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Paper/Poster-Abstract Form

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Title:
Particle Number Counting in Heavy Duty Diesel exhaust: Routine or still a challenge

Abstract: (min. 300 – max. 500 words)

The abstracts for papers and posters must contain unpublished information on your research subject: background, investigation methods, results and conclusions. Graphs and references are very welcome. Acronyms should be avoided. Abstracts with < 300 words can not be considered. General information on products which are already commercially available can not be accepted as presentations for the conference but are very welcome at the exhibition of particle filter systems and nanoparticle measurement instruments.

To enforce the use of closed DPFs for HD vehicles a particle number emission limit has been introduced for EuroVI. The Particle number measurement procedure for HD vehicles which is described in regulation 49 has been adopted from the passenger car regulation 83. The method itself was developed by the UNECE within PMP (Particle Measurement Programme) of the working group GRPE (Working Party on Pollution and Energy). The method itself is highly scientific. High dilution ratios of 10.000 or more are needed to reach the measurement range of the particle number counter (concentration and temperature). The determination of this so called "PCRF values" is quite difficult. To separate the volatile fraction of the particles from the solid ones an evaporation tube is used where the particles are heated up to 400°C. It was found that pyrolysis of organic material and morphological changes of the particles may occur. In the counting procedure itself we have some more interesting aspects. The chosen cut off point at 23 nm seems arbitrary. Why do we want to exclude the nucleation mode? We might have some organic material inside and also ash particles which are also important. Some say that the nucleation mode is a measurement artifact but as it occurs in real atmospheric dilution it cannot be an artifact. Another problem is the calibration of the particle counter. The counting efficiency dependents on the material, it is difficult to find a realistic calibration aerosol. A commercial particle counting system under real operation conditions can show of a decline of the counting efficiency of 50% or more in one year.
There are many problems to solve to make particle counting in diesel exhaust a reliable routine method for type approval and research.

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Reduction of the PN emission through engine measures and active exhaust aftertreatent

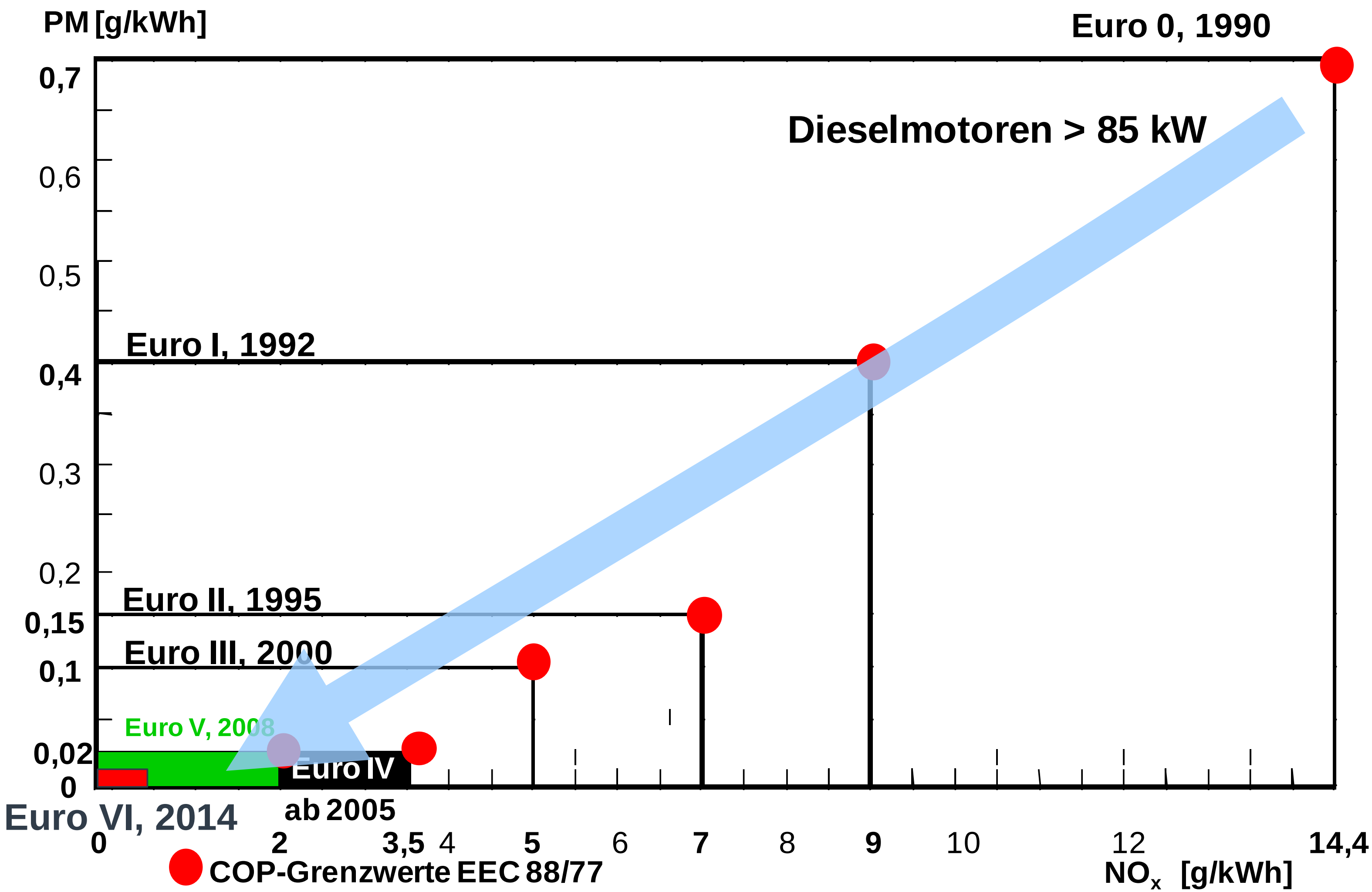
Dr. Dieter Rothe
Dominik Deyerling M. Sc.

ETH Nanoparticle Conference
Zürich, June 2012

Content

European Emission Limits

For HD-vehicles from Euro 0 bis Euro VI



Emission limits

Euro VI limits for HD vehicles

VERORDNUNG (EG) Nr. 595/2009 DES EUROPÄISCHEN PARLAMENTS UND DES RATES vom 18. Juni 2009

Anhang I der Verordnung (EG) Nr. 595/2009 erhält folgende Fassung:

„ANHANG I

Euro-VI-Emissionsgrenzwerte

	Grenzwerte							
	CO (mg/kWh)	THC (mg/kWh)	NMHC (mg/kWh)	CH_4 (mg/kWh)	NO_x (1) (mg/kWh)	NH_3 (ppm)	Partikelmasse (mg/kWh)	Partikelzahl (2) (#/kWh)
WHSC (CI)	1500	130			400	10	10	$8{,}0 \times 10^{11}$
WHTC (CI)	4000	160			460	10	10	$6{,}0 \times 10^{11}$
WHTC (PI)	4000		160	500	460	10	10	(3)

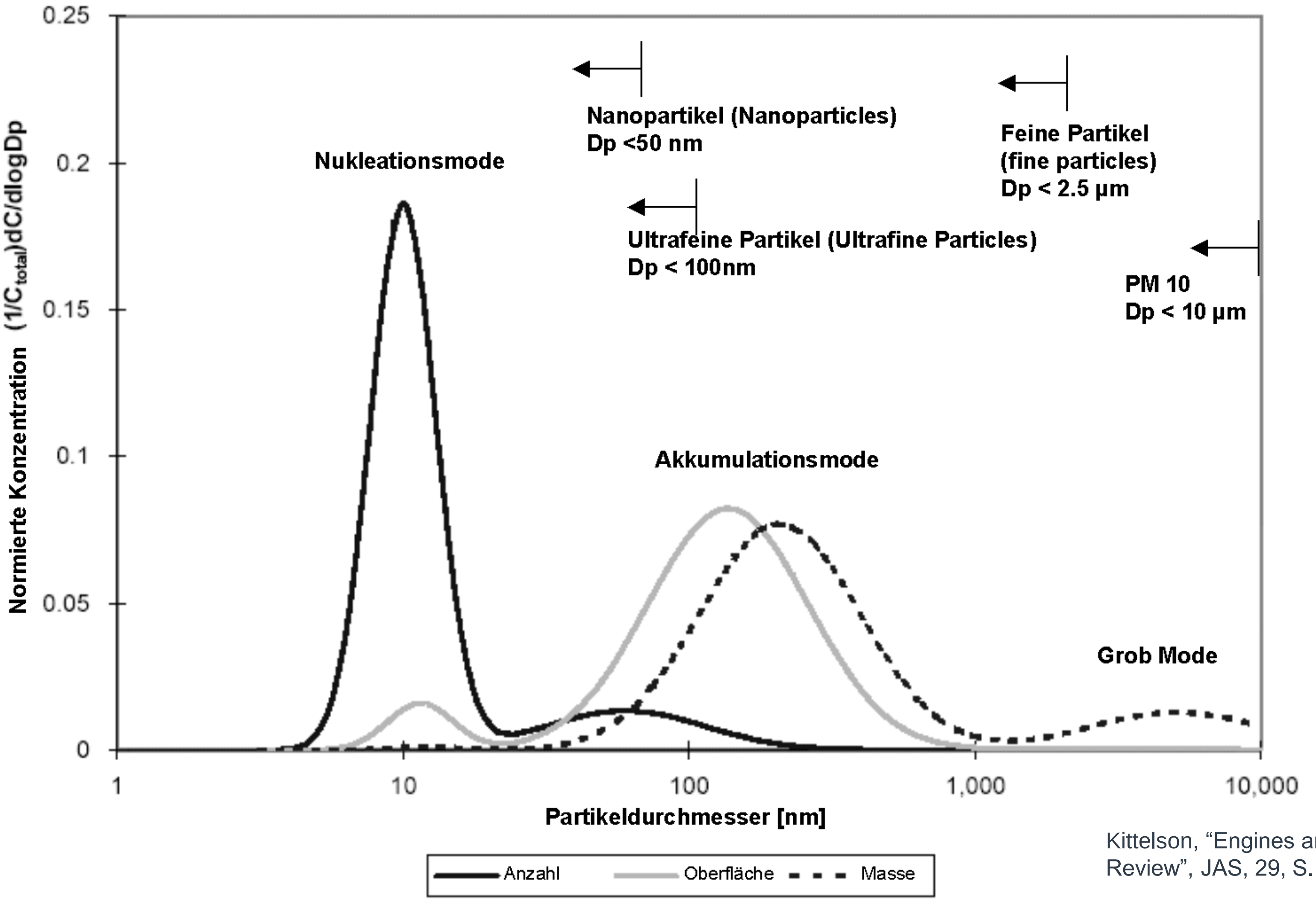
PI = Fremdzündungsmotor.
CI = Selbstzündungsmotor.
(1) Der Wert des zulässigen NO_2-Anteils am NO_x-Grenzwert kann zu einem späteren Zeitpunkt festgelegt werden.
(2) Vor dem 31. Dezember 2012 wird ein neues Messverfahren eingeführt.
(3) Vor dem 31. Dezember 2012 wird ein Grenzwert für die Partikelzahl eingeführt.“

VERORDNUNG (EU) Nr. 582/2011 DER KOMMISSION vom 25. Mai 2011

http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2011:167:0001:0168:DE:PDF

Fundamentals

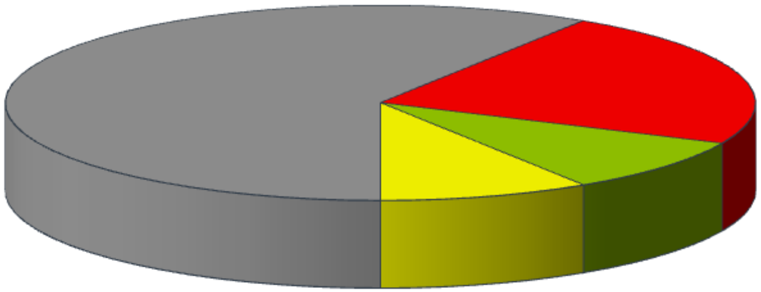
Typical particle size distribution in diesel exhaust



Kittelson, "Engines and Nanoparticles: A Review", JAS, 29, S. 575-588, 1998

Composition of diesel exhaust particles

typical composition before/after DPF



before DPF

after DPF (-95%)

Carbon
from engine combustion

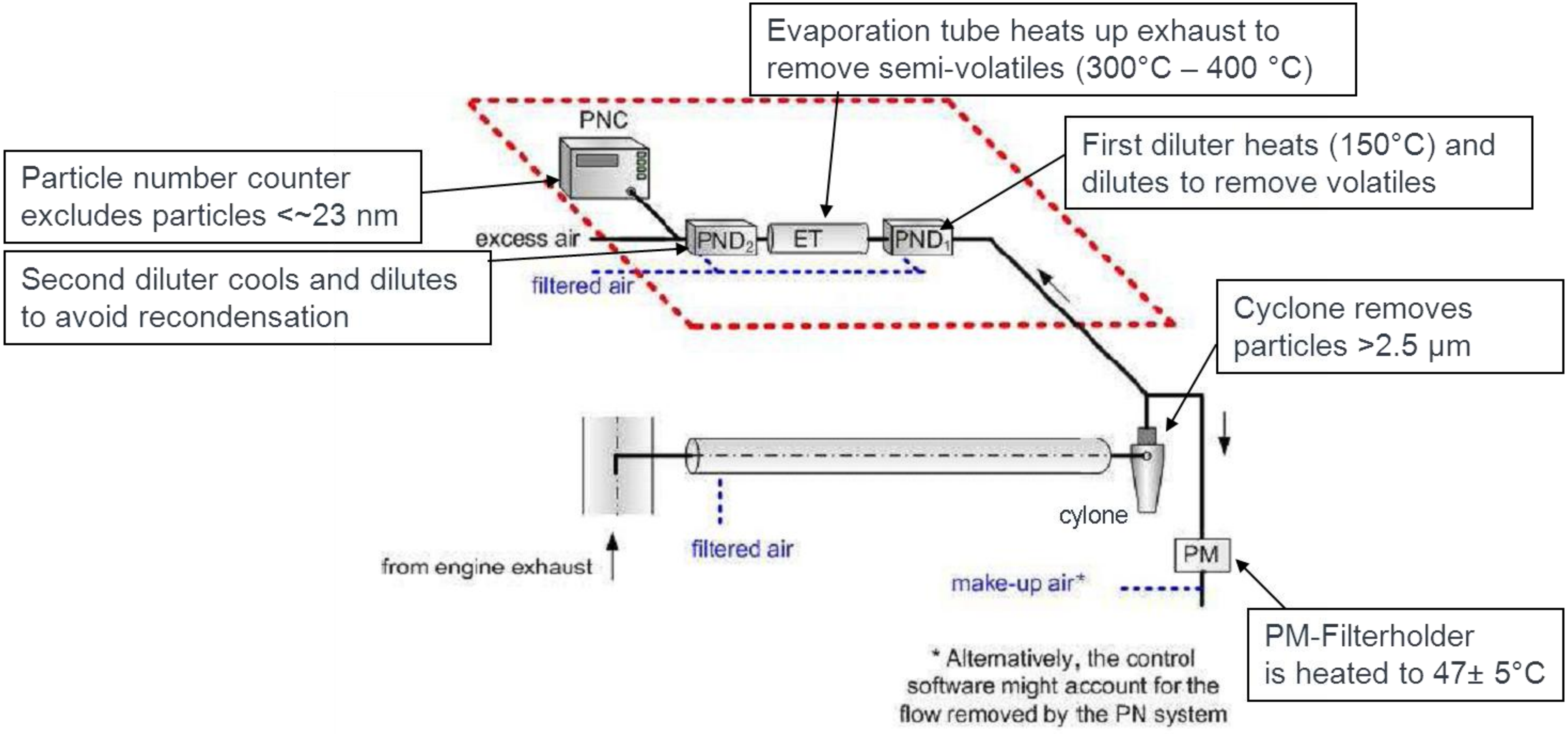
H_2SO_4/H_2O
from fuel and lube oil

Ash and Others
from lube oil additive components
from engine wear
others

Hydrocarbons
from unburned fuel and lube oil
formed in the combustion process

Fundamentals

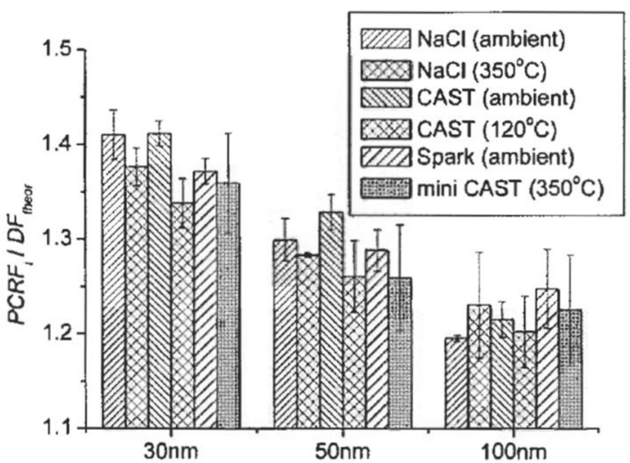
PMP PN measurement in HD diesel exhaust



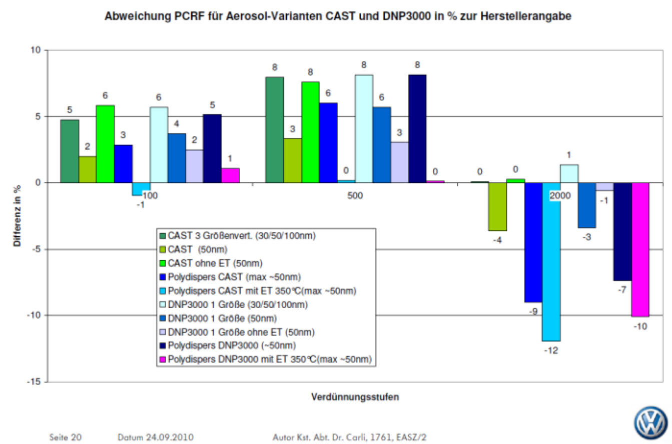
Fundamentals

Influence of dilution

- CPCs are developed for clean room measurement first
- because of that high dilution ratios are (up to 1:20.000) necessary
- Problem particle losses through dilution
- Gas dilution is displaced by PCRF (Particle Concentration Reduction Factor) (=dilution + Particle losses)
- Measurement of PCRFs is difficult and causes errors



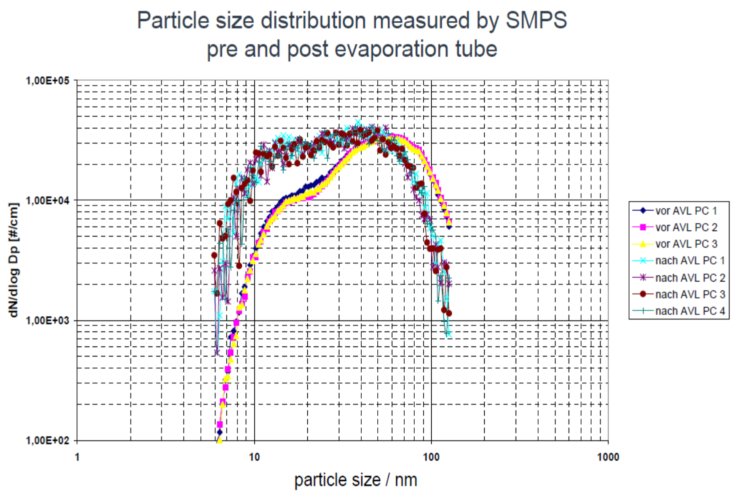
Source: AVL MST 2010



Source: VW FVV Workshop PN 2011

Fundamentals
influence of the Evaporation Tube

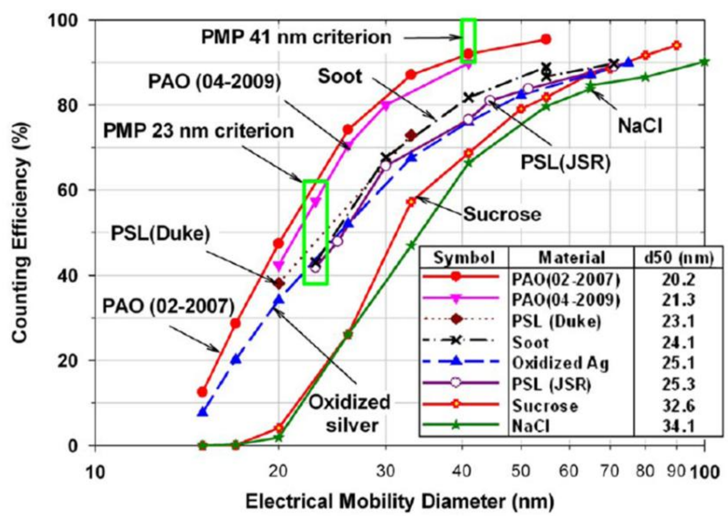
- We should count only solid particles
- So thermal conditioning of aerosol (300-400°C) is nessecary
- Pyrolysis (that means soot formation through the organic content is possible)
- Morphological changes of the soot (CNT)
- Thermophoretic sample losses



Fundamentals

Influence of the CPC

- Counting efficiency is material depended
- Interaction of aerosol with working fluid
- Aging of working fluid (formation of Esters inside of the wick, butanol drags water)
- Up to now no ideal calibration aerosol for diesel aerosol particles
- Counters are not stable in long time application in diesel exhaust
- Differences between single counters



Source: TSI, JAS, 2010

PNC validations

AVL

SN	Validation	Flow	Ref	23 nm	41 nm	55 nm	slope	Comment
70734133	2010-04-08	1.023	3775	*0.30*	***0.79***	0.89	0.95	not used
70810498	2010-02-02	-	*3790*	0.50	***0.85***	0.92	0.92	used
70933046	2010-04-06	-	3775	0.38	***0.88***	0.96	1.02	used
70831244	2010-04-16	-	*3790*	0.58	***0.73***	0.77	*0.77*	used
70835093	2010-04-06	-	3775	0.44	***0.87***	0.94	1.00	used
70842058	2010-04-16	1.012	3775	*0.23*	***0.60***	0.67	*0.71*	used
70734133	2007-11-01	-	*AE*	0.41	***0.76***	0.84	*0.84*	new
71005189	2010-04-15	0.990	3775	*0.25*	***0.81***	0.91	0.97	new
71005086	2010-04-15	*0.924*	3775	*0.30*	***0.79***	0.86	0.91	new
71011040	2010-04-16	1.001	3775	0.39	***0.87***	0.95	1.00	new
70810498	2010-04-08	1.034	3775	0.48	*0.95*	1.03	**1.07**	re-calibrated
70831244	2010-04-16	1.007	3775	0.41	***0.84***	0.92	0.97	re-calibrated
70949021	2010-04-16	1.001	3775	0.40	***0.87***	0.95	0.99	re-calibrated

	Flow	23 nm	41 nm	slope
Regulation 83 limits:	0.95 – 1.05	0.38 – 0.62		0.9 – 1.1
Failed:	1	4	(12)	3

In total 6/13 PNCs failed. Reasons:
- Flow (1)
- Different material used for the calibration (3)
- Degrading of PNC parts (2)

Source: AVL ETH 2010

Experimental setup
at the engine test bench

Engine and supplies

- D20 Euro 4 LF31 (440 PS)
- DF < 10ppm S and low ash engine oil Shell Rimula Signia

Exhaust measurement techniques

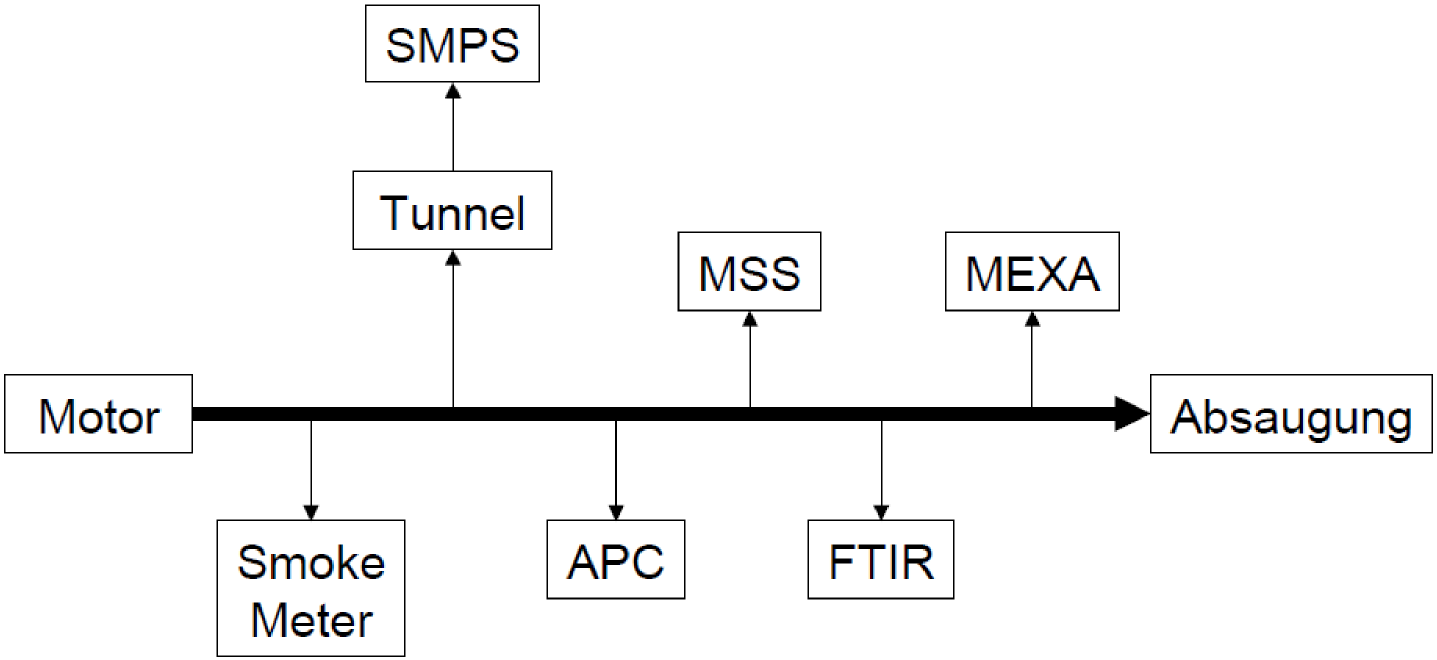
- Gaseous emissions: MEXA 7100 DEGR and Ansyco FTIR
- Particle emissions: AVL 415S, AVL MSS 483 (q=10) and Nova Mikrotrol 4
- Particle counter AVL APC 489 in raw exhaust
- Particle size distribution with TSI SMPS 3936

Exhaust aftertreatment (if used):

- HCI System
- HCI Kat 12"x8", 400 cpsi 7 mil, 60g Pt 4:1
- Filter 1 12"x12" 200 cpsi SiC, uncoated
- Filter 2 12"x12" 200 cpsi 12mil 12"x12" uncoated

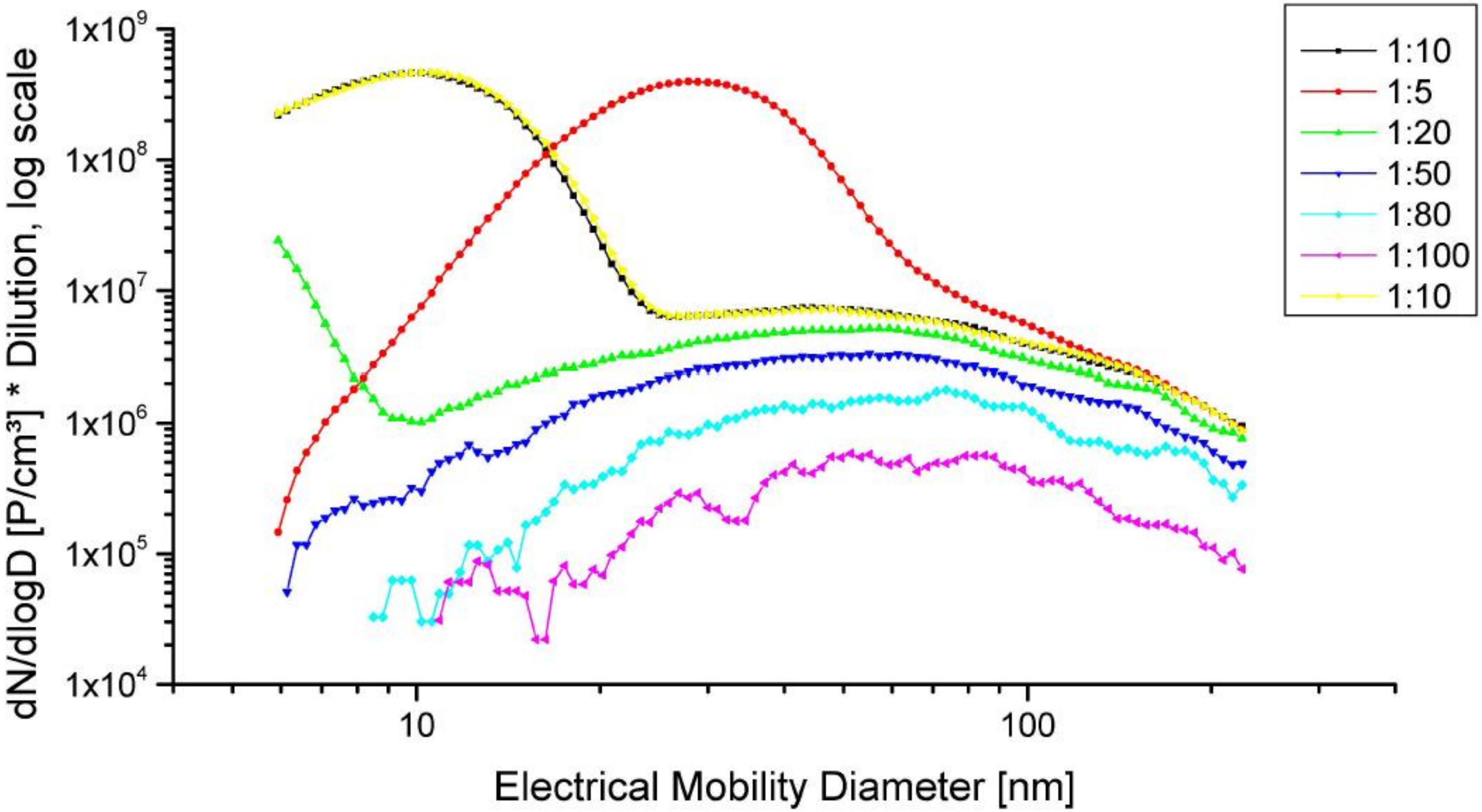
Setup

Infulence of dilution and engine measures



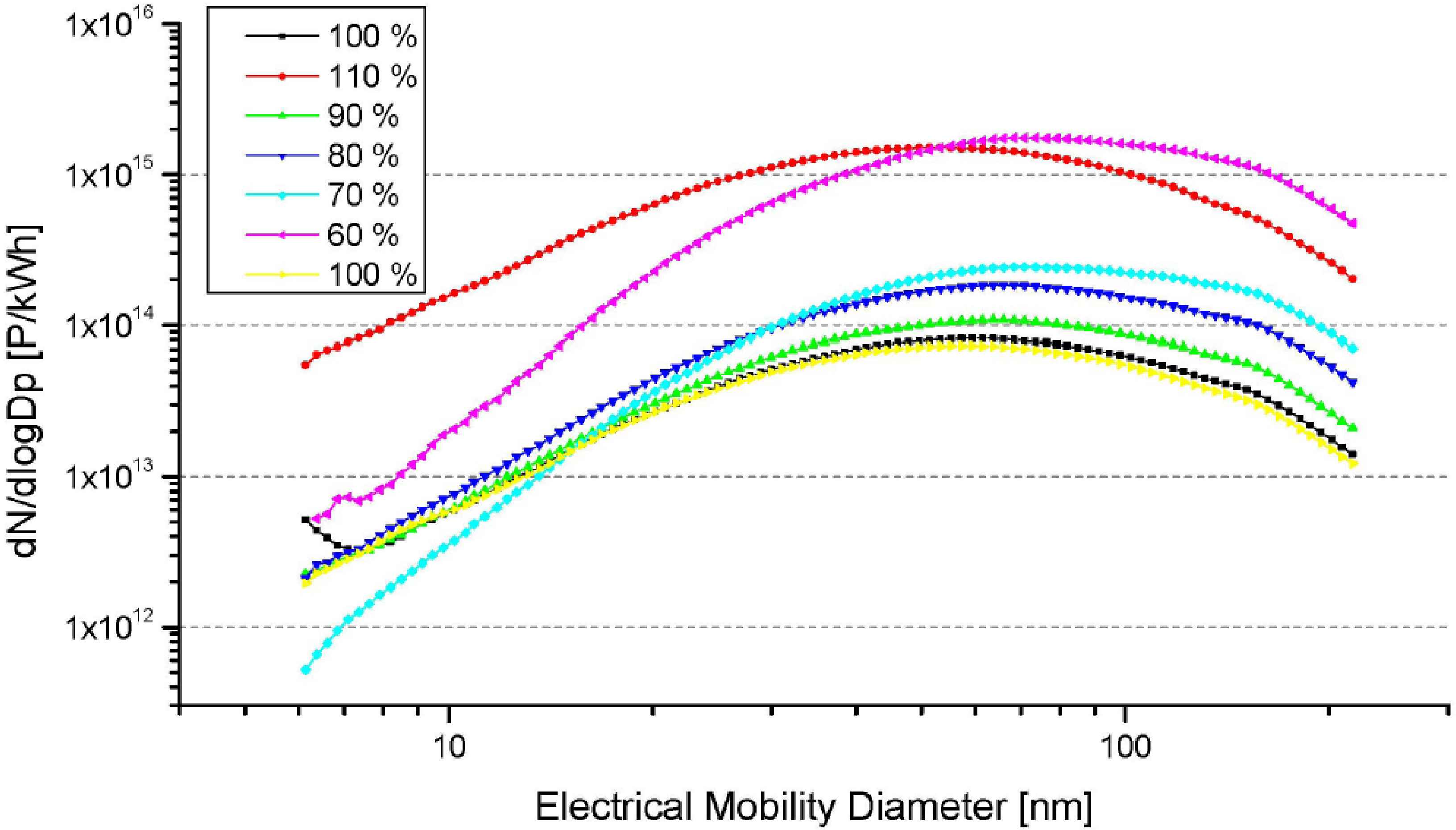
Influence of dilution

on particle size distribution



1500 min^{-1} 1400 Nm (ESC Stufe 4)

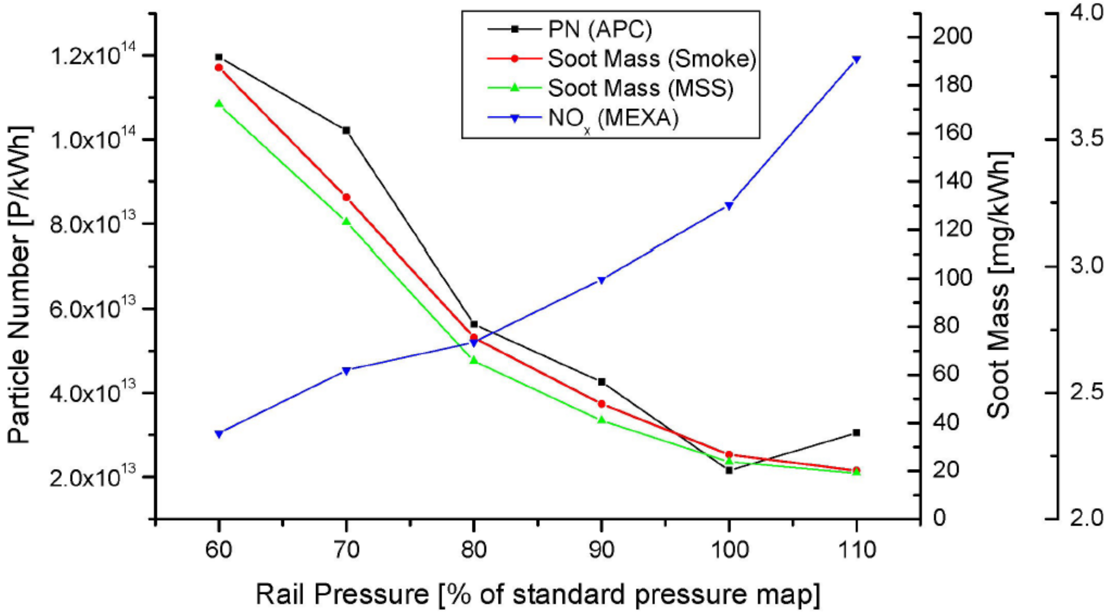
Influence of rail pressure
on particle size distribution



100% = 1600 bar, ESC-Ergebnisse

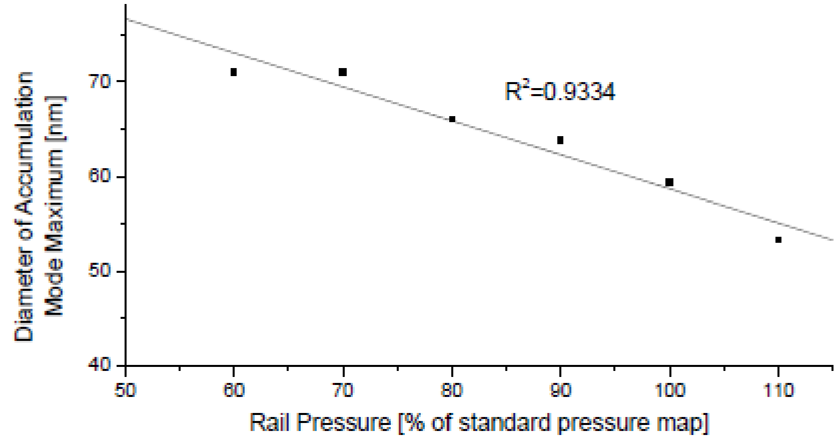
Influence of rail pressure

on other emissions

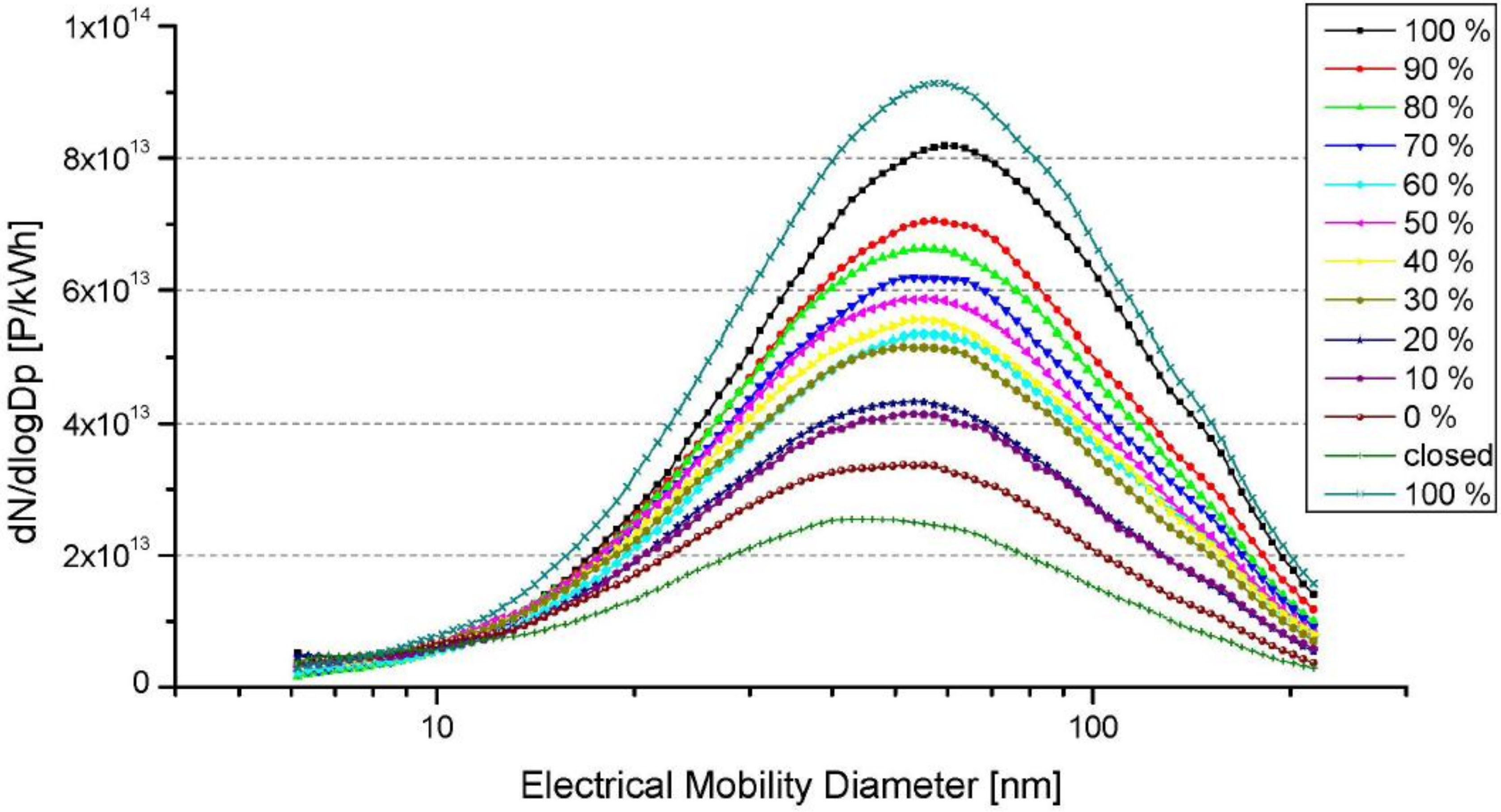


- PRail ↑ PN ↓ PartikelØ ↓
- PRail ↓ PN ↑ PartikelØ ↑

Rail Pressure [%]	Maximum [nm]
110	53.3
100	59.4
100	59.4
90	63.8
80	66.1
70	71.0
60	71.0

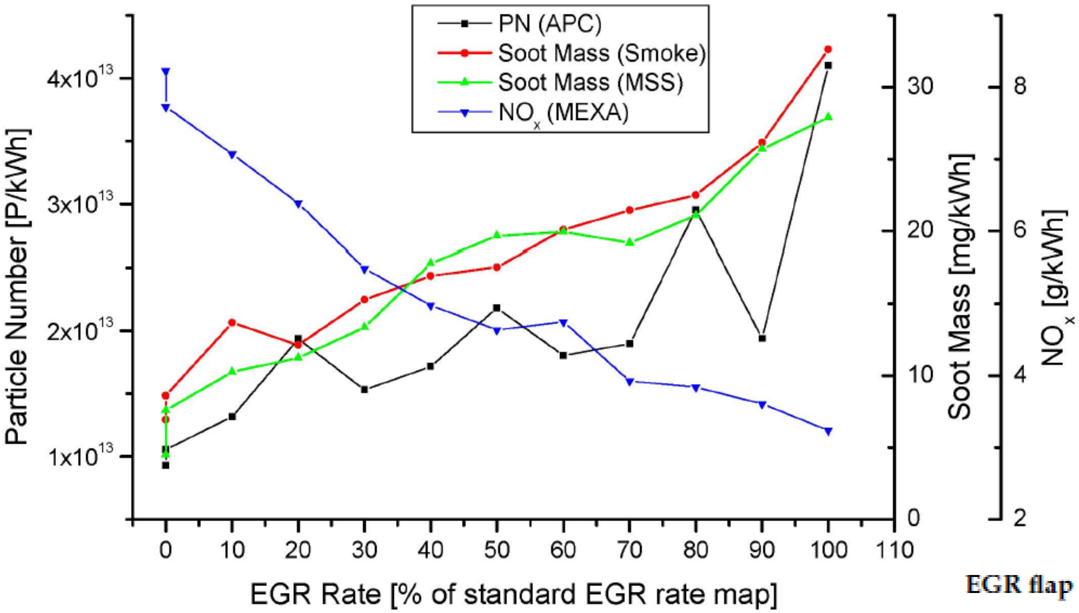


Influence of EGR
on particle size distribution

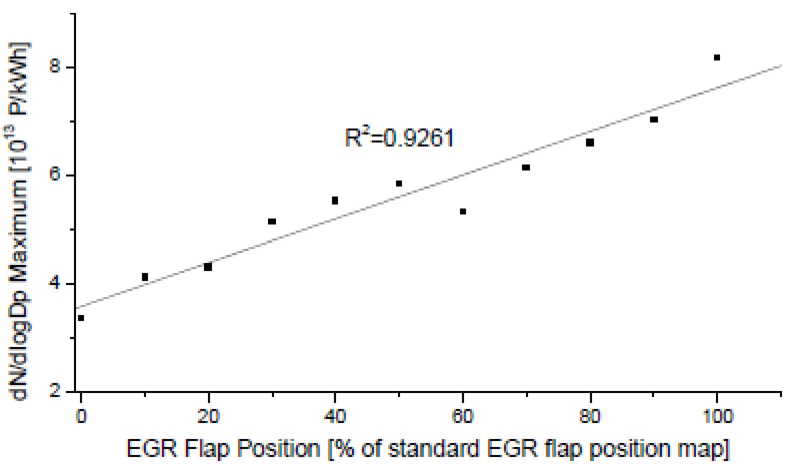


100% = Serieneinstellung AGR-Steller, ESC-Ergebnisse

Influence of EGR
on other emissions



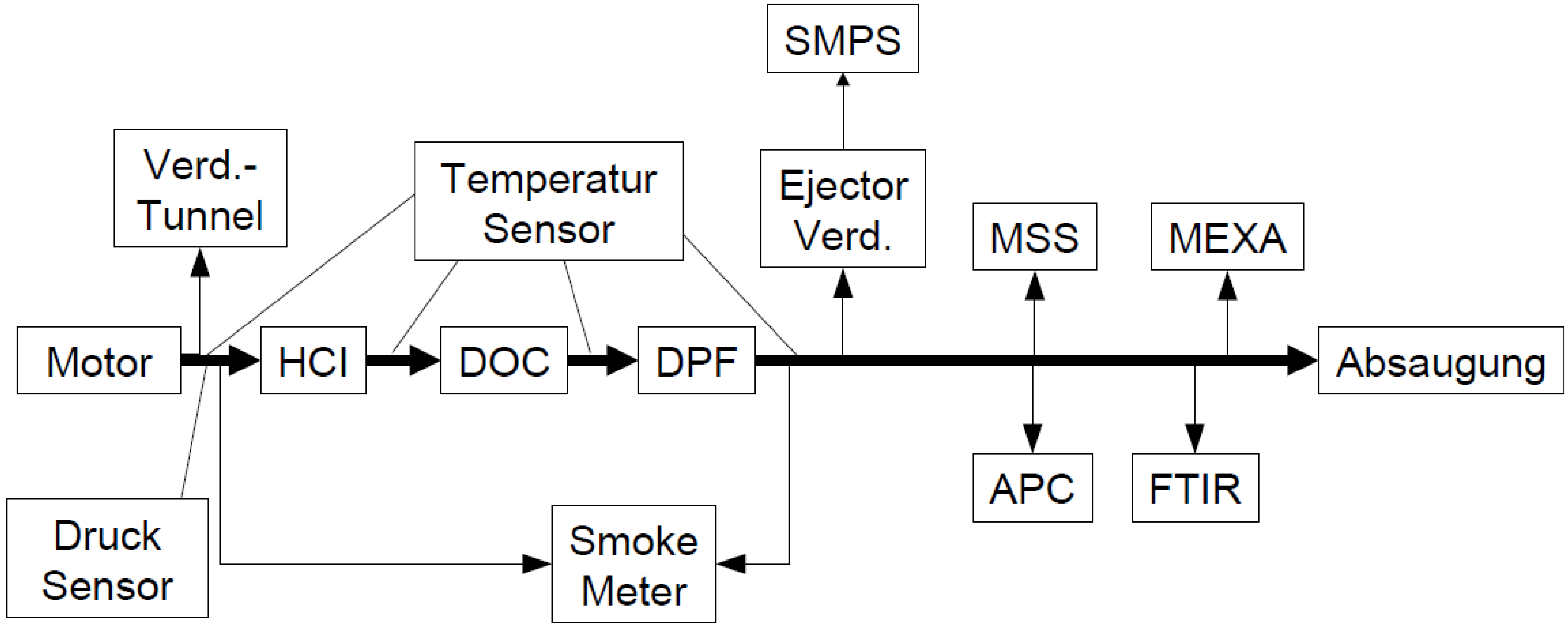
- AGR-Rate ↑ PN ↑ PartikelØ ↑
- AGR-Rate ↓ PN ↓ PartikelØ ↓



EGR flap position map [%]	ESC EGR-Rate [%]	dN/dlog(D_P) Max [10^{13} P/kWh]	Maximum [nm]
100	12.8	8.19	59.4
90	13.4	7.05	57.3
80	12.7	6.63	55.2
70	12.3	6.17	53.3
60	10.8	5.34	55.2
50	10.5	5.86	55.2
40	9.2	5.55	53.3
30	7.2	5.16	51.4
20	5.1	4.32	53.3
10	2.4	4.14	53.3
0	1.1	3.37	51.4
closed	0.1	2.55	46.1
100	13.8	9.17	61.5

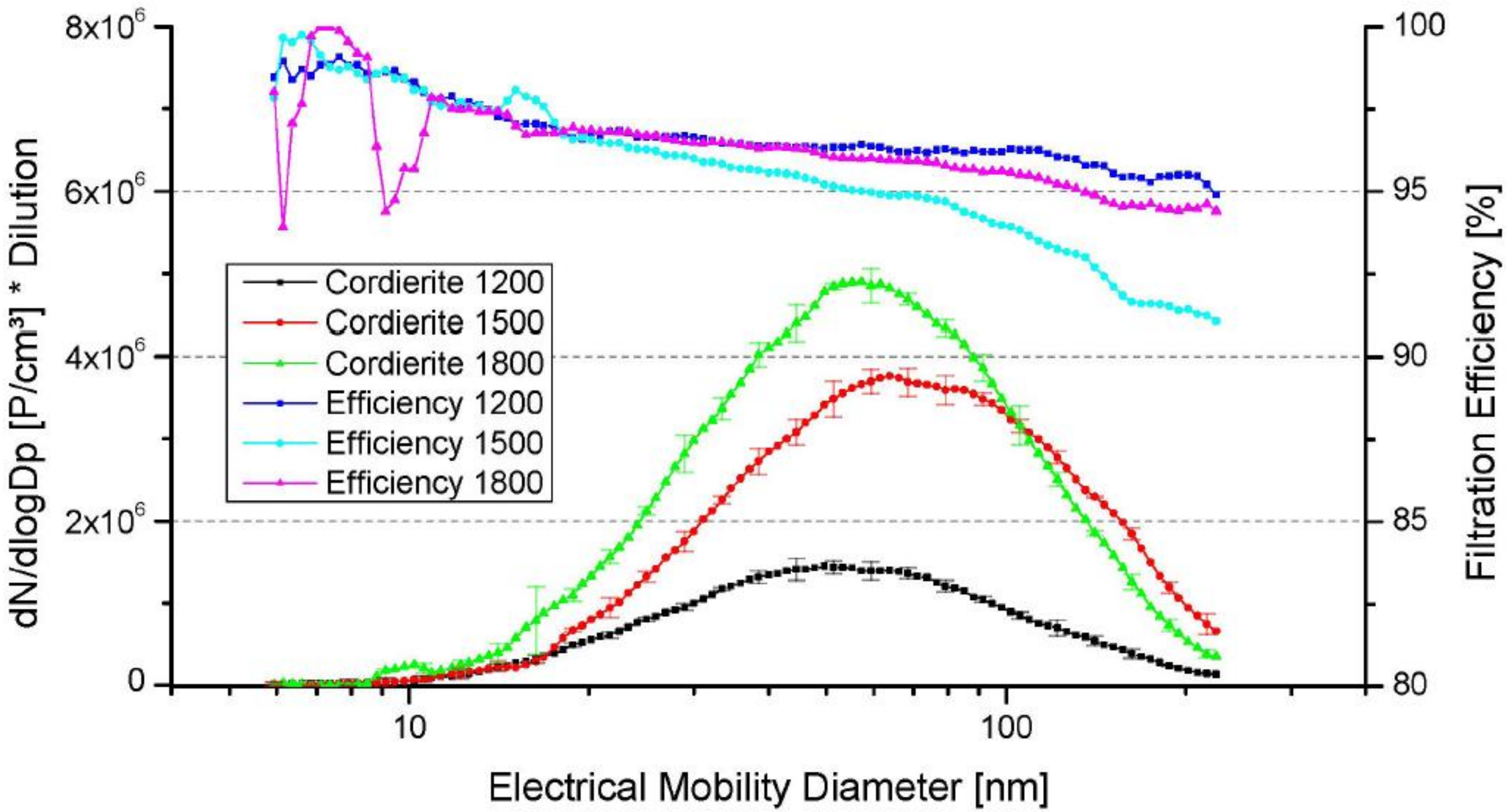
Setup

measurments after DPF with acitve regeneration



Messungen nach DPF 1

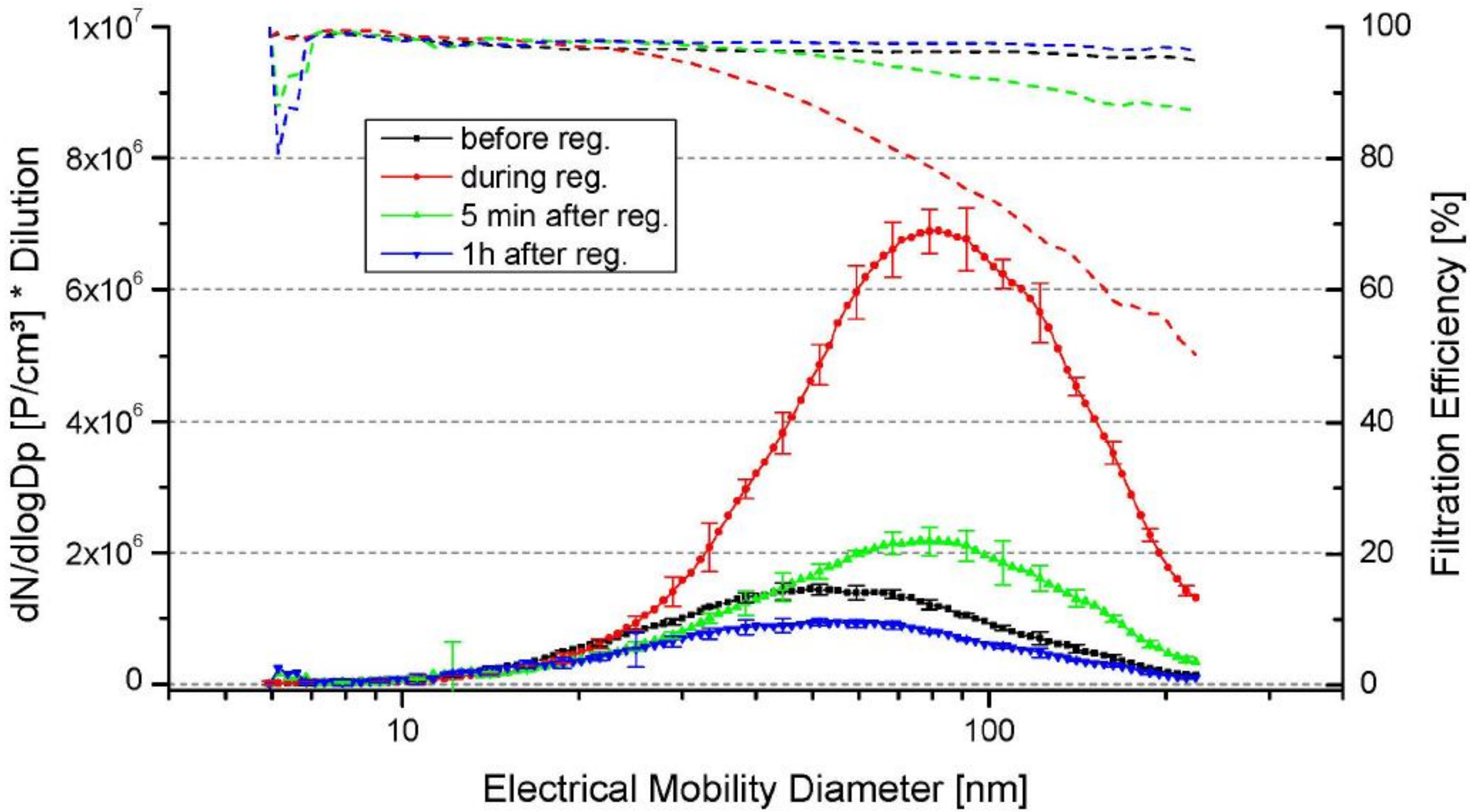
Cordierit unbeschichtet (beladen 6g/l)



25 % Last (n=6)

After DPF 1

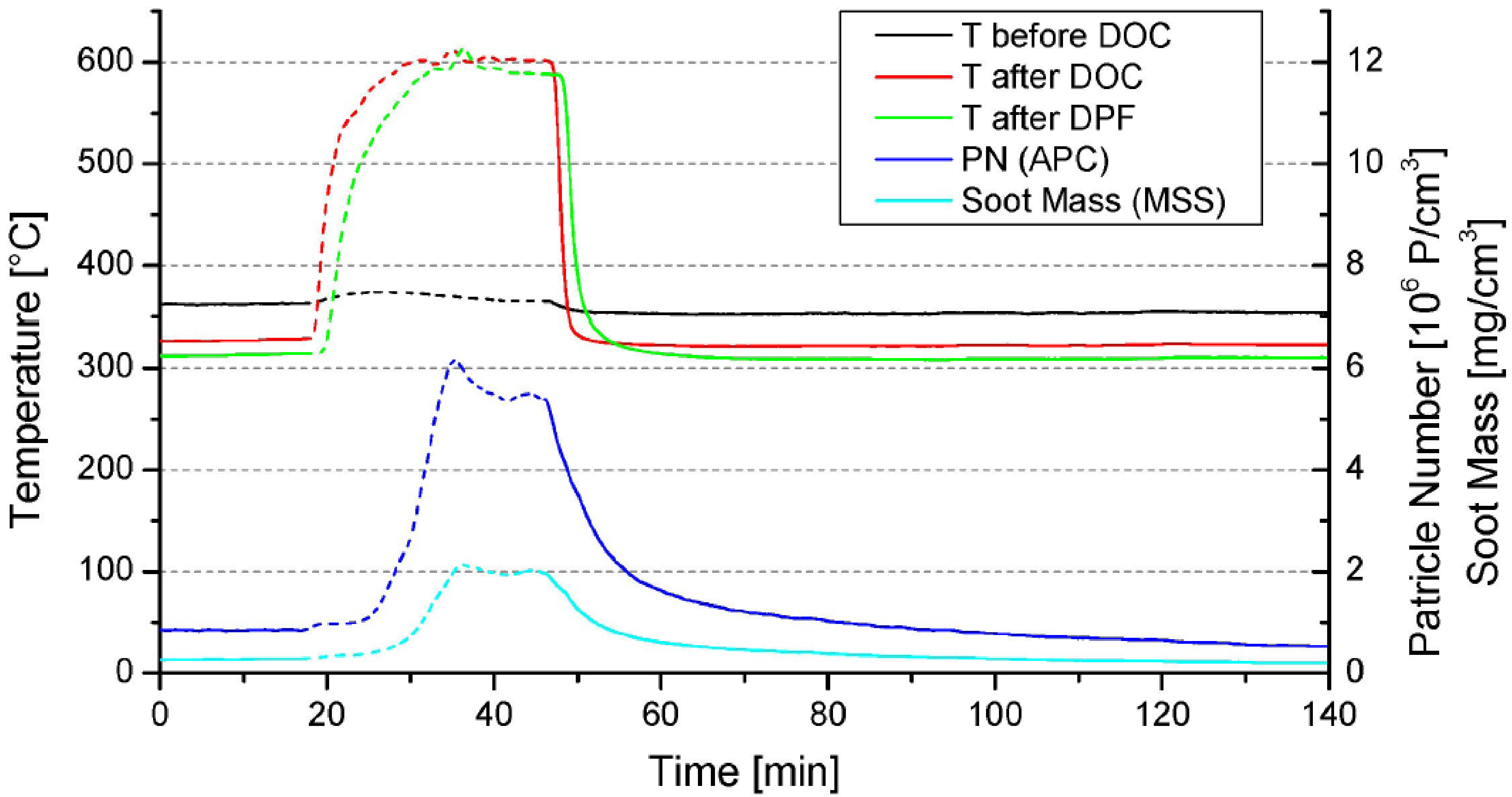
Cordierit unbeschichtet beladen (6g/l)



1200 min^{-1} 25 % Last

After DPF 1

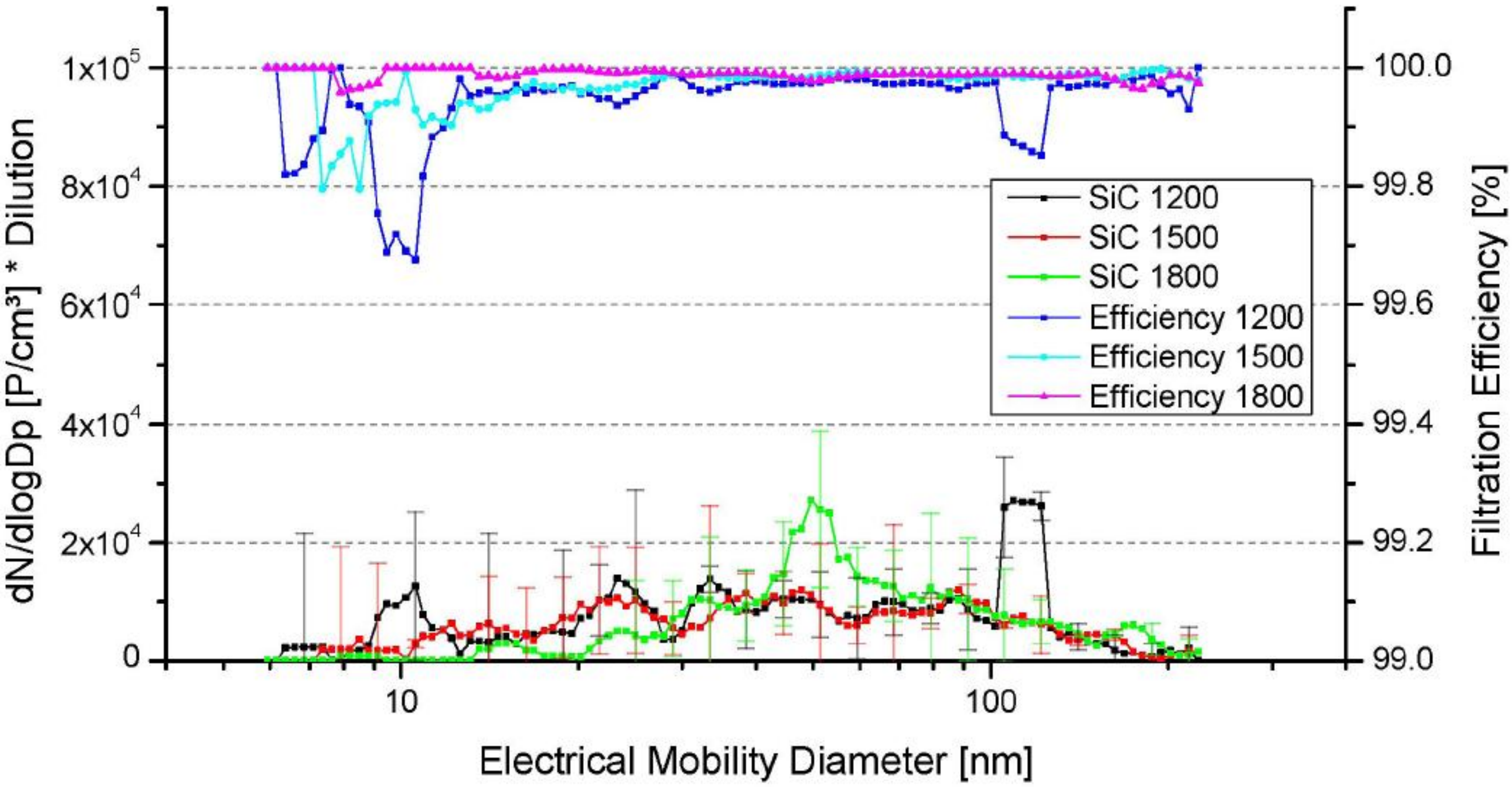
Cordierit unbeschichtet beladen (6g/l)



1200 min^{-1} 25 % Last

After DPF 2

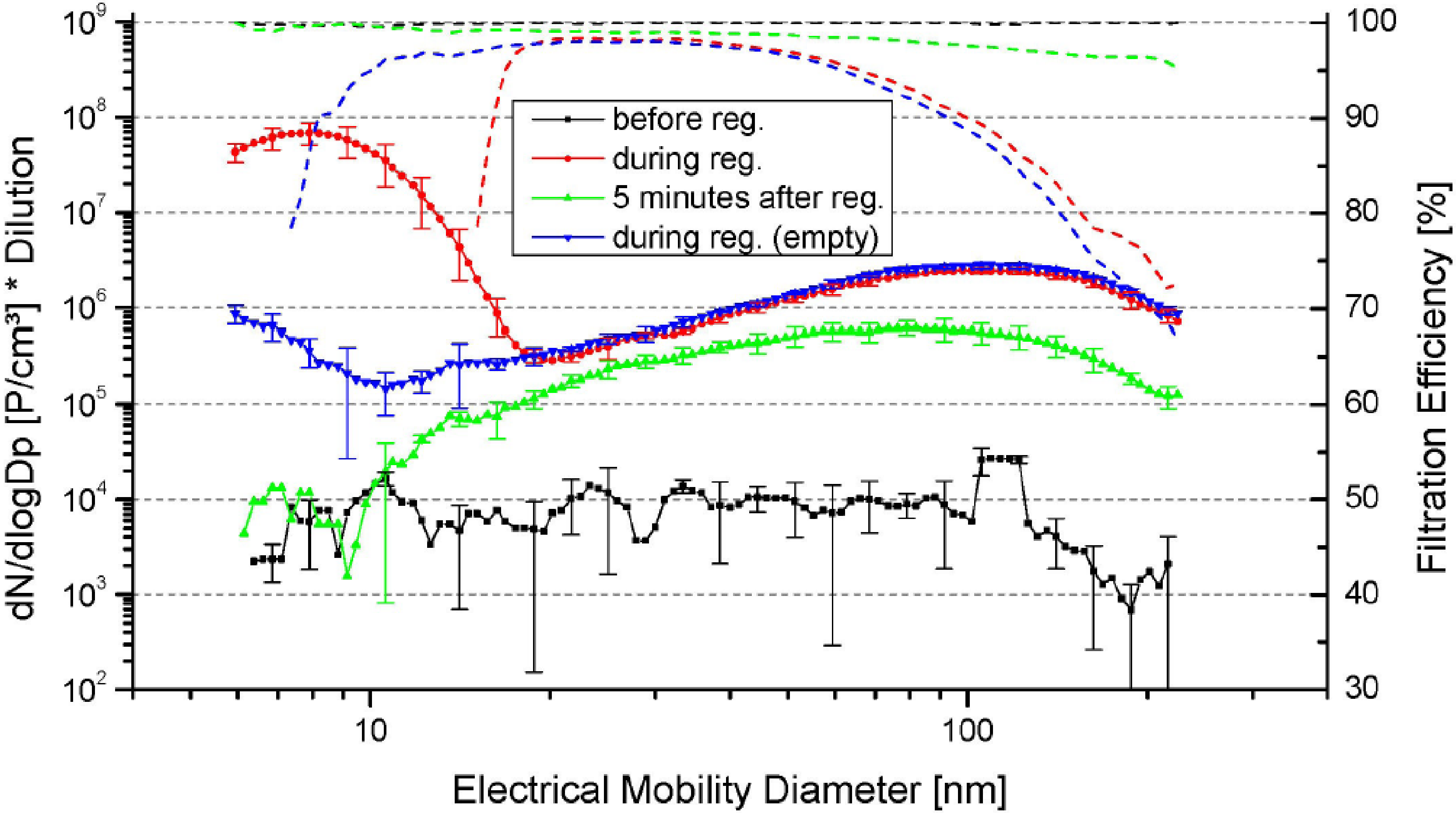
SiC unbeschichtet (beladen 6g/l)



25 % Last

After DPF 2

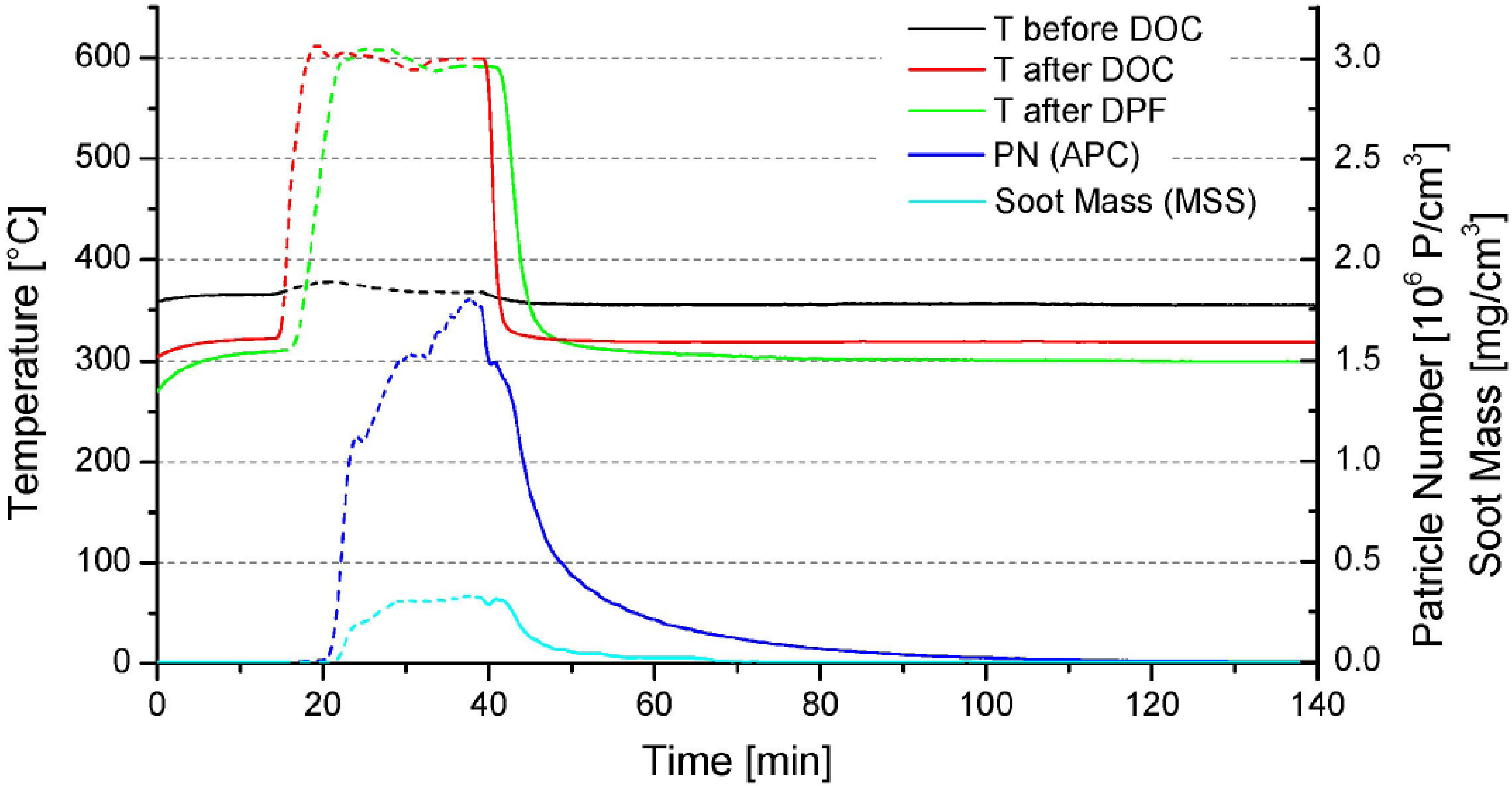
SiC unbeschichtet (unbeladen/beladen 6g/l)



1200 min^{-1} 25 % Last

After DPF 2

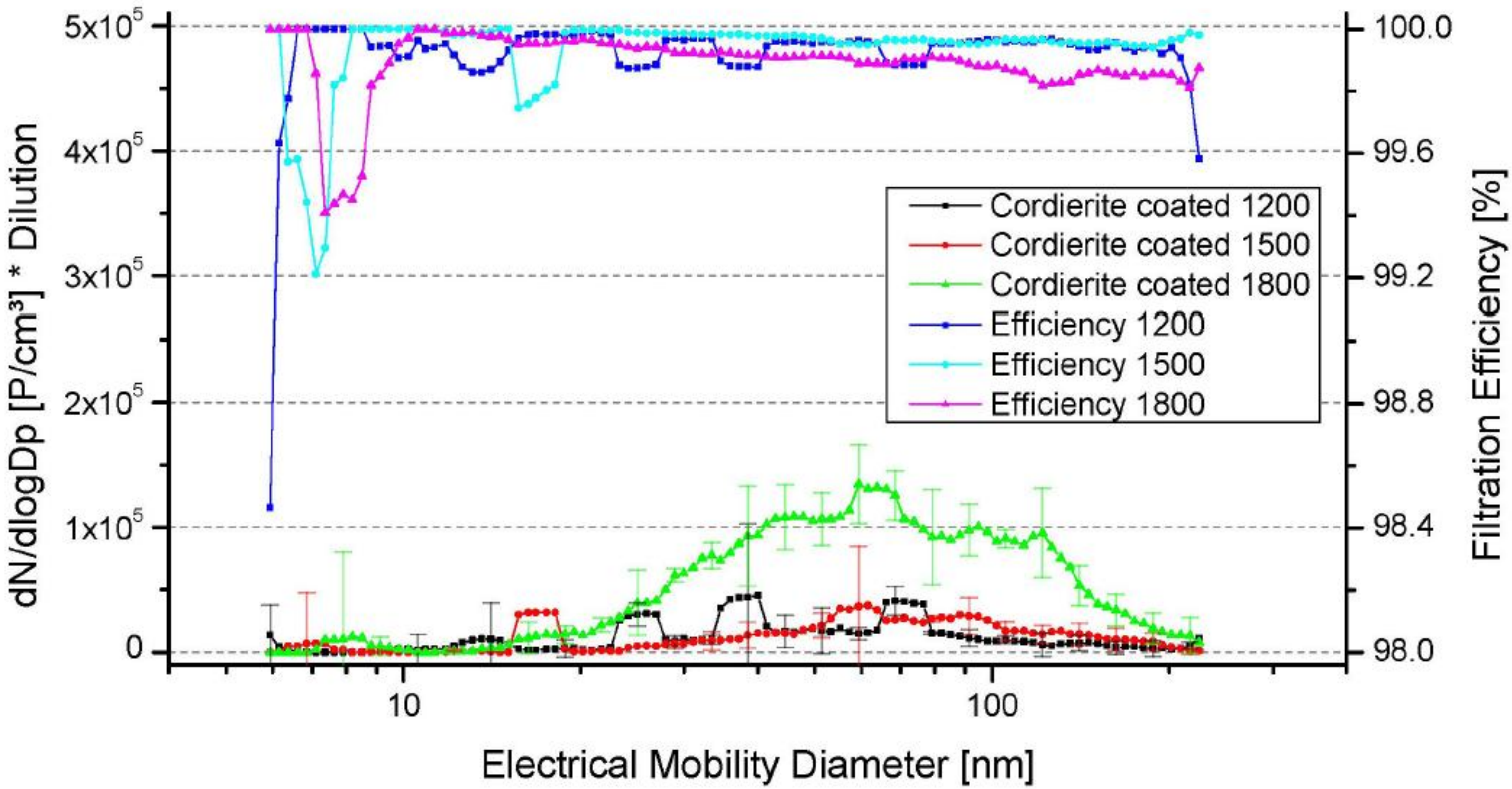
SiC unbeschichtet (beladen 6g/l)



1200 min^{-1} 25 % Last

Messungen nach DPF 3

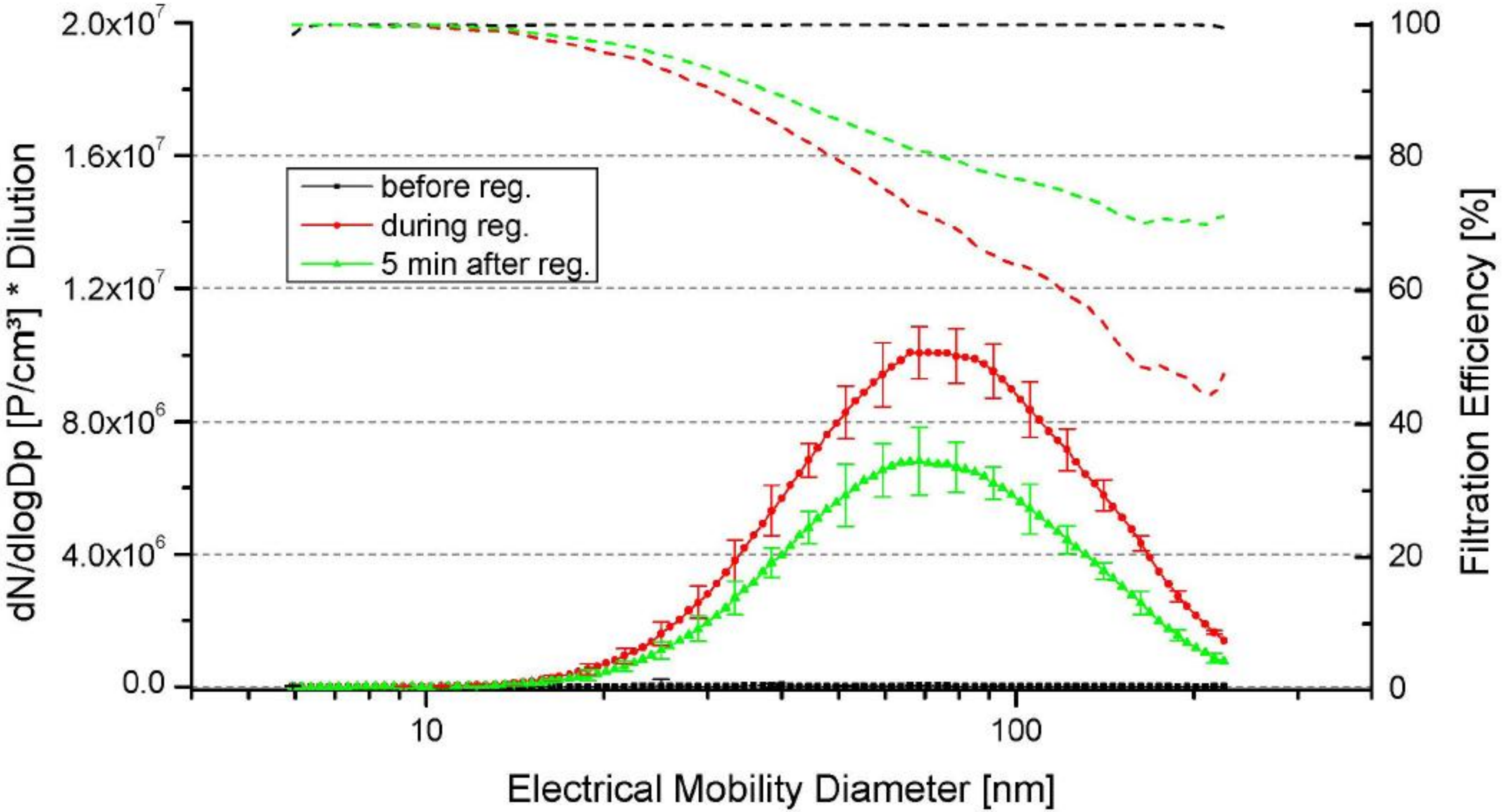
Cordierit beschichtet (beladen 6g/l)



25 % Last

Behind DPF 3

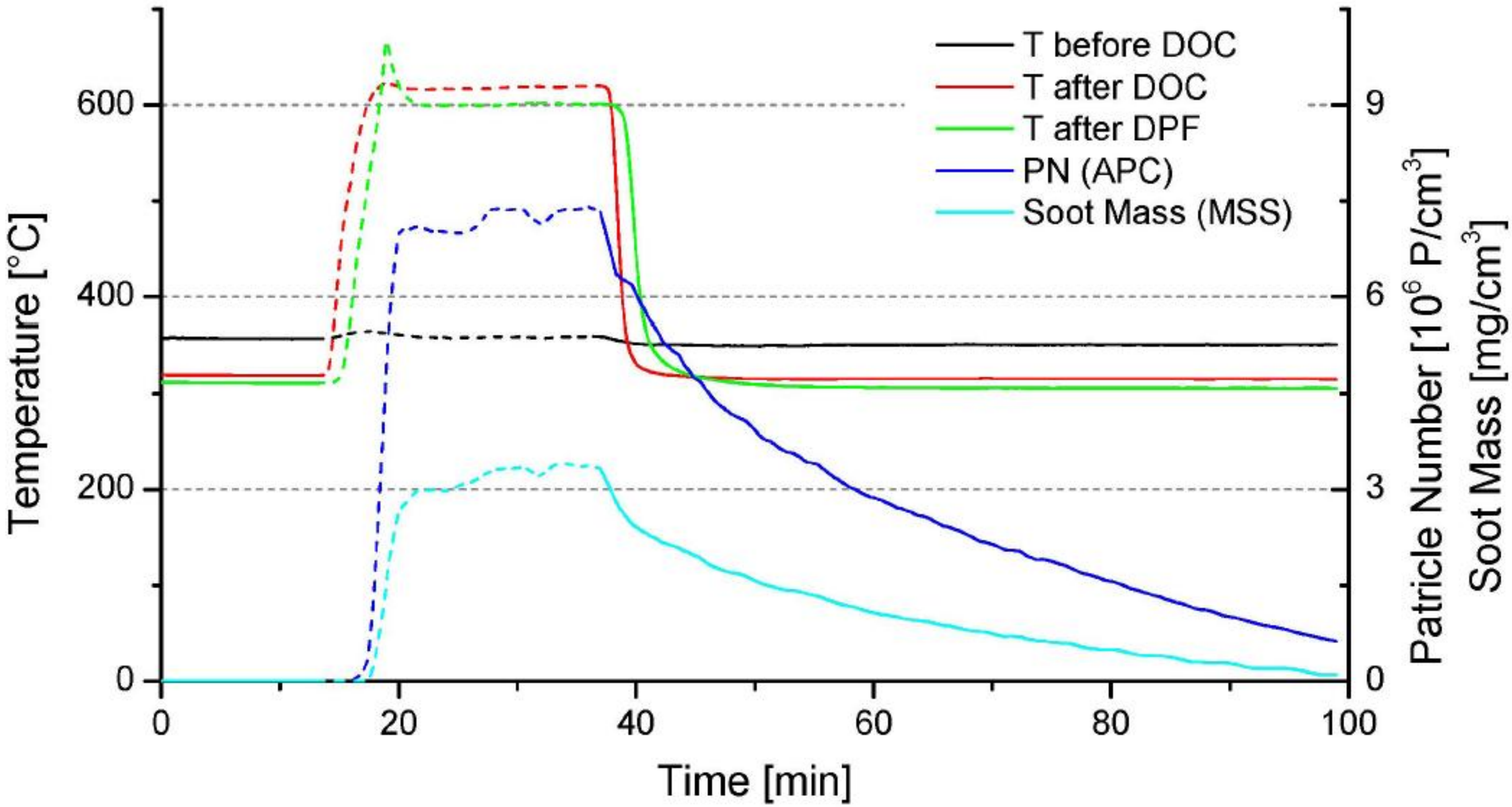
Cordierit beschichtet (beladen 6g/l)



1200 min^{-1} 25 % Last

Behind DPF 3

Cordierit beschichtet (beladen 6g/l)



1200 min^{-1} 25 % Last

Sumarry

- Particle number measurement in diesel exhaust is influences by different factors
- Engine measures (Rail pressure and EGR) causes influences on particle size distribution
- Under normal operation the filtration efficiency of al DPFs is higher that 99%
- During active regeneration the filtration efficiency decreases to 60%
- Good correlation of APC, MSS and SMPS data

Any questions?

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