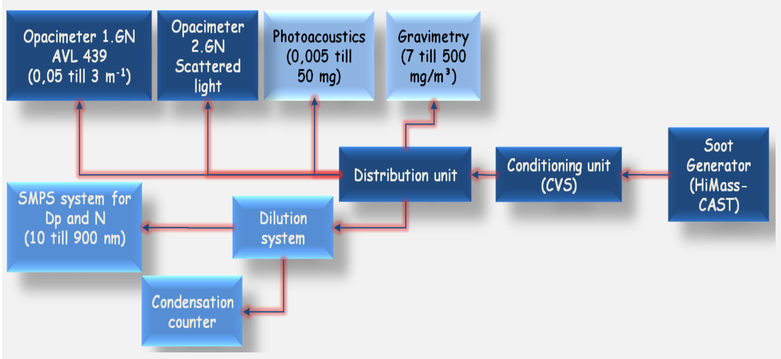
➢ Setup a metrological infrastructure for traceability of condensation particle counter for counting of soot particle number concentration (EMRP project, ENV02) → see posters

–Schlatter J. / Automotive Combustion Particle Metrics: Metrological Implementation within EMRP
–Klein T. / Generation and Traceable Electron-Microscopic Characterization of Monodisperse Aerosols
–Högström R. / A Novel Diesel Soot Particle Generator for Calibration Purposes
–Nicolet A. / Nanoparticles Trajectories in an Electrostatic Precipitator: Simulation and Experimental Validation

Setup of a national standard for soot mass concentration and opacity

Instrumentation

• Using different diagnostic devices to determine correlation factors between soot mass (m), transmission coefficient (k) and number concentration (N).



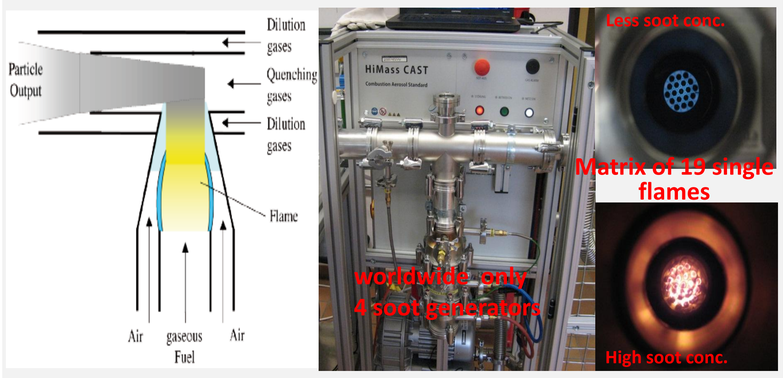
Scheme of setup for a national standard

• Following diagnostic instruments were implemented:

– Opacimeter (AVL 439) as reference system
– Particle mobility spectrometer (non-commercial SMPS)
– Engine exhaust condensation particle counter (EECPC, TSI)
– Unit for loading of filters (gravimetrical mass)
– Planned: Micro Soot Sensor (AVL 483)

Soot Aerosol Generation

• Providing a homogeneous soot aerosol with high dynamic range and temporal stability.



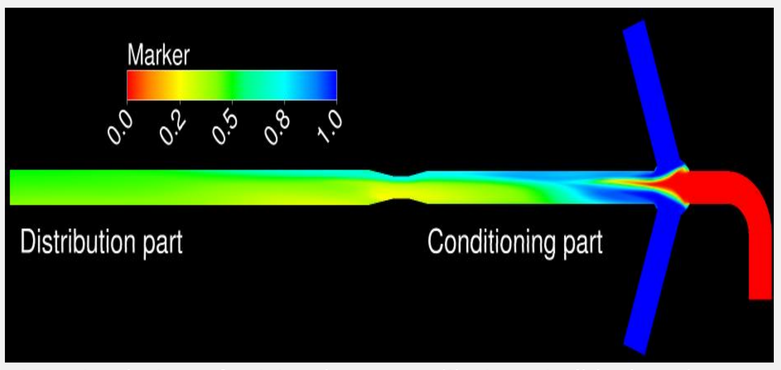
Diffusion flame generator in different operating modes and a process scheme of a single flame

• Installing a modified HiMass-CAST (Jing Ltd) for:

– Generating „diesel like“ soot aerosols under a highly stable and accurately characterized conditions
– **Goal:** Developing a primary standard for soot generation

Aerosol Conditioning

• A new conditioning unit for dilution was developed and investigated in an internal PTB co-operation.



CFD simulation of mixing between dilution air (blue) and soot aerosols (red), green indicates homogeneous dilution

• Three-dimensional CFD simulation to optimize the flow condition in the setup by:

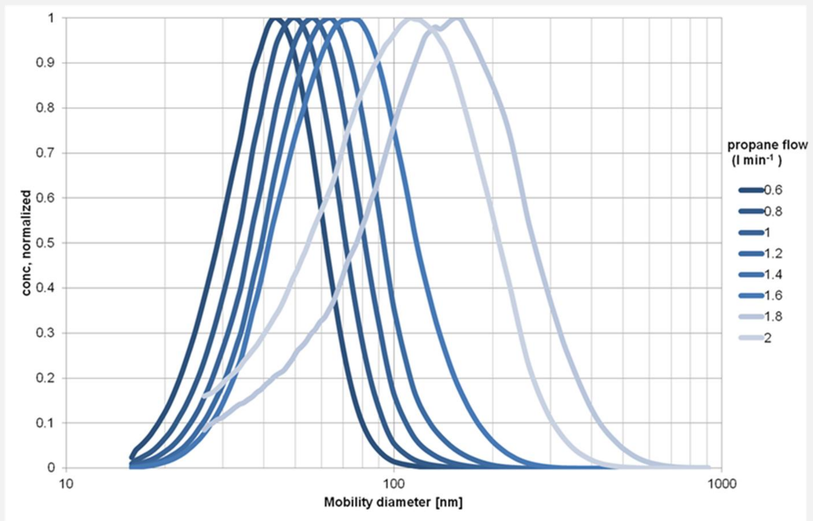
– Investigating of the gas mixing capabilities
– Solving the Navier-Stokes equations in steady state
– Estimating different mixing characteristics by the incoming volume flow rate and the angle of inclination

First results

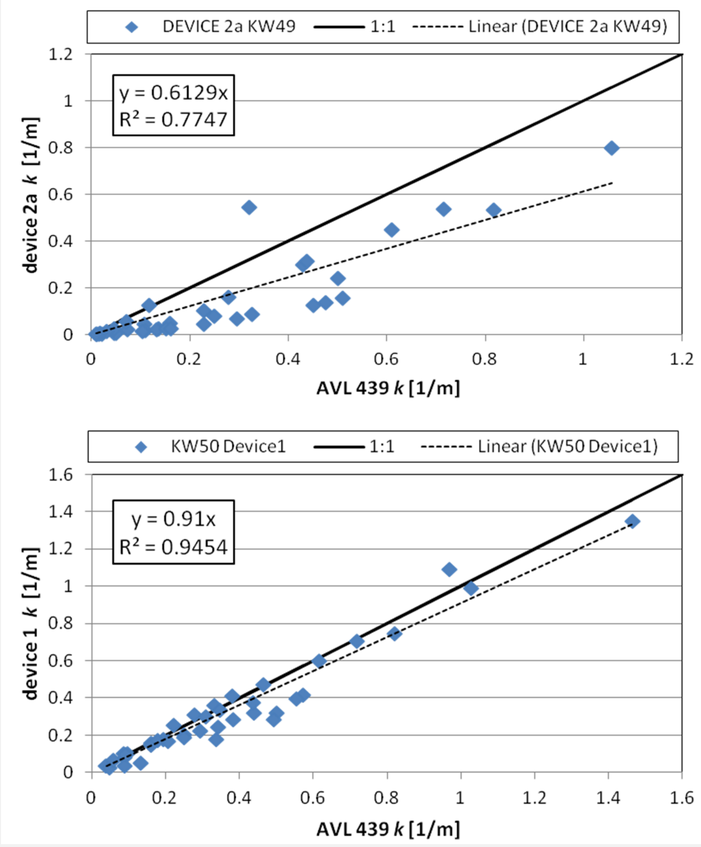
• A variation of the internal flows of the soot generator allows a wide range of operation conditions :

– Propane: 0.6 up to 2.0 l/min
– Nitrogen: 0 up to 30 l/min
– Dilution air: 417 l/min

• First results based on two campaigns realized in Dec 2011 with a non-modified generator.



Normalized particle size distributions emitted by CAST generator for different operation points



Comparison between reference opacimeter (AVL 439) and two test devices including linear correlation for k

Conclusion

➢ First studies were preformed for k-values between 0,01 m^{-1} (1 mg/m^3) and 1,5 m^{-1} (250 mg/m^3).

➢ Good correlation for k-values between common reference opacimeter and the novel instruments could be found.

➢ For stabilizing the concentration the HiMass-CAST were modified.

Outlook

➢ More studies are necessary, especially for k-values below 0,1 m^{-1} and m below 13 mg/m^3 with focus on the new level of the emission test sticker values

➢ Traceable correlation for m and k

➢ Full uncertainty budget for measurement of k and m

➢ Calibration service for novel devices for industrial association and manufactures of measuring instruments

➢ Extension of the infrastructure towards soot particle counting