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Extensive Characterization of the Particulate Emission from Modern IC Engines

The Laboratory of Internal Combustion Engines and Combustion Technology of the Swiss Federal Institute of Technology in Zurich (ETHZ) had the lead in a project, dealing with measurements of particulate emissions of engines with different combustion systems, - from a 2-stroke marine diesel engine to a prototype gasoline engine with direct injection. The intention was to learn more about particulate size/number distributions and their chemical composition under various running conditions.

The project was initiated by a Swiss working party, dealing with all aspects of the particulate emission of internal combustion engines and composed of exponents of industry, federal administration and technical universities. The engine tests were performed by Wärtsilä (Switzerland) Ltd., the Laboratory of Internal Combustion engines of ETHZ and the Swiss Federal Laboratory for Materials Testing and Research (EMPA). The particulate measurements were done by EMPA, the Laboratory of Solid State Physics of ETHZ, and Matter Engineering Ltd., Wohlen (CH).

Tested engines:
- 2-stroke marine diesel engine)
- 1-cylinder (truck type) diesel engine with common rail fuel injection
- CNG-SI stationary engine (truck engine based)
- 1-cylinder prototype gasoline engine with direct fuel injection

The influences of the following parameters were of special interest with respect to the particulate size/number distribution and the chemical composition:
- engine size and combustion system
- engine load and speed
- EGR
- fuel (e.g. Heavy Fuel Oil, oxygenated and other diesel fuels, RME)

All measurements demonstrated that there is some correlation between the particulate mass calculated on the base of the SMPS measured total particulate number densities and the directly measured mass. Especially from the 2-stroke marine diesel engine tests it is known that the calculated masses without thermodesorber correspond to the total mass, defined as the sum of soluble and insoluble fractions. However, there are exceptions and further investigations are necessary, e.g., to identify the chemical composition of the particulates left after the thermodesorber.

A DI-SI-engine, when run in the stratified charge mode provoking a diffusion combustion phase, generates particulate emissions much closer to modern diesel engines in mass and number density than conventional gasoline engines with similar count median diameters somewhere between 60 and 80 nm. Furthermore, in most operating conditions the biggest part of the particulate mass is elemental carbon, similar to vehicular diesel engines.

With modern, fully electronically controlled high pressure fuel injection systems it is possible to influence the particulate emissions by number and mass at least within a range of more than ten to one. But the known trade-off between NO_x and particulate emissions still exists and reduces the freedom of choice to reduce the particulate emissions by internal means. The influence of oxygenated components added to the diesel fuel on the particulate emissions is less pronounced, - e.g., with a mixture of 50% butylal/50% diesel fuel a reduction of 40% was achieved. Recently developed fuel injection and combustion systems are able to reduce the particulate emissions by mass and about proportional to number significantly. However, their potential to further reduce exhaust emissions of NO_x and particulates for diesel driven on-road vehicles without exhaust gas aftertreatment is not (yet) sufficient.

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Extensive Characterization of the Particulate Emission from Modern IC Engines

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Project in cooperation with

EMPA, Laboratory of Solid State Physics of ETHZ,
TTM, FH Aargau

Goals

Characterisation of Particulate Matter Emissions out of I.C. engines, based on a comparative study, in order to clarify the influence of

⇒engine combustion system, fuel composition, operating conditions, air/fuel-path optimization and engine size on

⇒particle size/number distribution, PM-mass, particulate composition, morphology, exhaust gas opacity using

⇒a variety of complementary measurement techniques and methods of analysis.

Test Engines

- 2-stroke **marine diesel** engine, Sulzer 4RT-flex58T-B, common rail fuel injection
- 1-cylinder (**truck type**) diesel engine common rail fuel injection, Liebherr
- **CNG**-SI stationary **engine** (truck based), Liebherr
- 1-cylinder prototype gasoline engine, direct fuel injection

Parameters of Interest

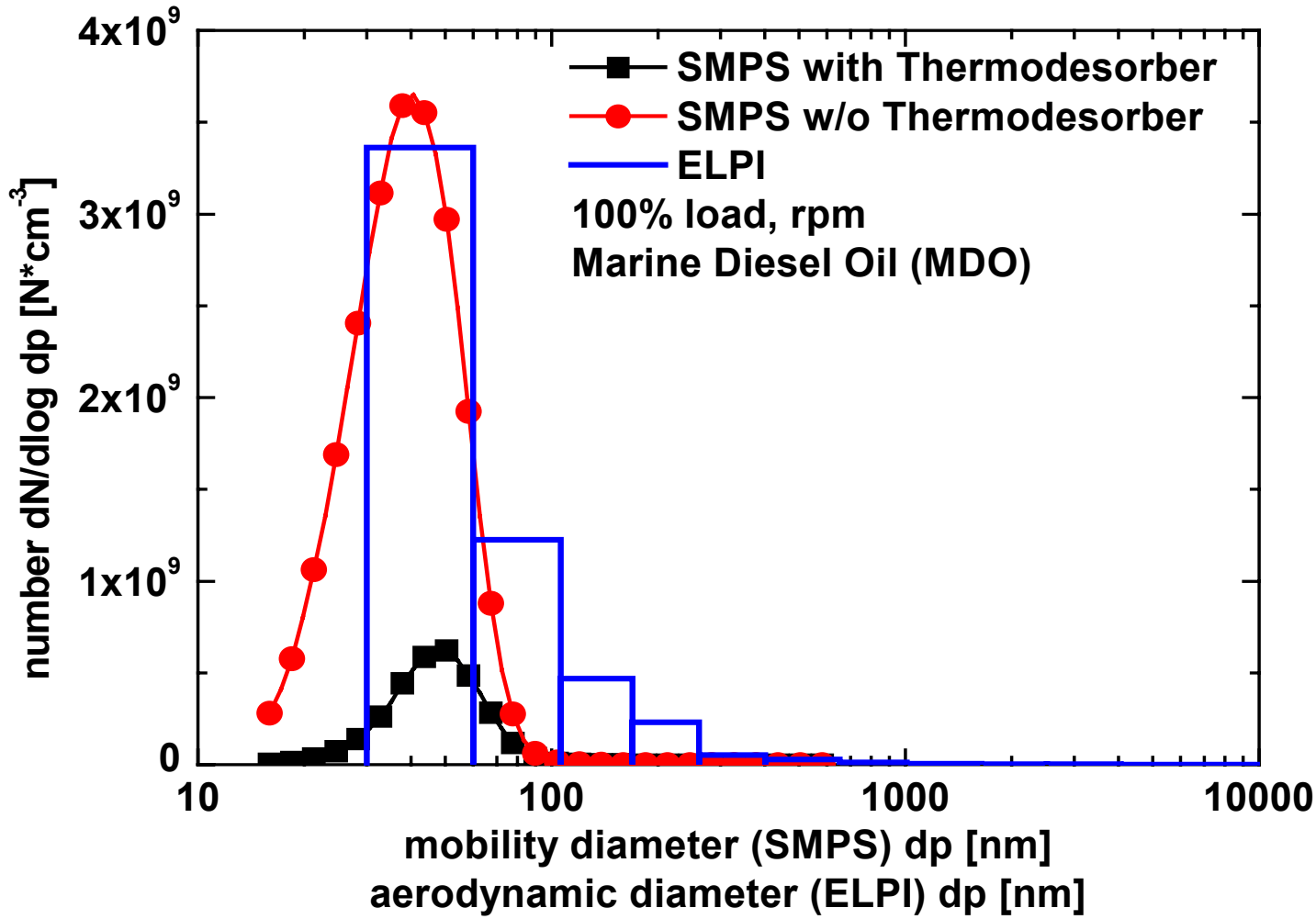
- engine size and combustion system
- engine load and speed
- EGR (Exhaust Gas Recirculation)
- fuel (e.g Heavy Fuel Oil, oxygenated and other diesel fuels, RME)

Measuring Systems

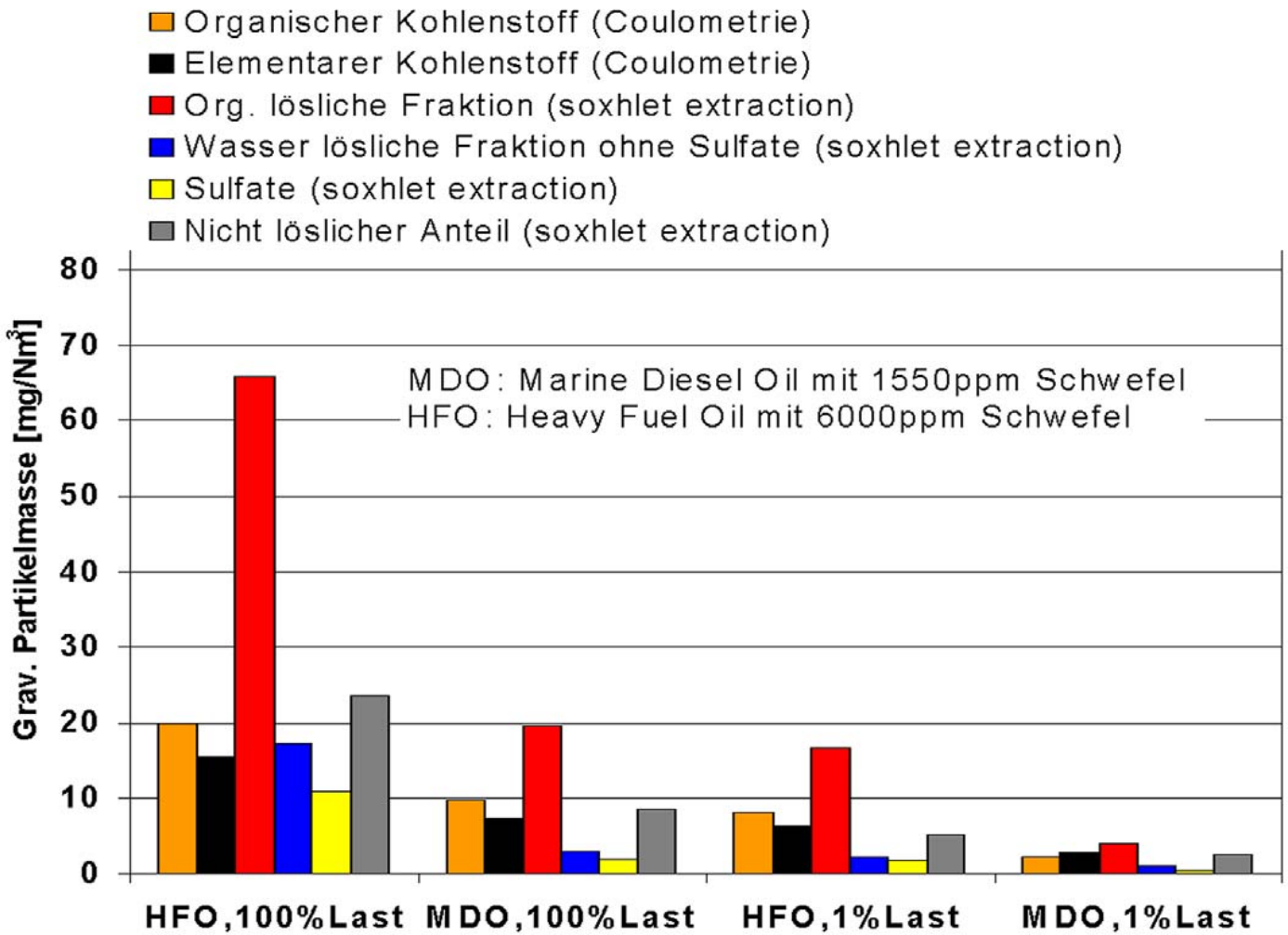
- **SMPS** Scanning Mobility Particle Sizer
- **ELPI** Electrical Low Pressure Impactor
- **PAS** Photoelectric Aerosol Sensor
- **DC** Diffusion Charging Sensor
- **Opacimetry**
- **Gravimetric mass analysis**
- **Coulometric carbon analysis**

Typical Size/Number Distribution of the 2-Stroke Marine Diesel Engine

(with/without Thermodesorber)



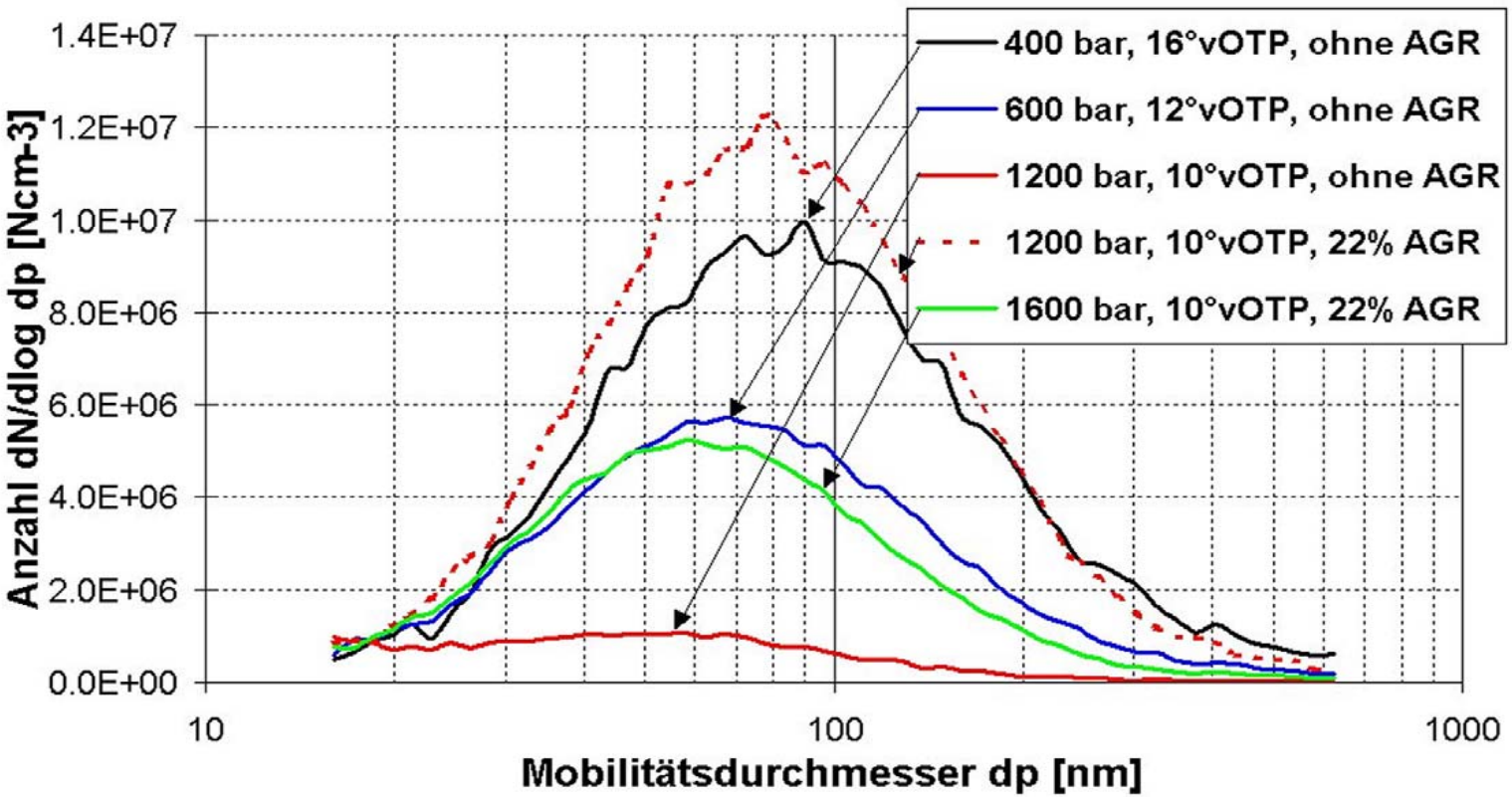
2-Stroke Marine Diesel Engine
Results of Filter Analysis of Selected Running Modes



1-Cylinder Diesel Engine

Particle Size/Number Distribution, with Thermodesorber (350°C) Variation of Rail Pressure and EGR

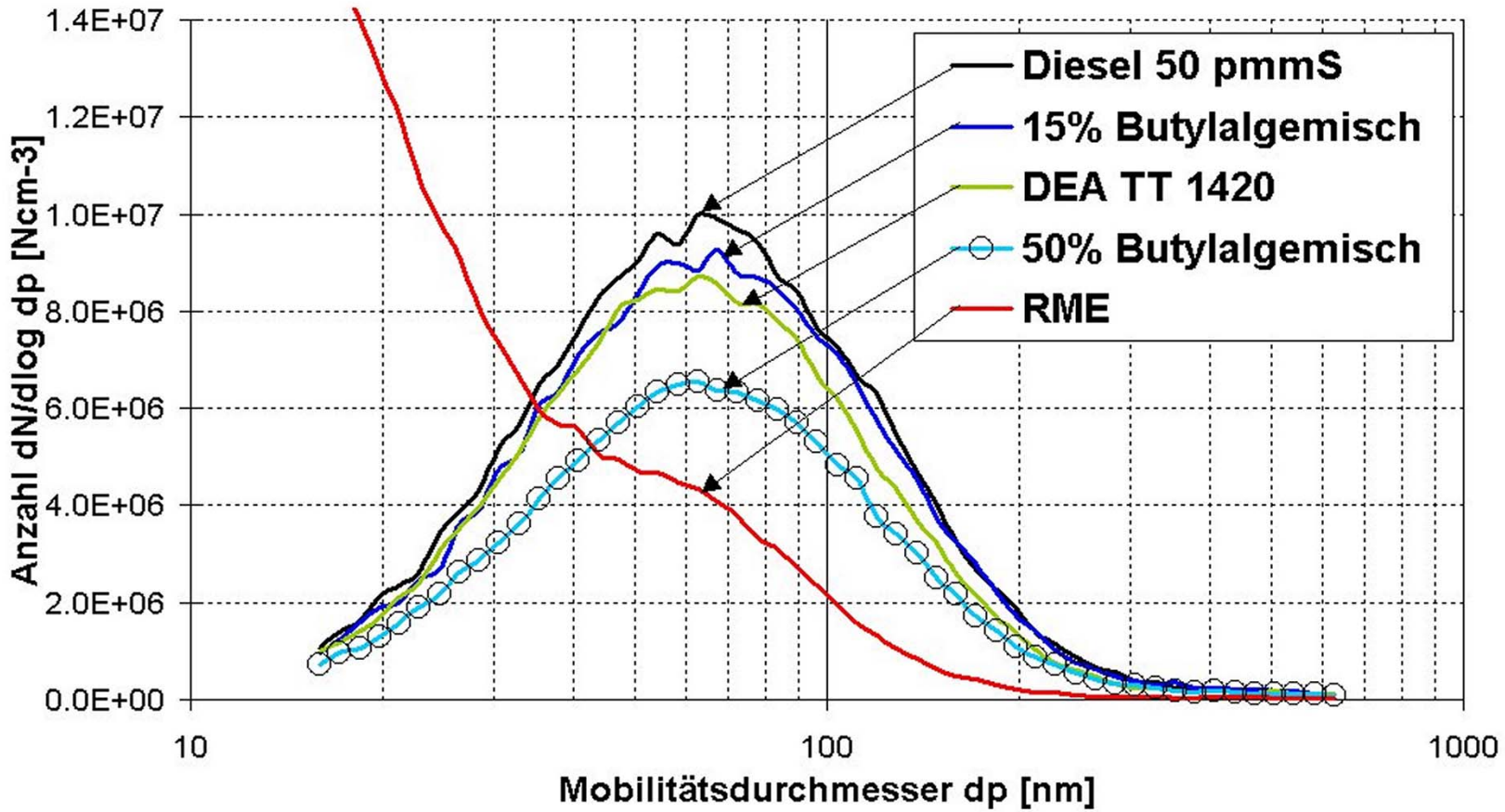
n = 1460 rpm, bmep = 9.3 bar, diesel fuel with 50 ppm S, thermodesorber at 350ºC



1-Cylinder Diesel Engine

Particle Size/Number Distribution for Different Fuels

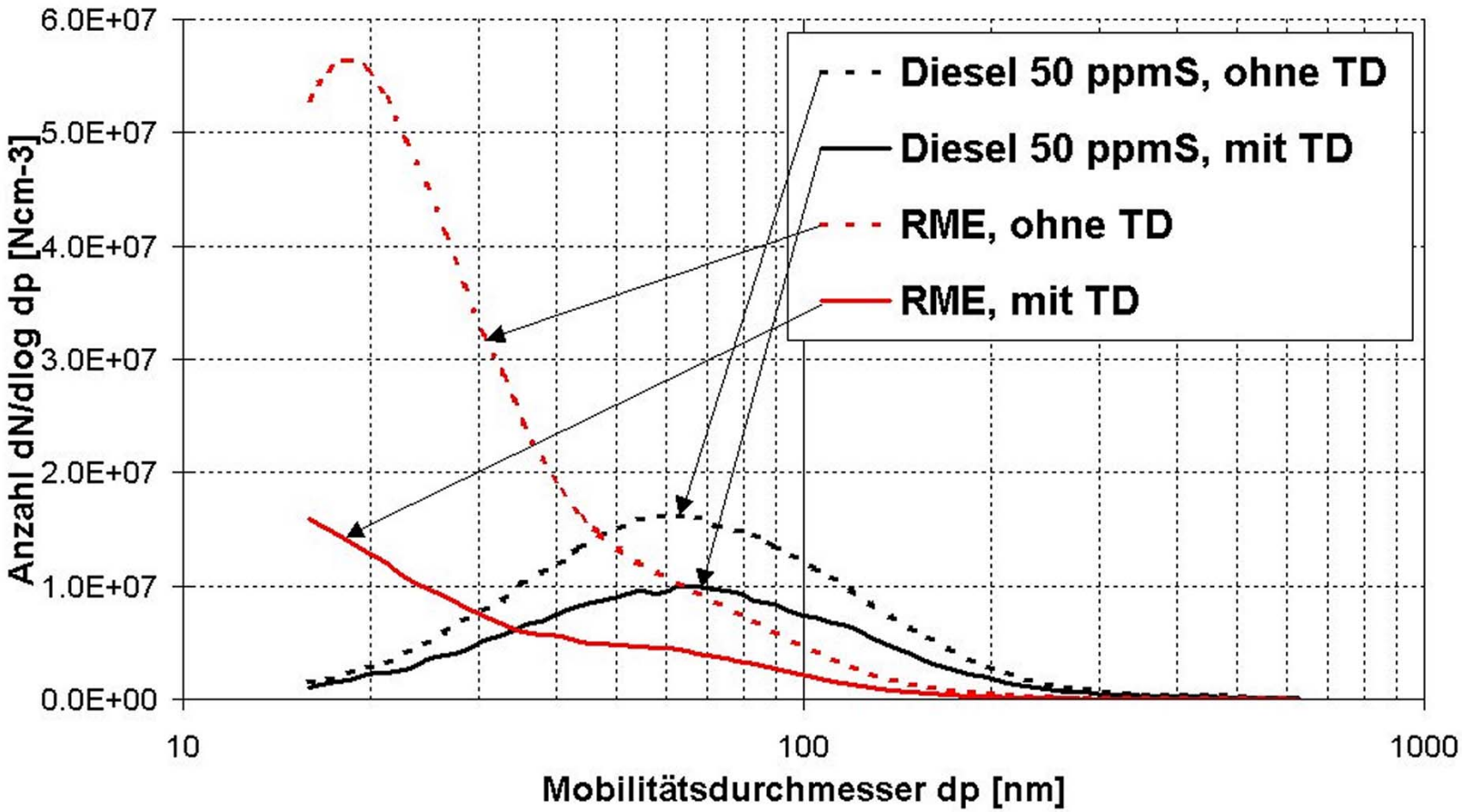
n = 1180 rpm, bmep = 4.7 bar, rail pressure 500 bar, thermodesorber at 350ºC



1-Cylinder Diesel Engine

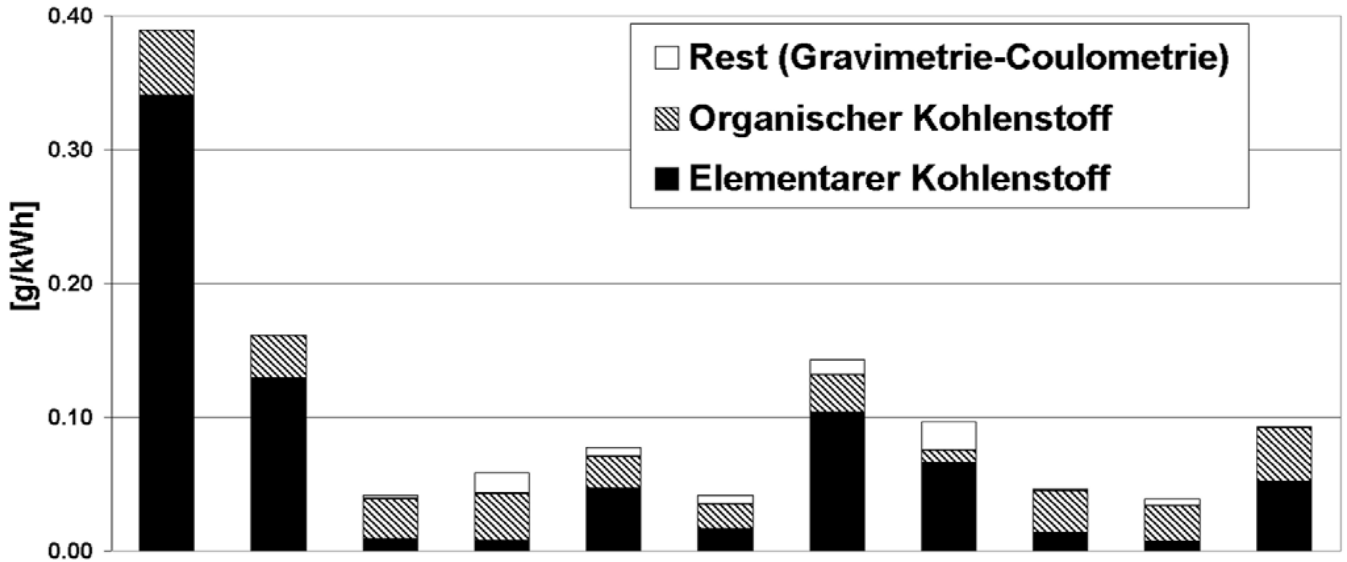
Particle Size/Number Distribution for Different Fuels

n = 1180 rpm, bmep = 4.7 bar, rail pressure 500 bar, **without/ with TD** (350°C)



1-Cylinder Diesel Engine

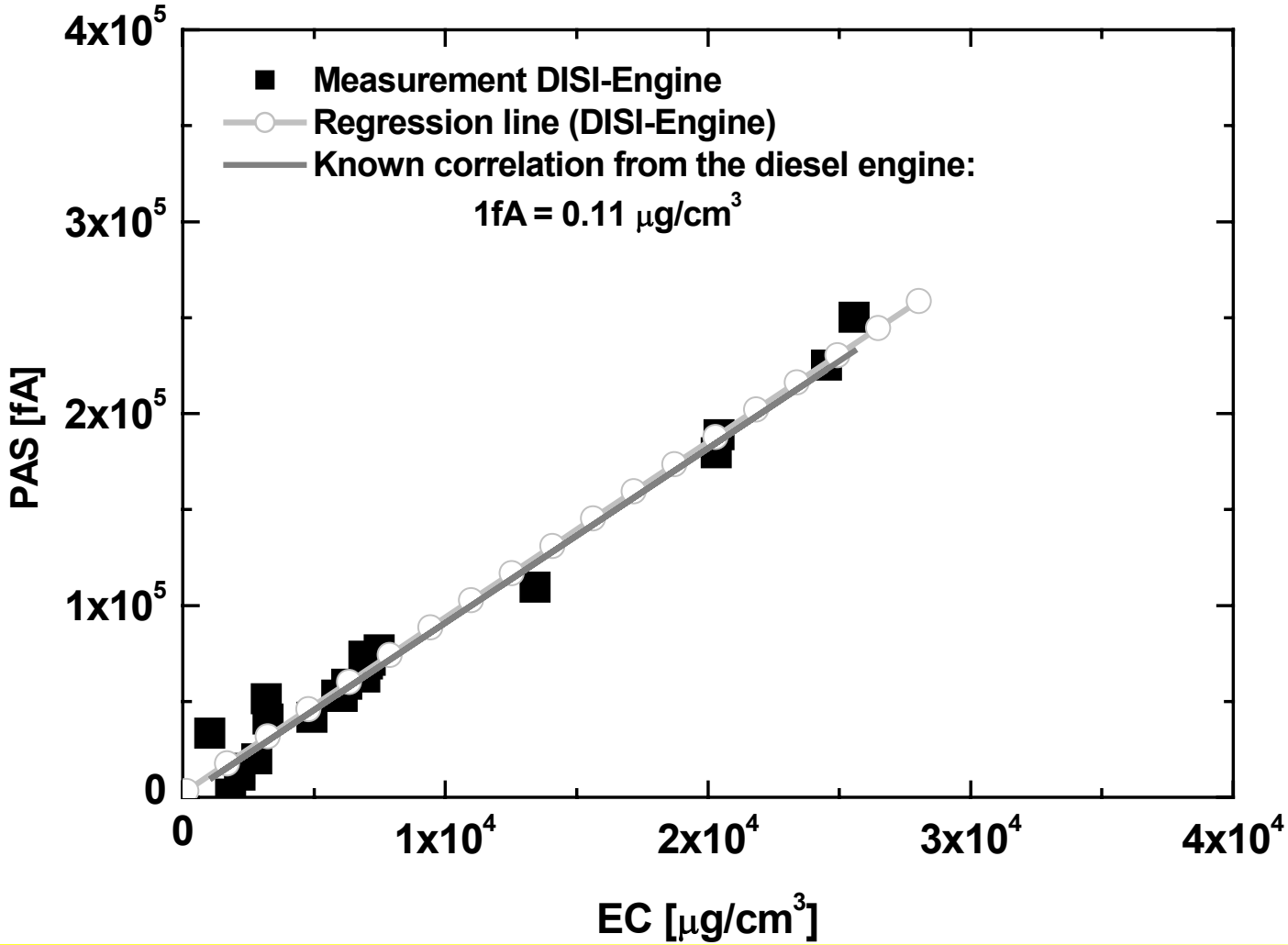
Results of Filter Analysis of Selected Running Modes



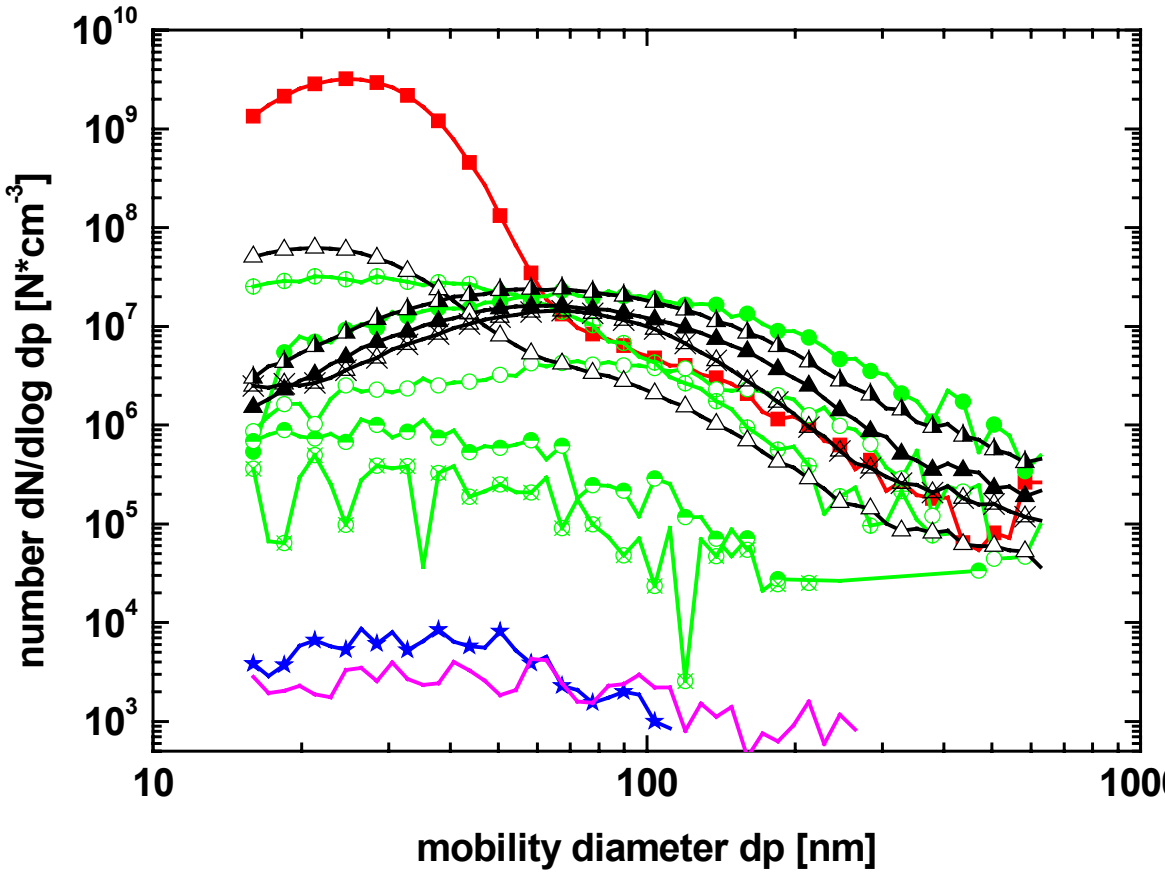
n [1/Min]	1180	1180	1180	1460	1460	1460	1740	1740	1740	1180	1740
pme [bar]	4.7	4.7	4.7	9.3	9.3	9.3	12.3	12.3	12.3	4.7	12.3
p Inj [bar]	300	300	1200	1200	1200	1600	700	700	1100	1200	700
tB [°KWvOTP]	8	12	12	10	10	10	8	8	10	12	9
Butylal [%]	0	0	0	0	0	0	0	0	0	50	50
AGR-Rate [%]	0	0	0	0	22	22	0	0	0	0	0
Nacheinspritzung	nein	nein	nein	nein	nein	nein	nein	ja	nein	nein	nein

DI SI Engine with Stratified Charge

Correlation PAS-Elementary Carbon



Comparison of Particulate Size/Number Distributions for Selected Operating Conditions of All Engines Investigated



- Marine diesel engine, 2 stroke, 25% load,105 rpm
- Diesel engine, 25% load, 500 bar, 1180 rpm, 6°BTDC
- Diesel engine, 25% load, 1200 bar, 1180 rpm, tB 12°BTDC
- Diesel engine, 25% load, 1200 bar, 1180 rpm, tB 12°BTDC, 36% EGR
- Diesel engine 75% load, 900 bar, 1740 rpm, 5°BTDC
- DISI stratification (DI), 25% load, 2000 rpm
- DISI homogeneous charge (DI), 50% load, 2000 rpm, λ= 1.0
- Homogeneous charge (multi point injection), 50% load, 2000 rpm, λ= 0.8
- Homogeneous charge (multi point injection), 50% load, 2000 rpm, λ= 1.0
- Homogeneous charge (multi point injection), λ= 1.3
- Gas engine, 50% load, 1500 rpm
- air

All results without thermodesorber

Conclusions

- PM-mass and particle number concentration in the exhaust are in reasonable agreement to each other in almost all cases investigated
- For diesel engines, the potential for substantial further reduction of PM-emissions is highest on the basis of innovative fuel-/air-path systems, the fuel composition having a supportive influence
- Direct-injection gasoline engines exhibit a similar behaviour to DI-Diesel engines, when operated in stratified mode
- The large, low-speed diesel engine with common-rail fuel injection showed an expected influence of Heavy us. Marine fuel, but also rather surprising trends with regard to smaller observed particle size and high-percentage of organically-bound, volatile compounds
- Optimised premixed combustion, particularly with CNG as fuel helps achieve particle number concentrations in the engine exhaust comparable to laboratory air quality.

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