10.ETH-Conference on Combustion Generated Nanoparticles 2006

Solid Particle Emissions of HDV
Euro 3 – DPF
Euro 4 – PM-Kat
Euro 5 – SCR

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22nd Feb 1939 – 6th Dec 2005

Questions

- **EURO 4 – PM-Kat**

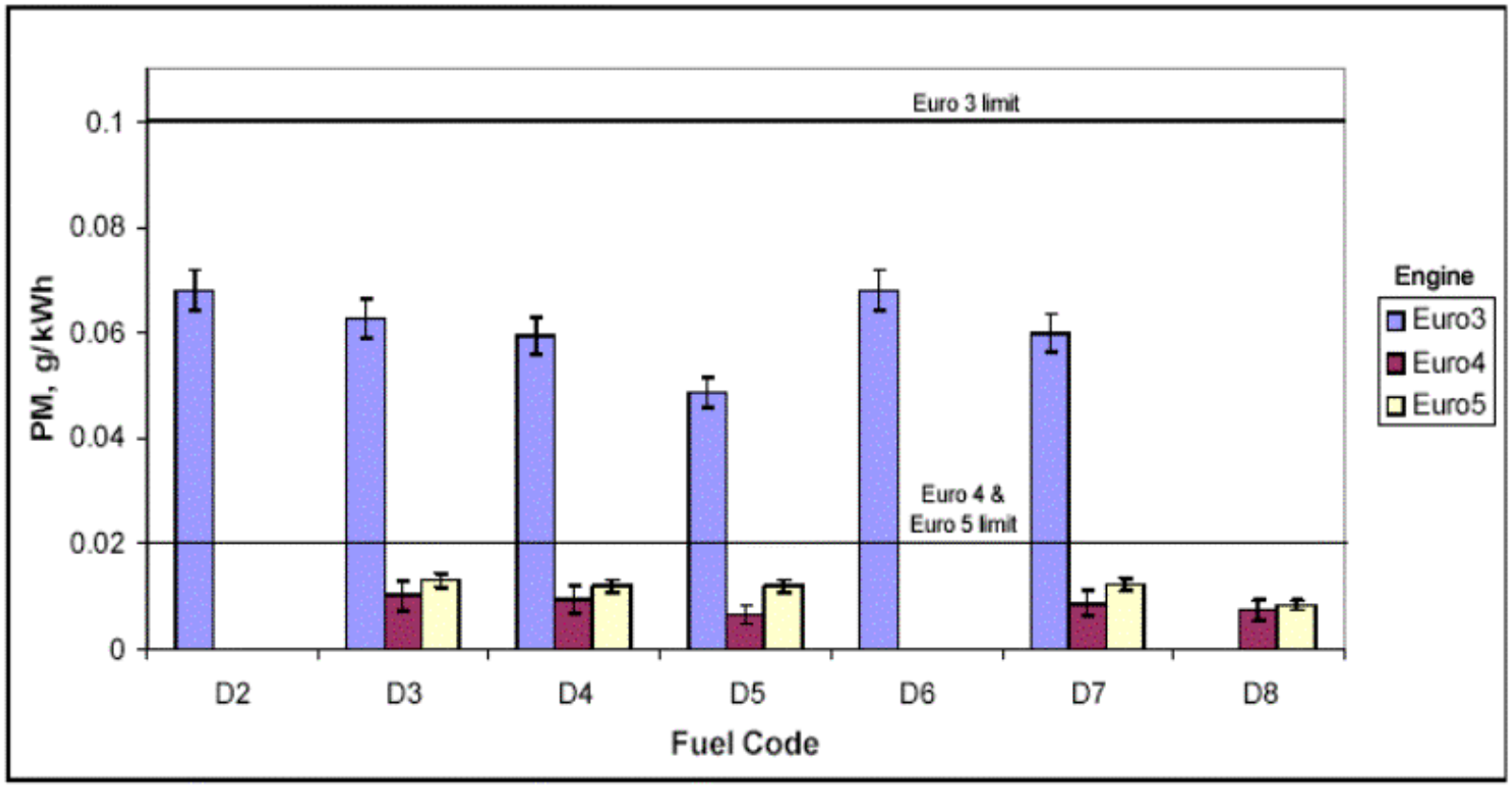
  - Nanoparticle Emissions compared to Euro3/DPF
  - Nanoparticle Reduction = f (Particle Size and Engine Load)
  - Influence of Soot Load, Regeneration, Temperature, Transients
  - Secondary Emissions: NO_2, Catalyst Metals

- **EURO 5 – SCR**

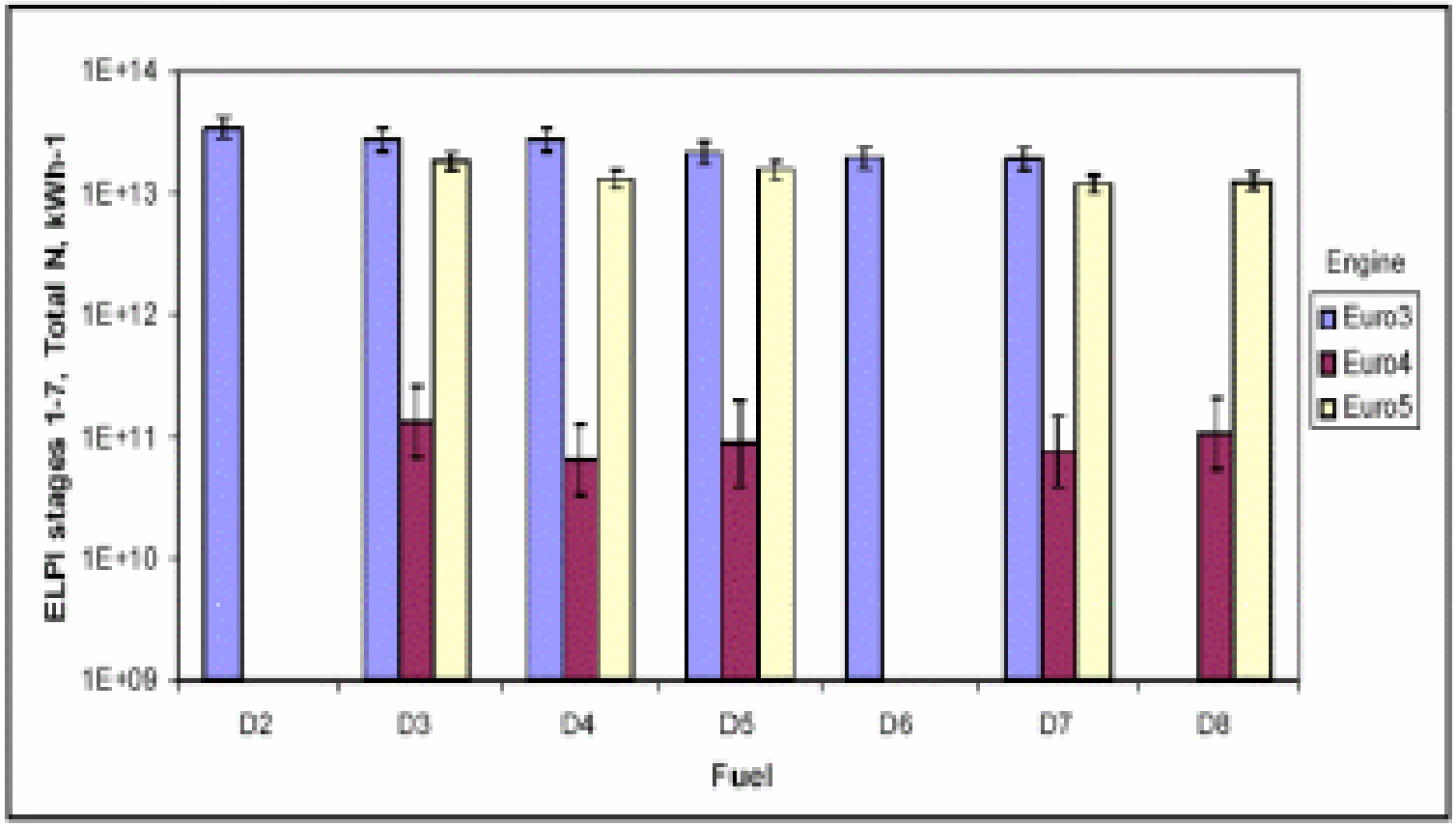
  - Nanoparticle Emissions compared to Euro3/DPF and Euro4/PM-Kat
  - SCR-Influence on Nanoparticle Reduction/Formation
  - NOx-Reductions at light load (bus city-driving)
  - Secondary Emissions: NO_2, N_2O, NH_3, Catalyst Metals

PM : E5/4 w.DPF/3 – CONCAWE 2005

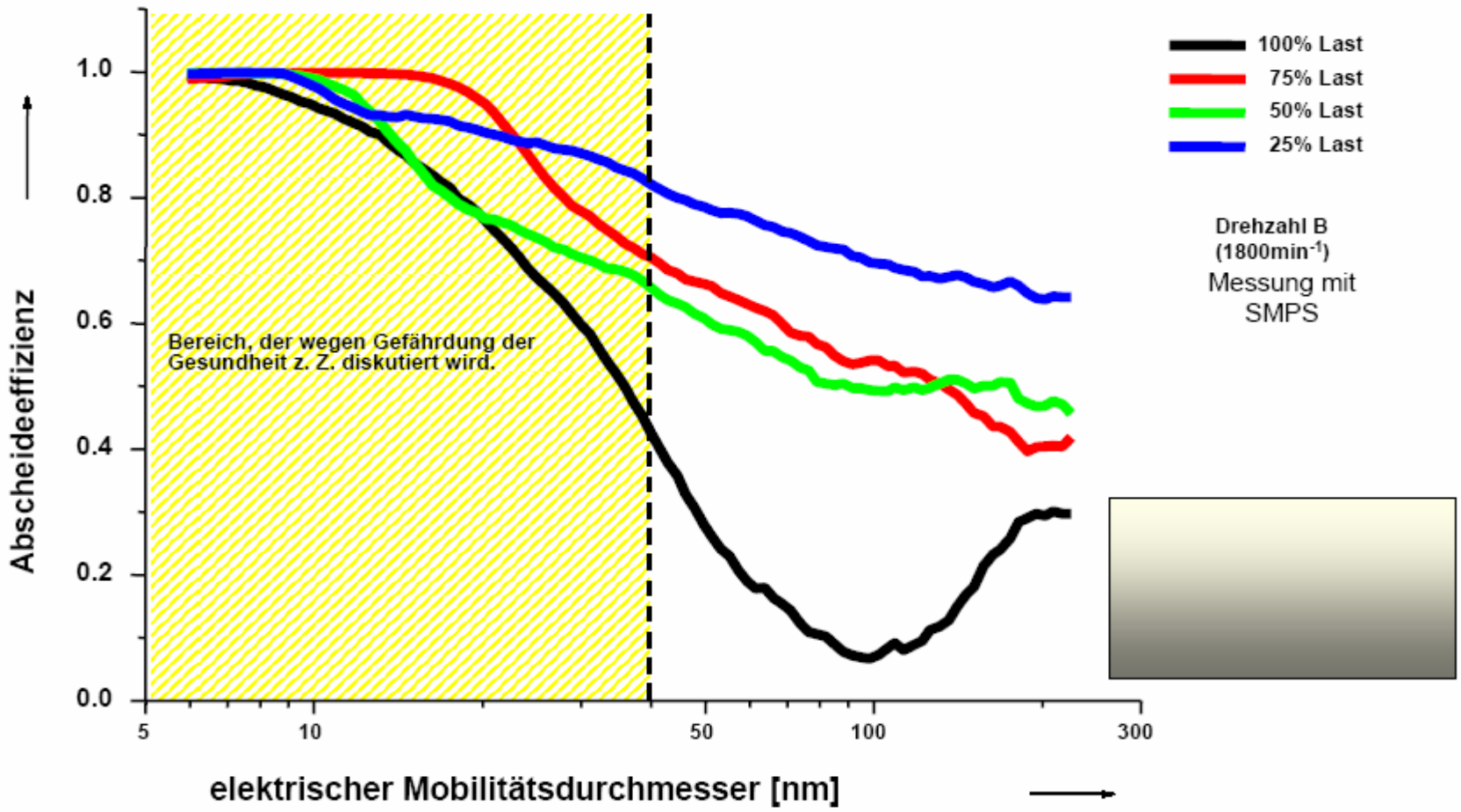
Figure 2 PM emissions - ESC



PN : E5/4 w.DPF/3 – CONCAWE 2005



MAN-published Data of Nanoparticle Emissions with PM-Kat-System



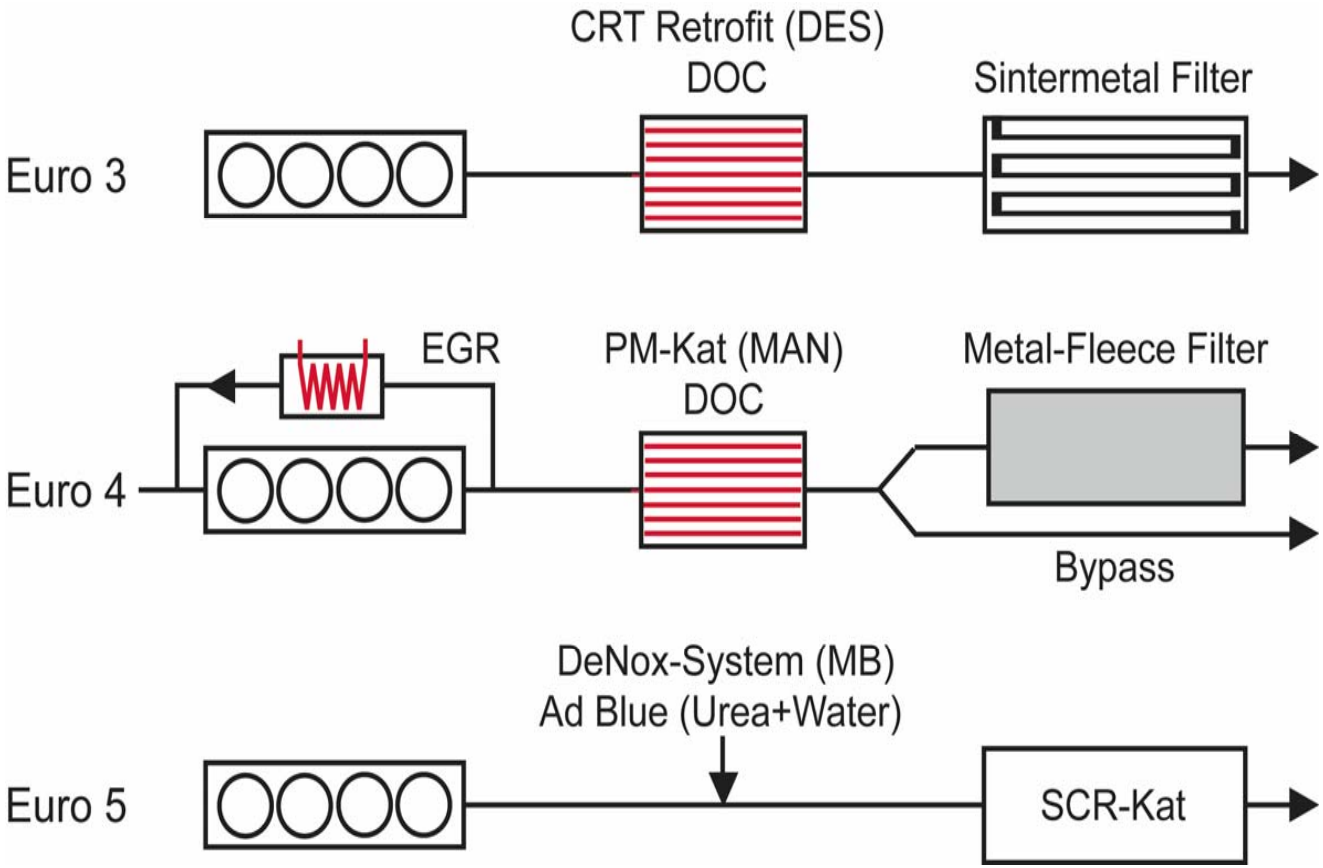
Experimental Setup

Vehicles and Exhaust Aftertreatment Concepts

Mercedes Benz 1846-LS (49'051 km)
- 355 kW / 1695 rpm

MAN TGA 18.430 (31'196 km)
- 316 kW / 1900 rpm

Mercedes Benz 1846-LS (2'863 km)
- 348 kW / 1796



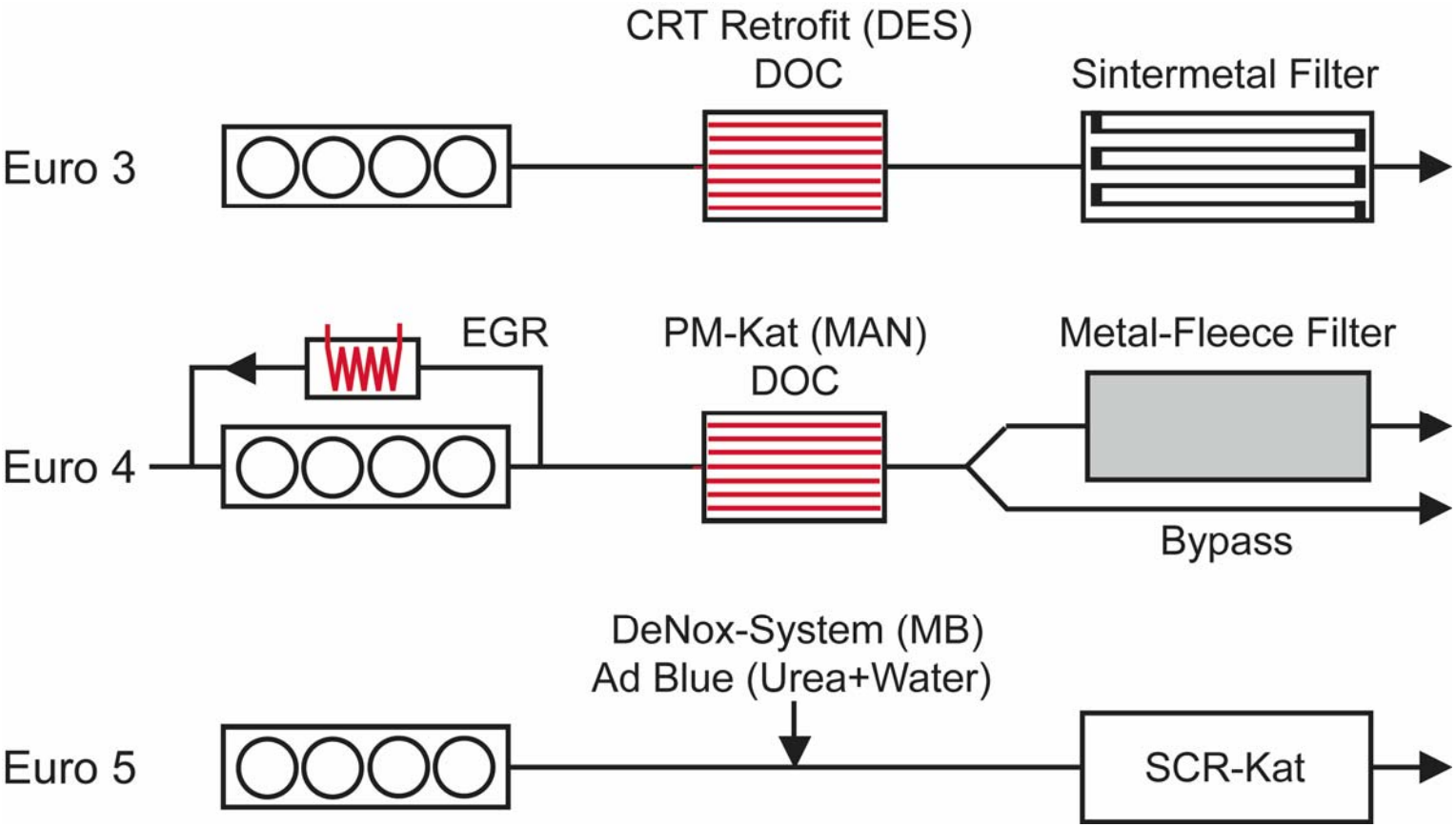
Test Vehicles

- **EURO 3 - DPF**
  - Mercedes Benz 1846-LS EURO 3
  - 355 kW / 1695 rpm
  - 49’051 km
  - DPF: HJS sintermetal wall flow , regeneration CRT, Retrofit

- **EURO 4 – PM-Kat**
  - MAN: TGA 18.430
  - 316 kW/1900 rpm
  - 31’196 km

- **EURO 5 – SCR**
  - Mercedes Benz 1896-LS Euro 5
  - 348 kW / 1796
  - 2’863 km

Exhaust Aftertreatment Concepts

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BLUETEC

1.

Bis heute haben sich über 200 Schweizer Kunden für mehr als 480 Actros der Euro5-Generation entschieden.

[illegible]

2.

Alle Lkw-Hersteller werden SCR-Technologie wählen müssen, um die Euro5-Norm zu erfüllen.

[illegible]

3.

Nur Euro5 bietet einen langfristigen Investitionsschutz bei Neufahrzeugen.

[illegible]

4.

SCR-Technologie spart mindestens 3% Treibstoff.

[illegible]

5.

Die AdBlue-Versorgung in der ganzen Schweiz ist heute sichergestellt.

[illegible]

6.

Nur bei einem SCR-Lkw bleiben die Wartungsintervalle gleich hoch.

[illegible]

7.

OBD I (On-Board-Diagnose) bei Mercedes-Benz Lkw schon jetzt an Bord.

[illegible]

8.

Bei Mercedes-Benz bleibt die Nutzlast trotz SCR-Technologie gleich hoch.

[illegible]

9.

Mit SCR können alle Diesel- und Ölqualitäten verwendet werden.

[illegible]

10.

Nur Mercedes-Benz kann heute schon Euro5-Lkw mit bis zu 600 PS liefern.

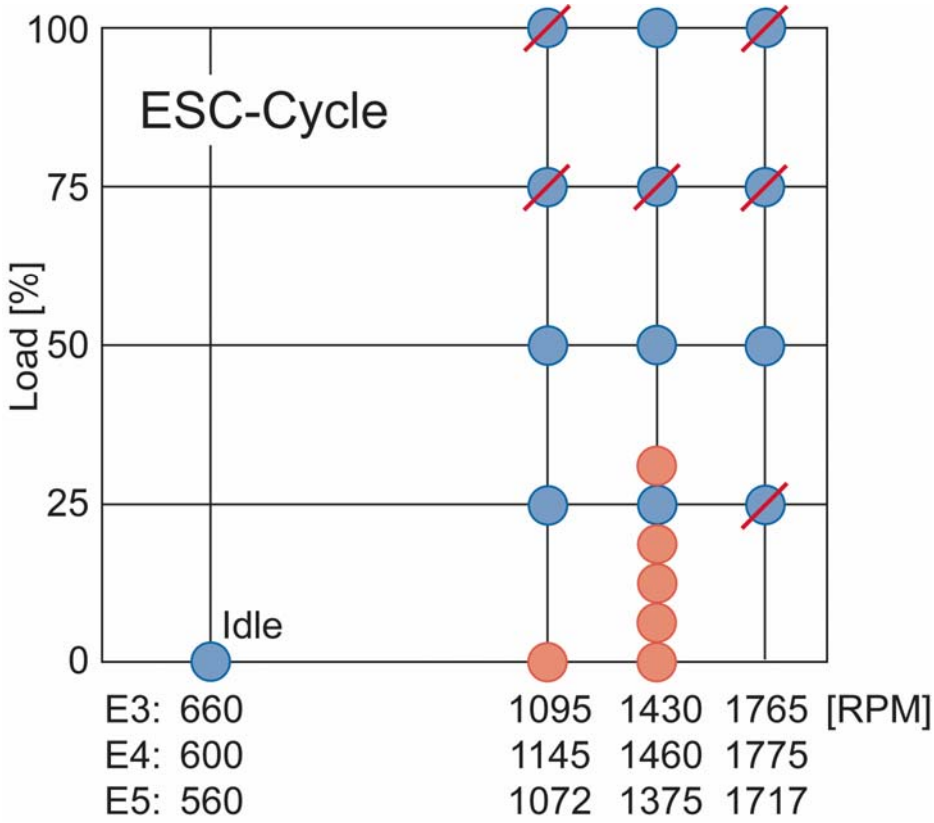
[illegible]

Noch mehr Infos zu SCR-Technologie und Euro4/5 auf www.mercedes-benz.ch

Certified Emissions ESC

[g/kWh]	CO	HC	NOx	PM	EC	PZ	NO_2
EURO 3 w/o DPF	< 2.1	< 0.7	< 5.0	< 0.1	?	?	?
Limits	*2.1*	*0.7*	*5.0*	*0.1*			
EURO 4 - PM-Kat	0.1	0.01	3.02	0.014	?	?	?
Limits	1.5	*0.5*	*3.5*	*0.02*			
EURO 5 – SCR	0.27	0.01	1.56	0.013	?	?	?
Limits	*1.5*	*0.5*	*2.0*	*0.02*			

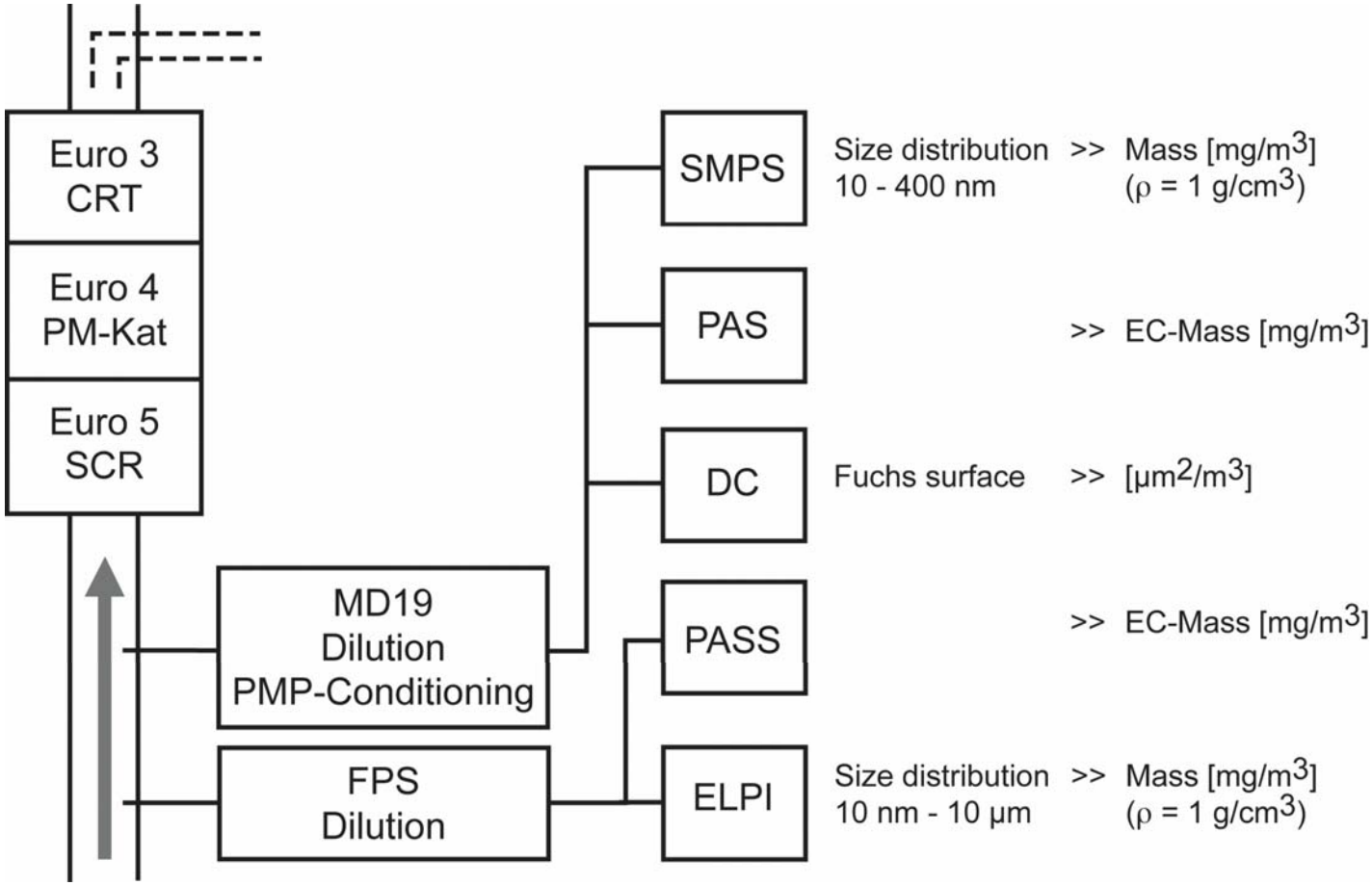
Selected Operating Points



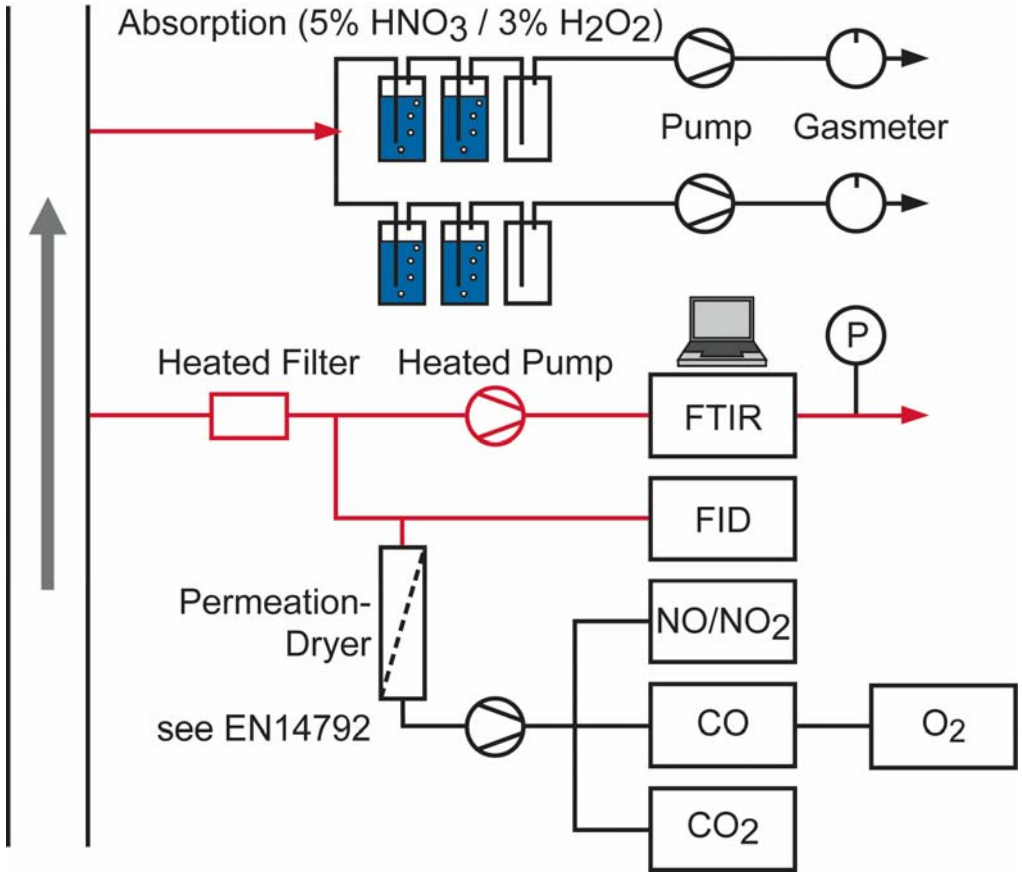
Instruments for Particle Analysis

	Product	Measurement Principle	Size Range	Result
SMPS	TSI	electric mobily sizing and CNC-counting	10-400 nm 60 classes	count per class → volume, mass
PAS	ME PAS 2000	photoelectric charging comb.aerosol surface	< 1000 nm	electric charge → EC-mass
DC	ME LQ1-DC	diffusion charging Fuchs-surface-meas.	< 1000 nm	electric charge → Fuchs-surface
PASS	AVL	Photoacustic measurement of EC	< 10‘000 nm	Pressure signal → EC-mass
ELPI	DEKATI	Aerodynamic sizing online counting	< 10‘000 nm 12 classes	counts per class → volume, mass

Sampling and Instrumentation



Gas Analysis and Metal Sampling



Test Set-Up

- **Chassis-Dynamometer**

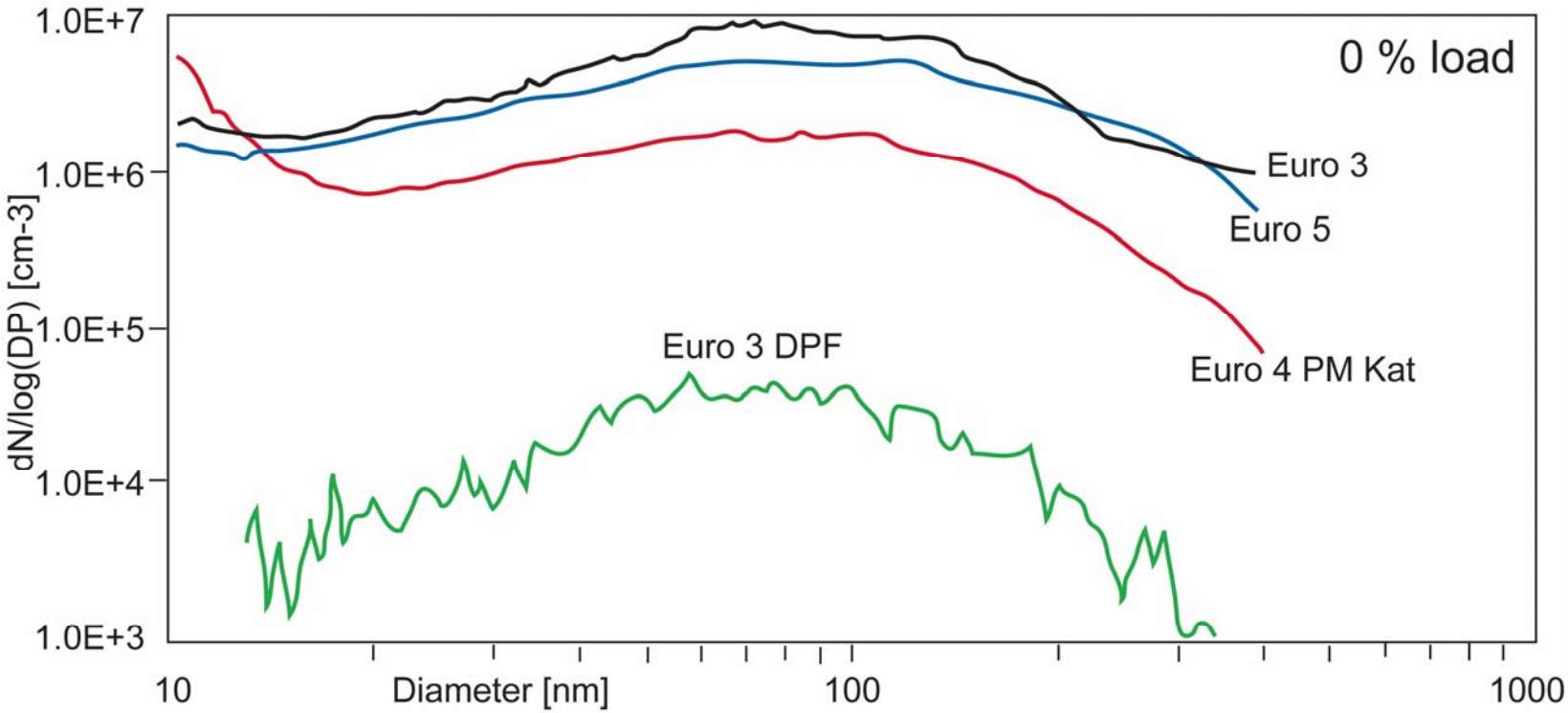
  - Stationary Test Conditions (no dynamic cycle)
  - Transient Tests (free acceleration etc)

- **Measurements**
  - Nanoparticle Analysis: SMPS, PAS, DC, PASS, ELPI
  - Gaseous Compounds: NO, NO_2, CO, HC, N_2O, NH_3,
  - Catalyst Metals: Pt, V
  - Temperatures, Pressures,
  - no PM-measurement - CVS-Tunnel not available

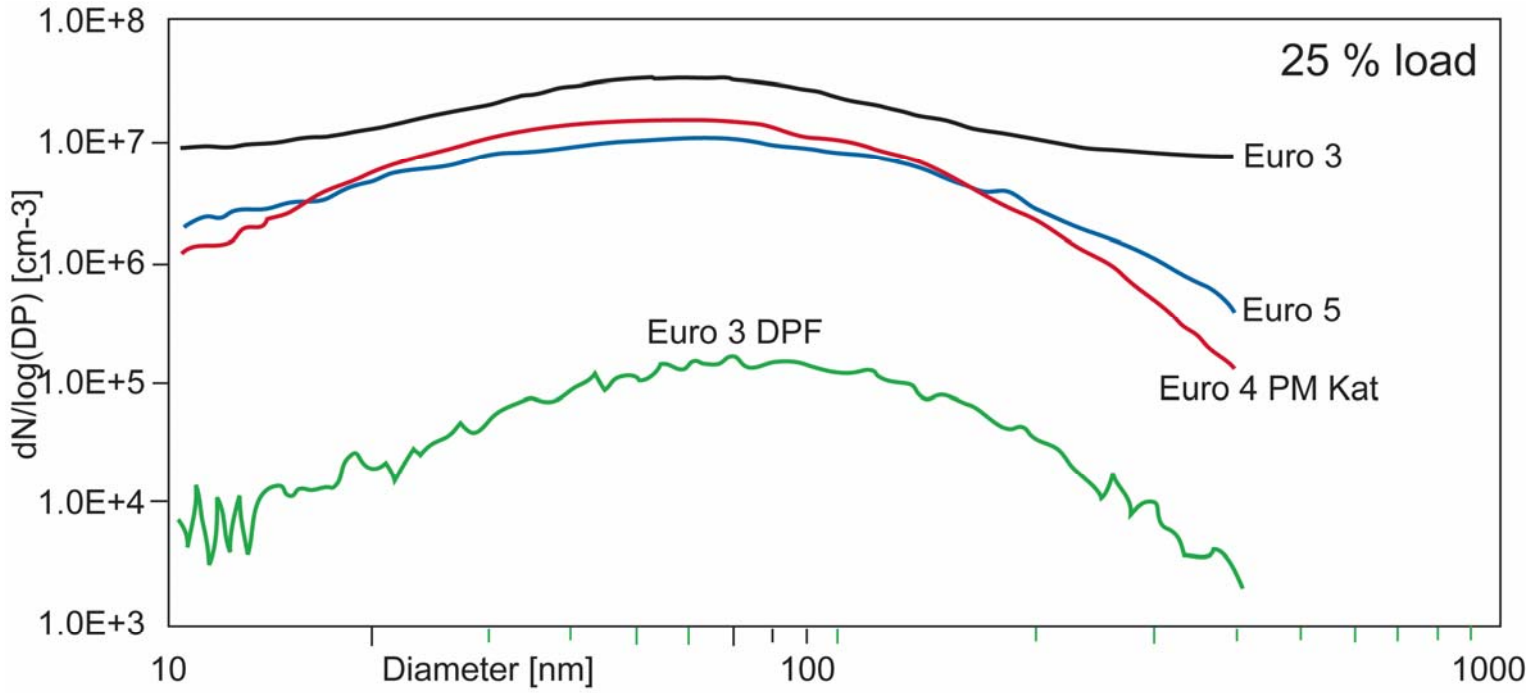
- **Fuel:** SN 181160 -1, S < 10 ppm

Particle and Gas Emissions - General

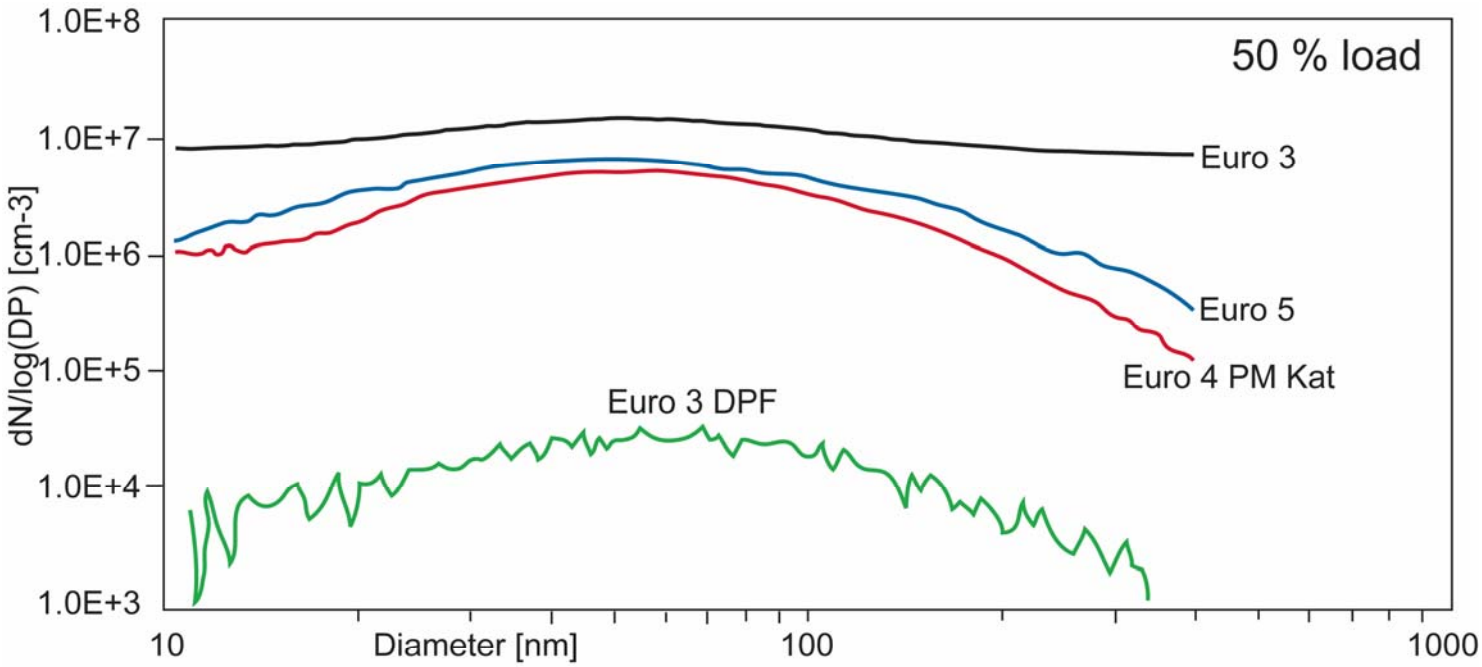
Size Distribution (SMPS) at Low Idle



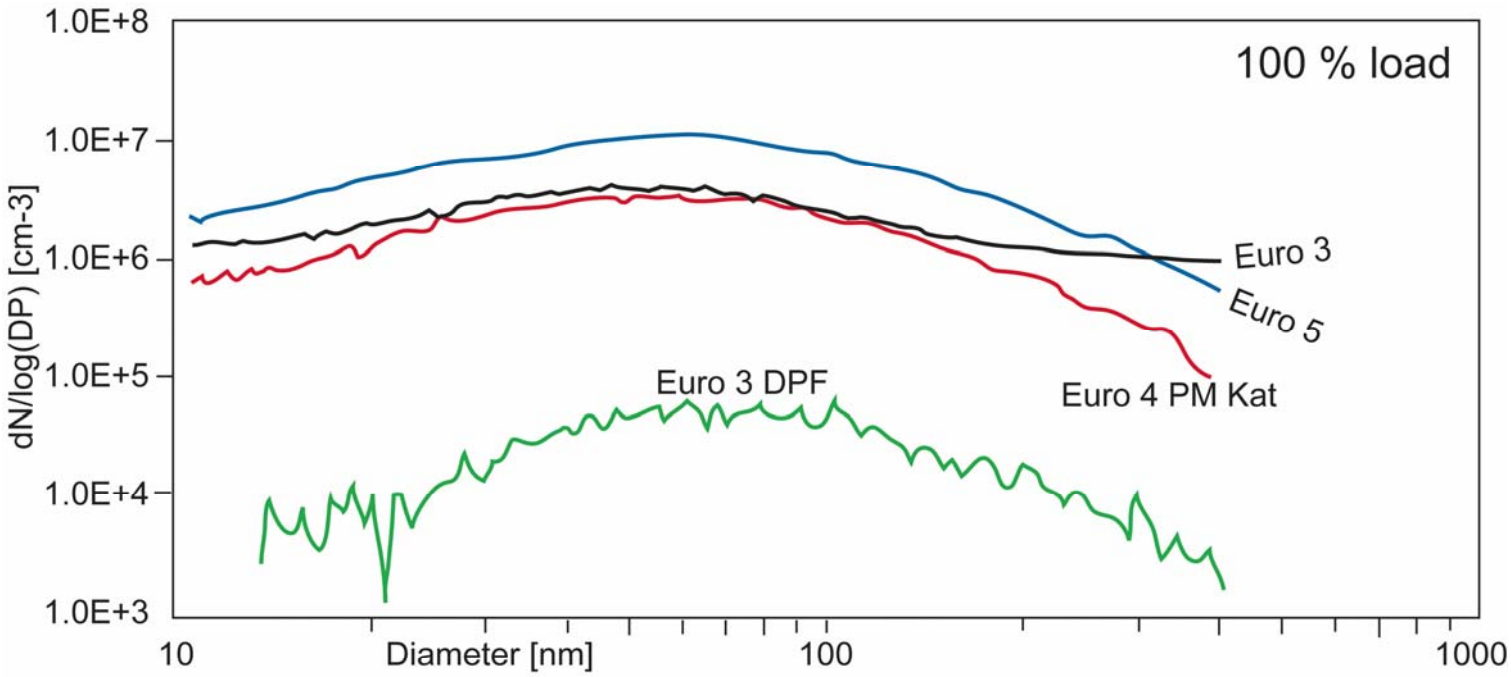
Size Distribution at 1400 rpm 25% Load



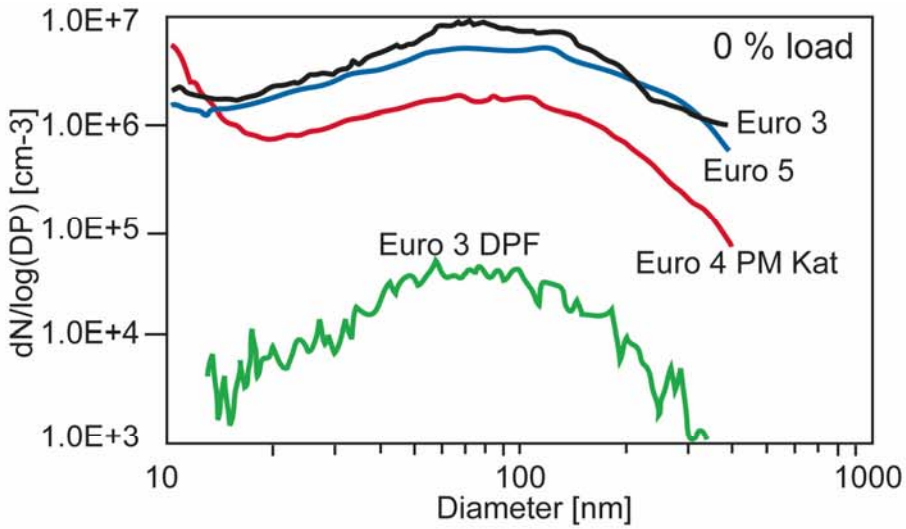
Size Distribution at 1400 rpm 50% Load

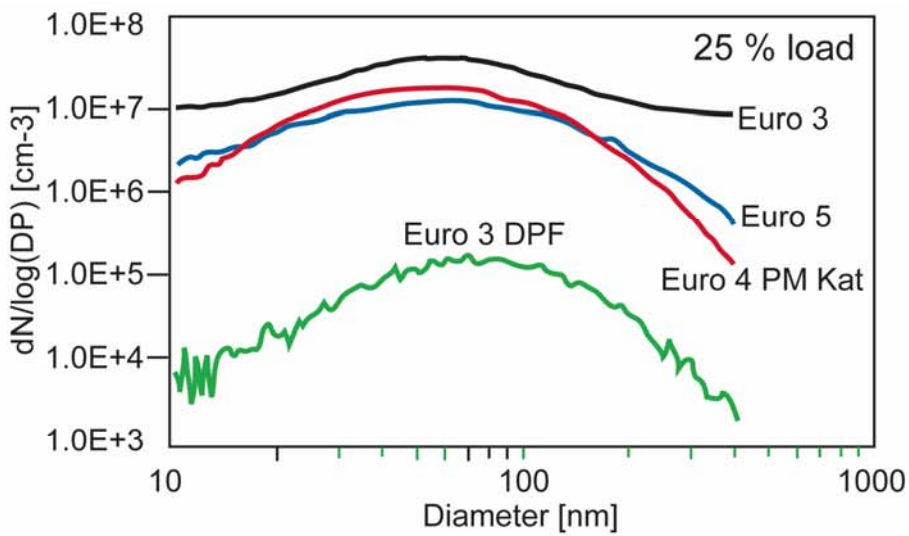


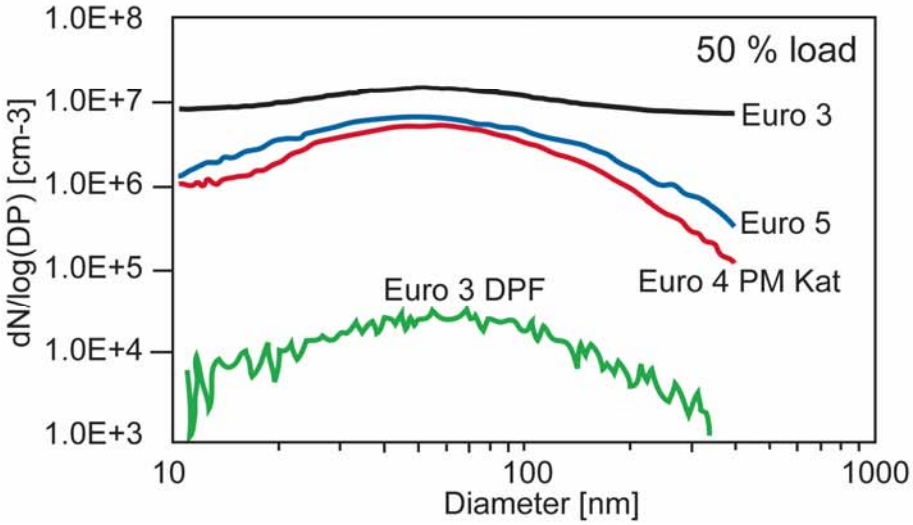
Size Distribution at 1400 rpm Full Load

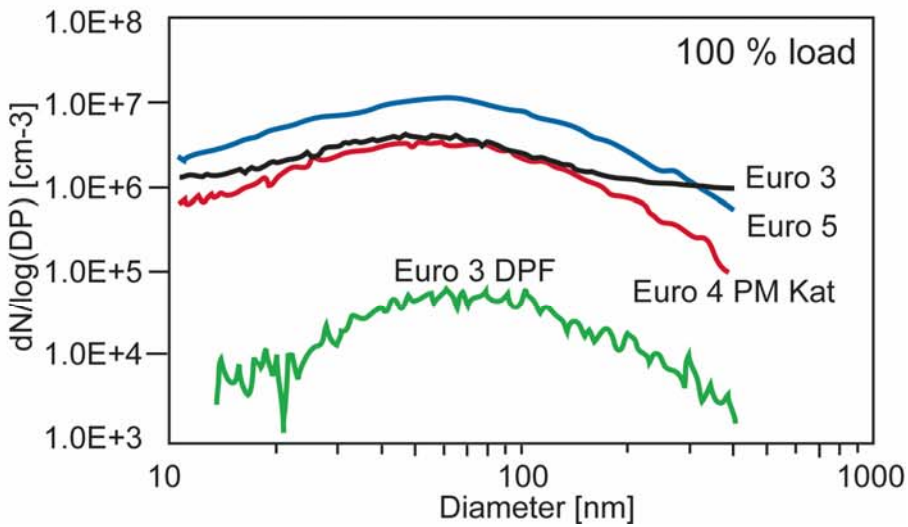


Size Distributions at 1400 rpm



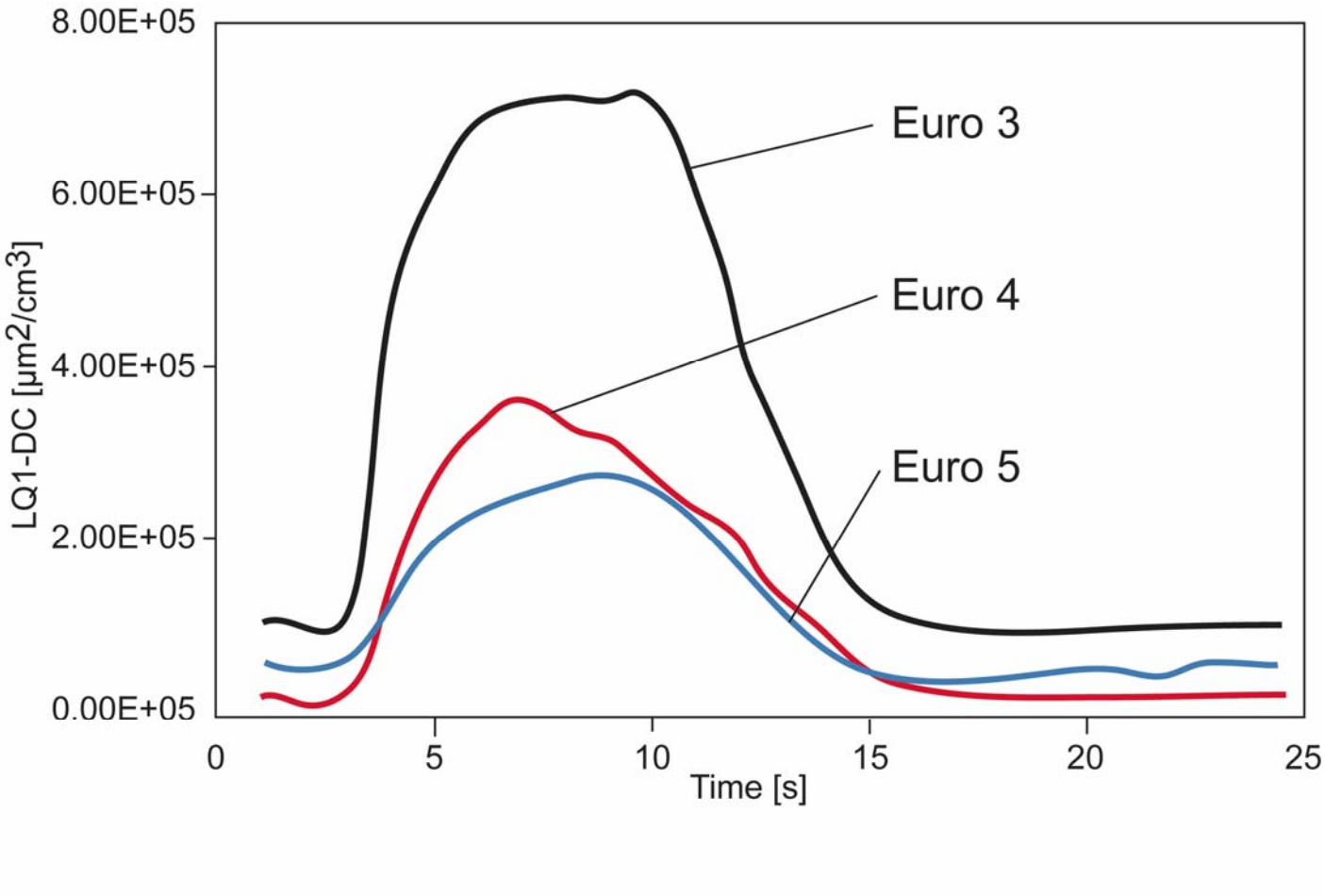




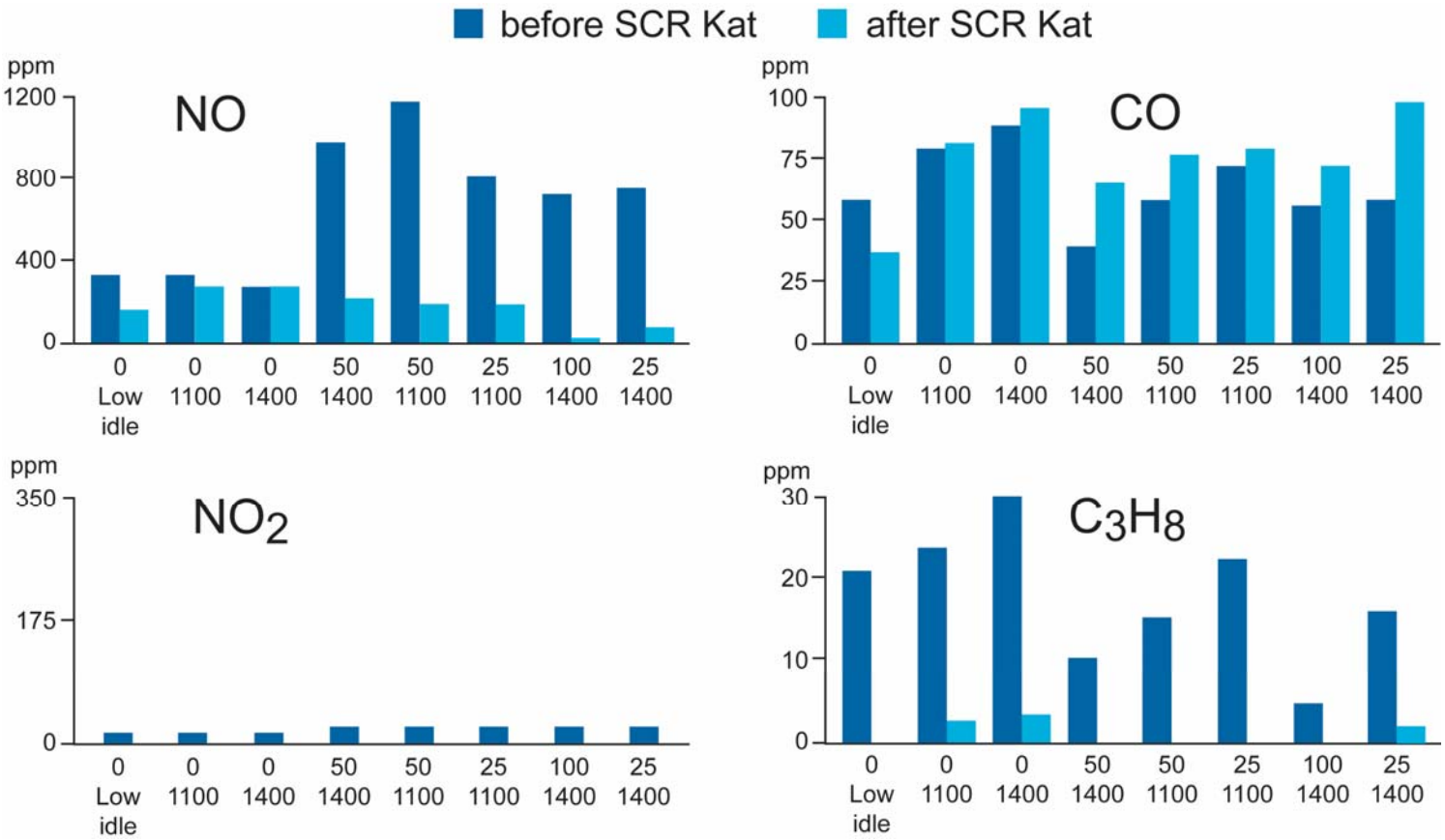


Free Accelerations, DC-Sensor

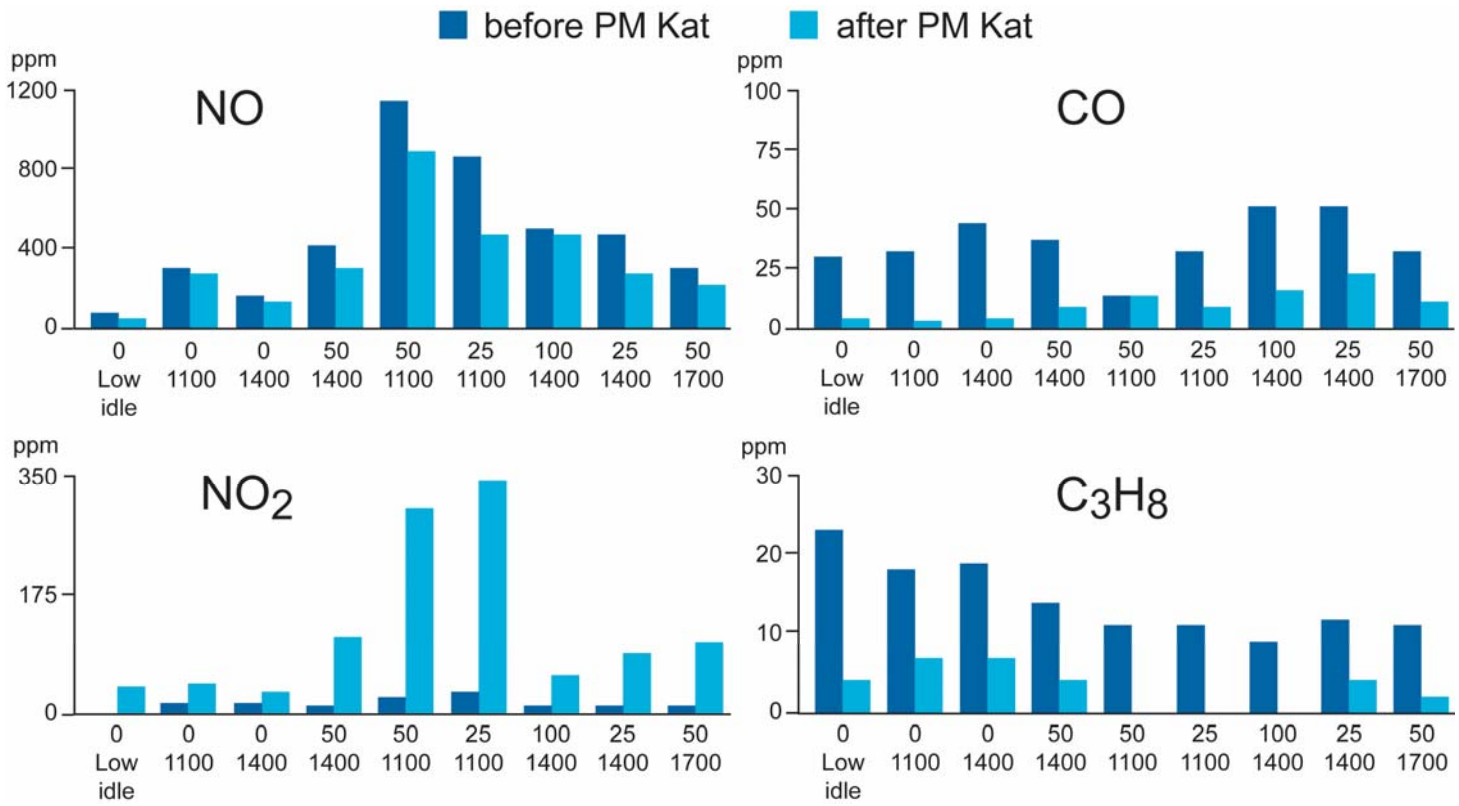
Full Load E3: 1.6 x 10^4
Full Load E4: 2.2 x 10^4
Full Load E5: 2.6 x 10^4



Gas Emissions Euro 5 [ppm]

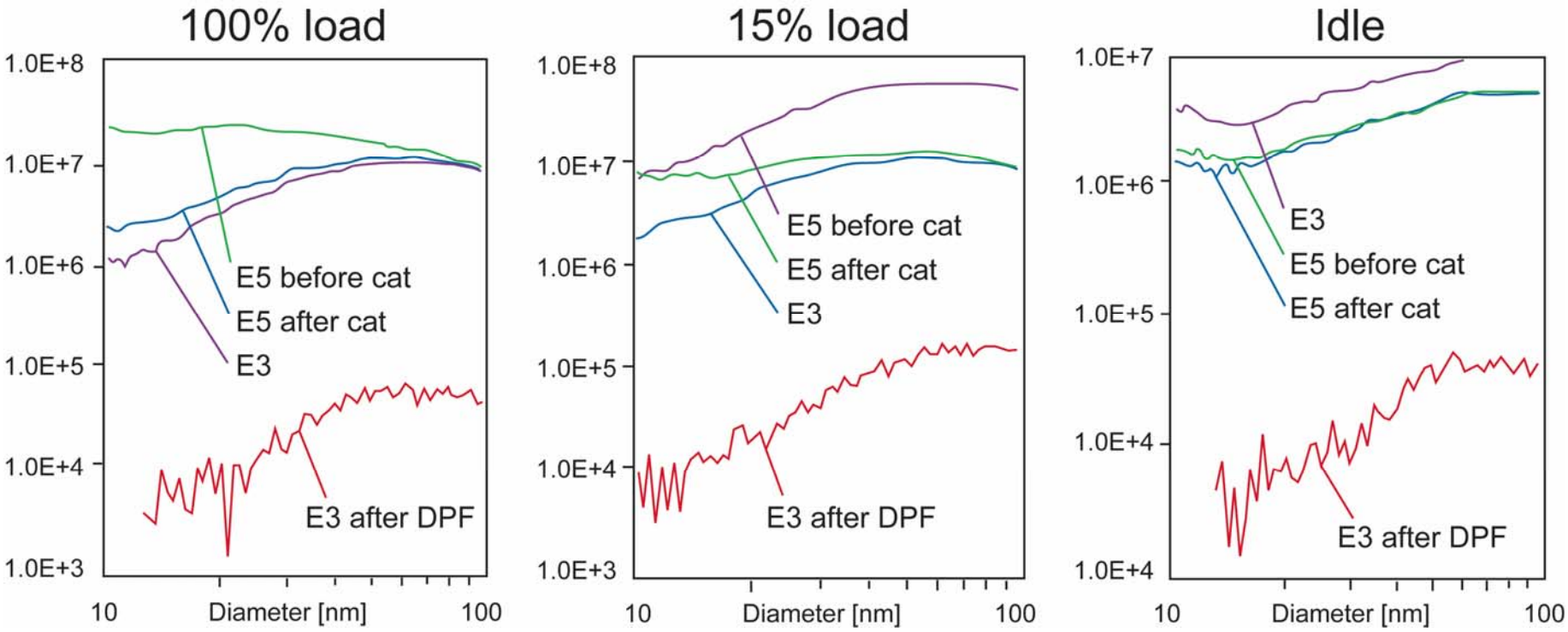


Gas Emissions Euro 4 [ppm]

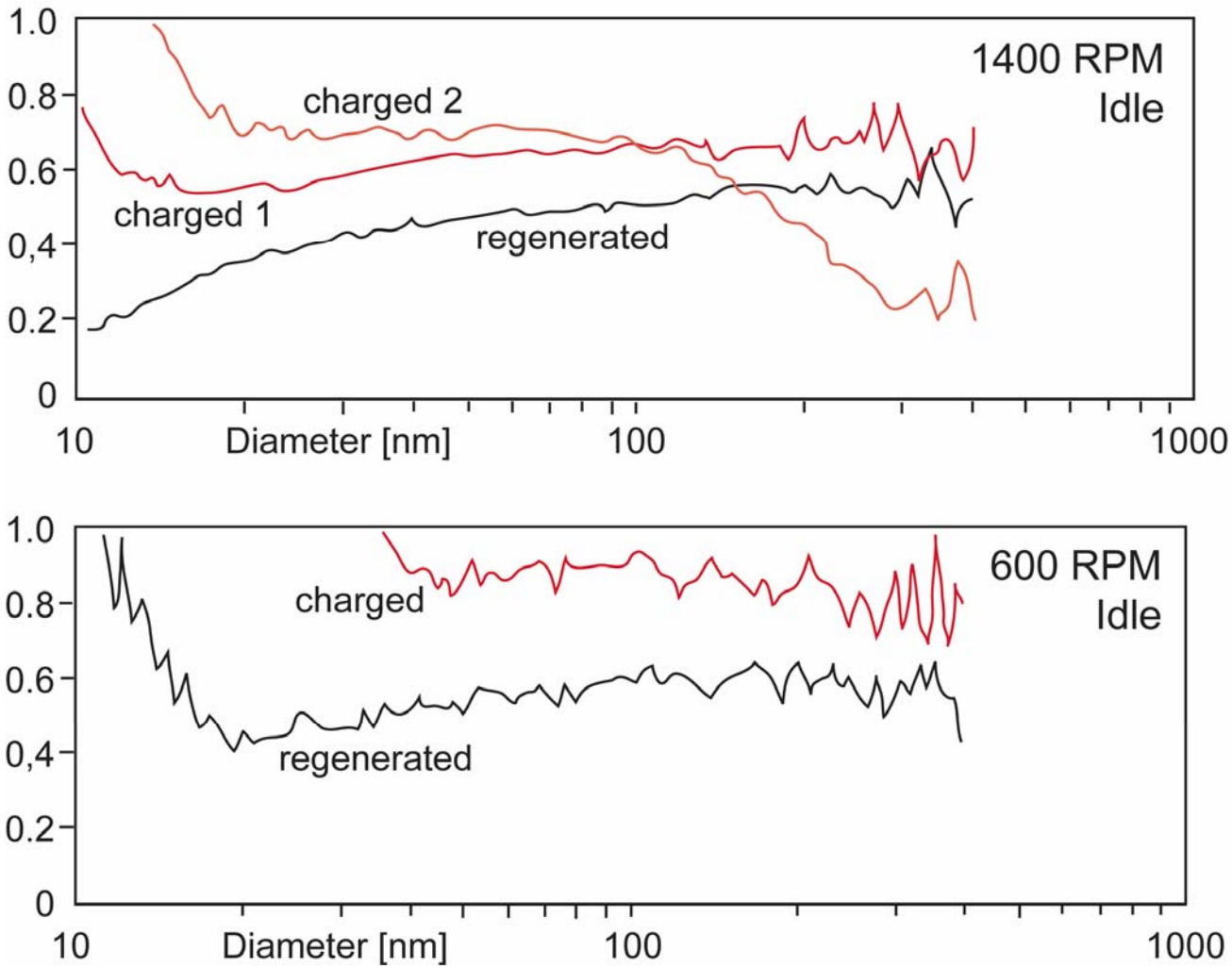


Particles:
SCR *vs* PM-Kat *vs* DPF

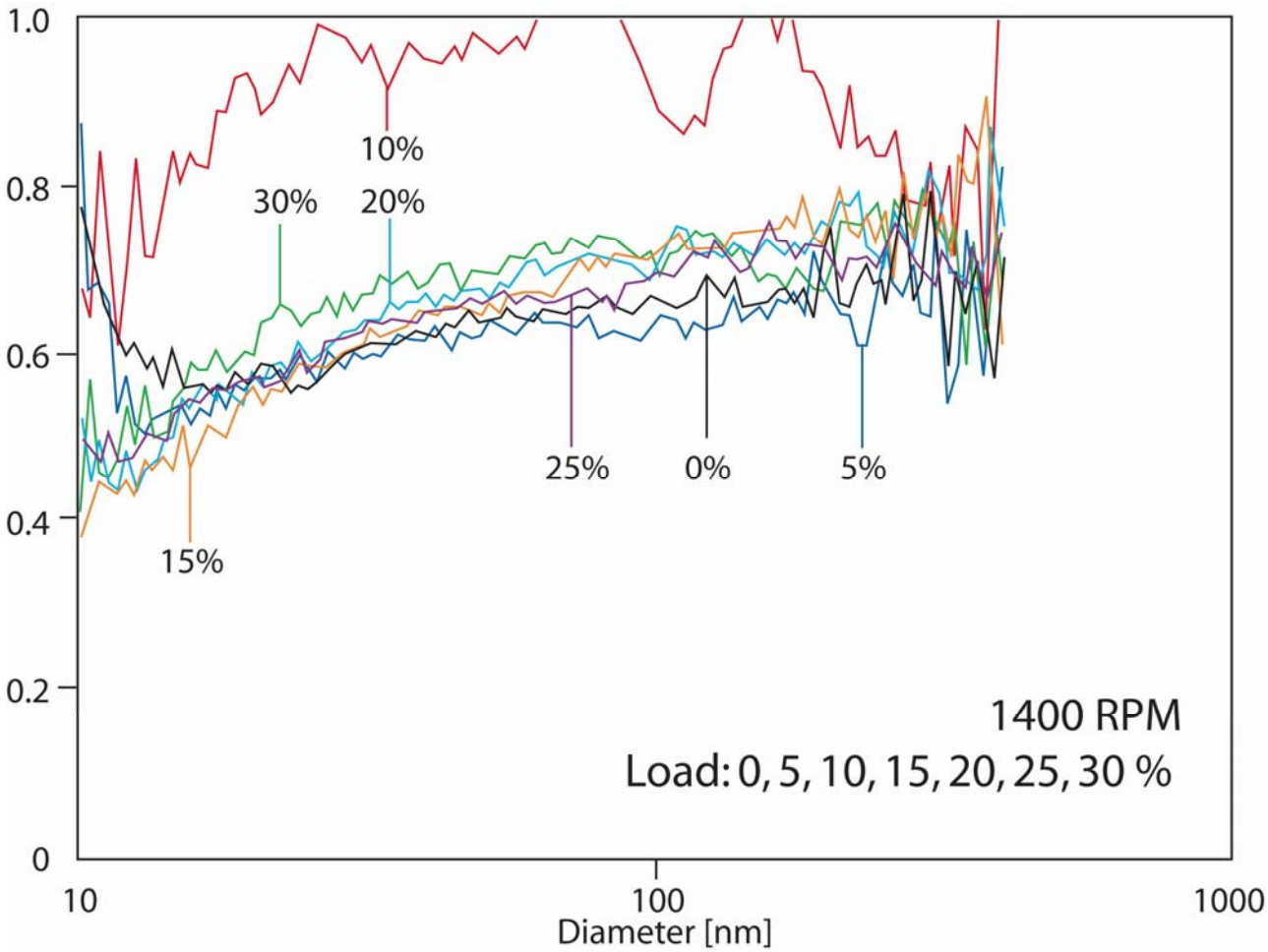
Nanoparticle Emissions with SCR



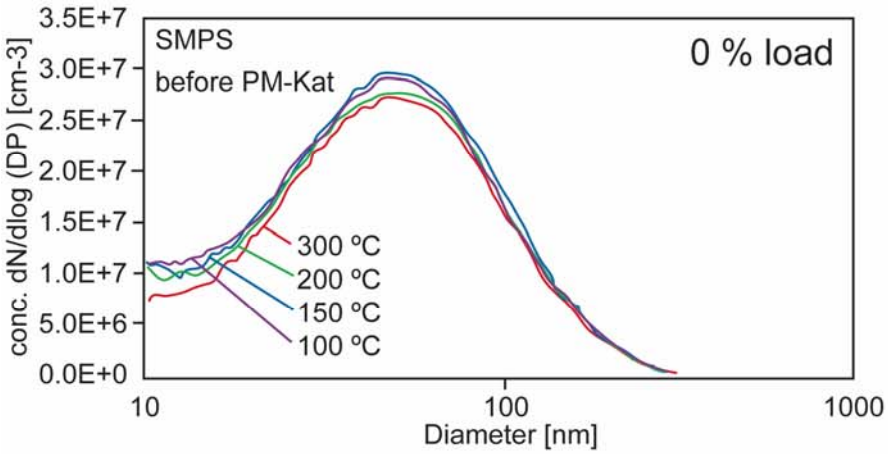
PM-Kat Regenerated and Soot Charged

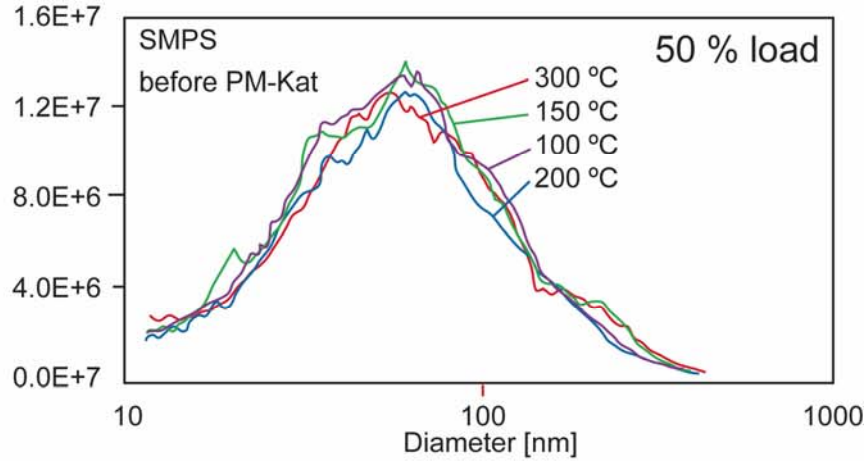


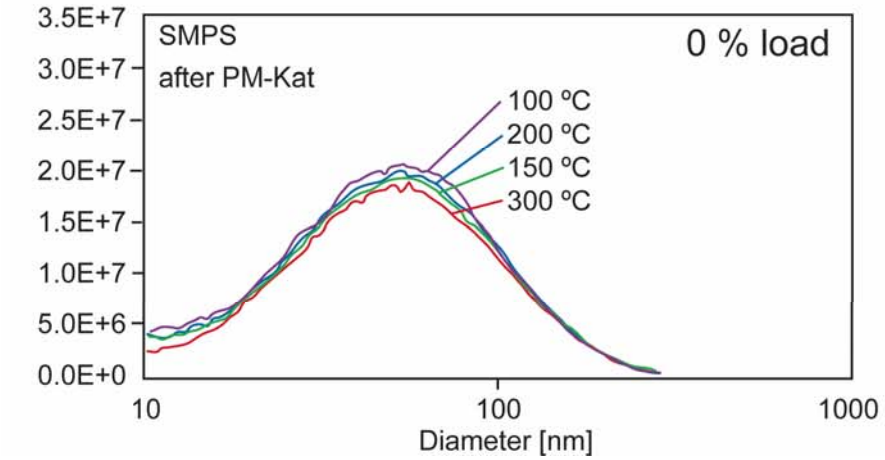
PM-Kat : Penetration-Instabilities

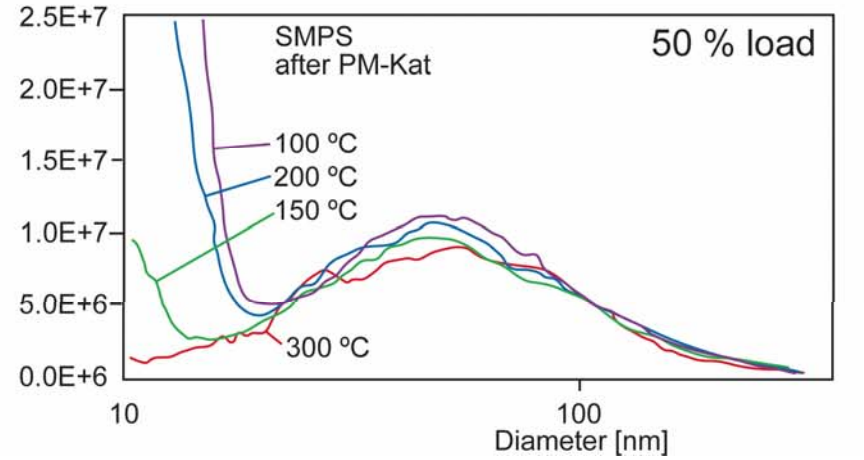


PM-Kat: Thermogramms at 2 Loads



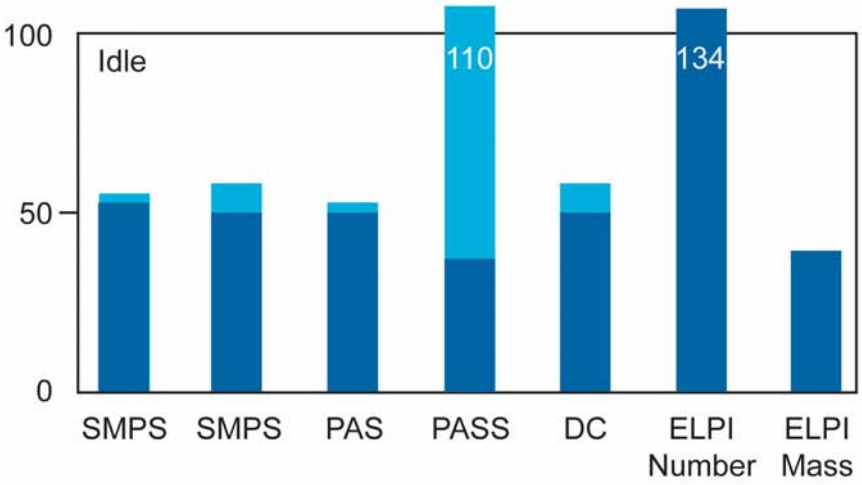


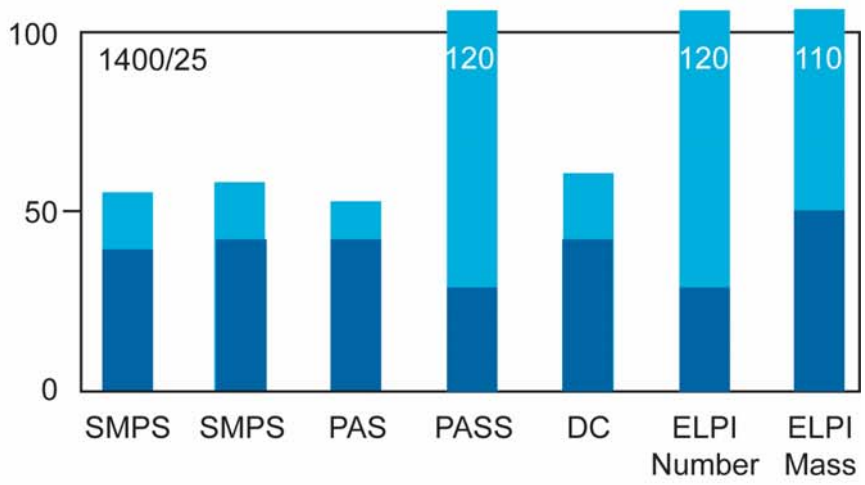


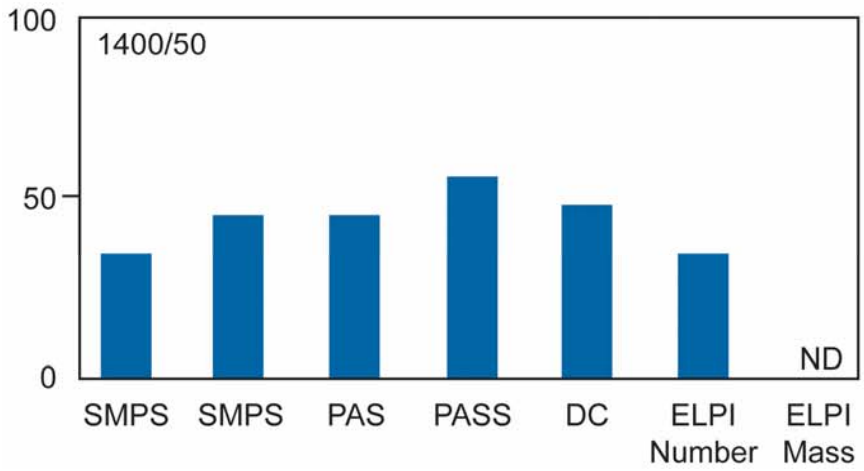


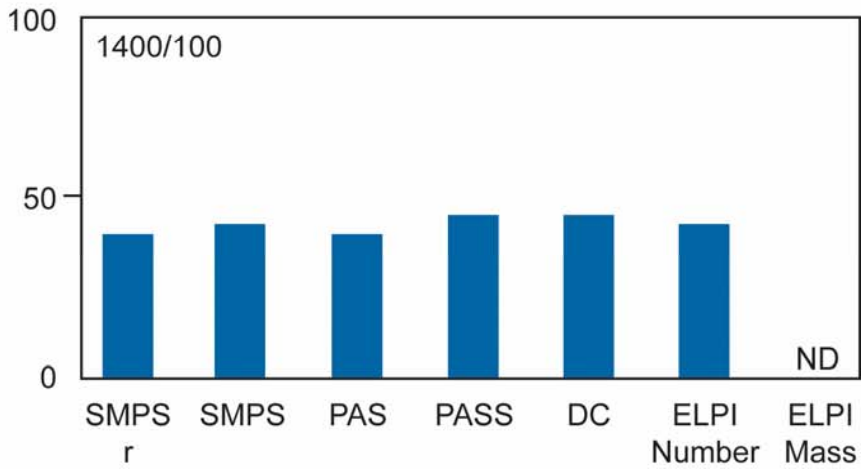
PM-Kat-Penetrations, all Instruments

not meassured at exactly same time







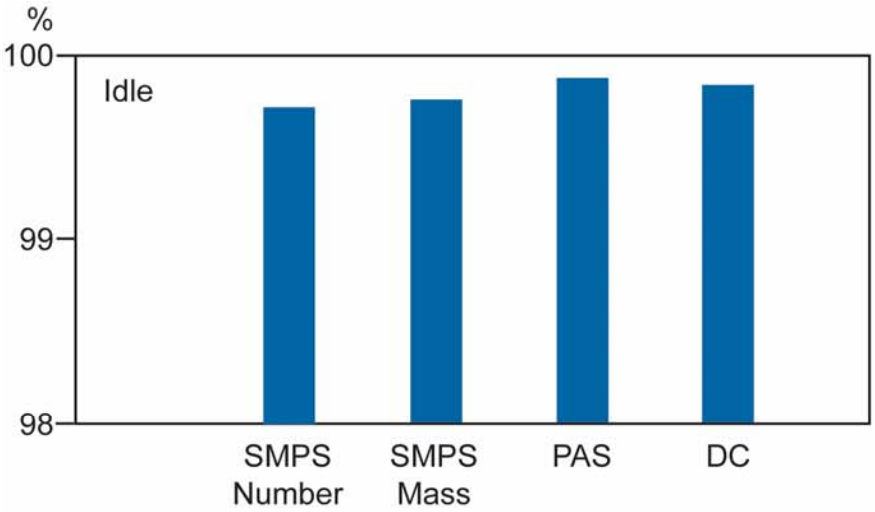


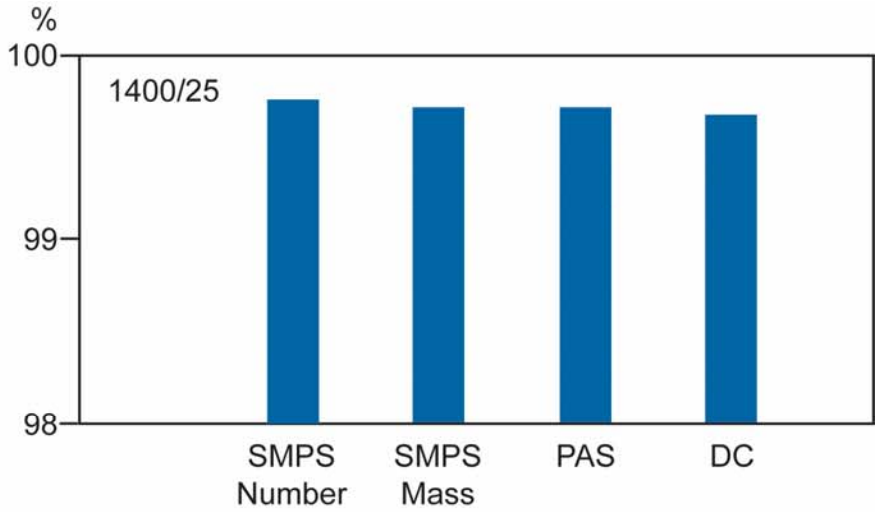
Penetration Euro 4-PM-Kat

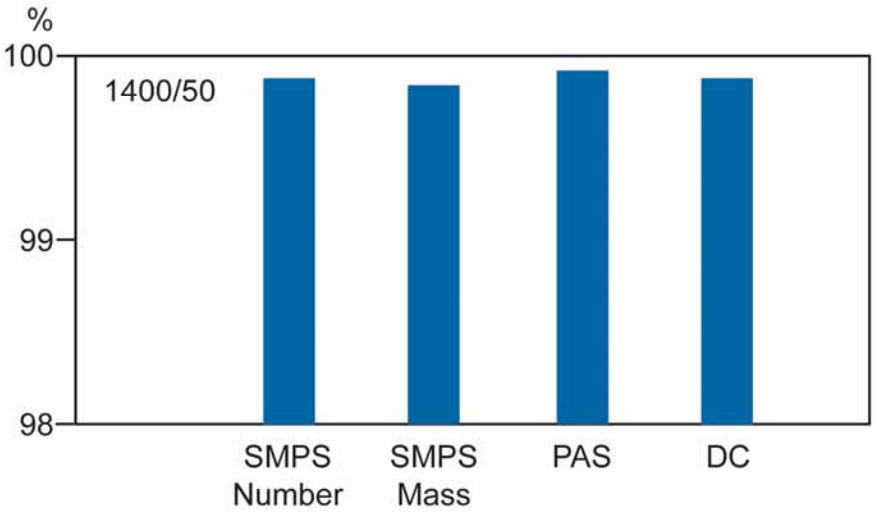
measured with different methods not exactly at the same time

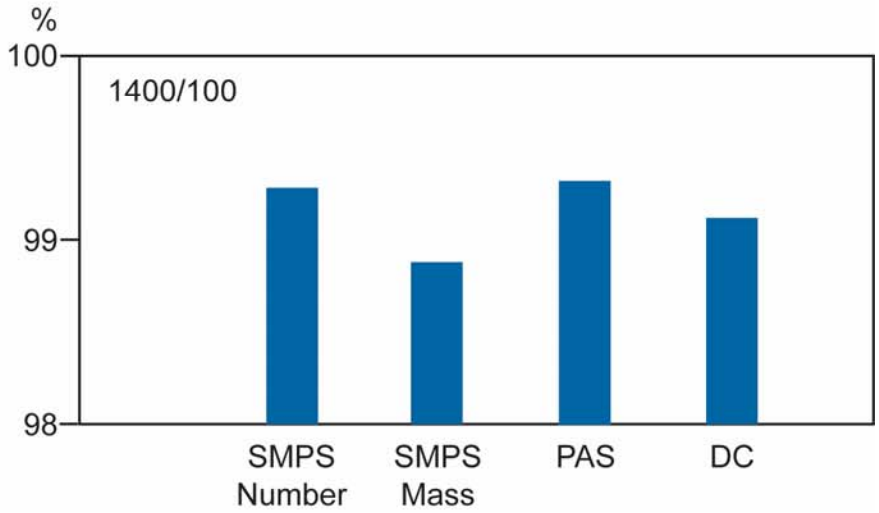
	SMPS count	SMPS mass	PAS	PASS	DC	ELPI count	ELPI mass
Idle 600 rpm	0.60	0.58	0.52	0.41	0.58	ND	ND
1400 rpm	0.62	0.67	0.59	1.10	0.65	1.34	0.46
1400 rpm 25% Load	0.45	0.49	0.47	0.34	0.48	0.32	0.57
	0.64*	0.69	0.59	1.20	0.69	1.20	1.10
1400 rpm 50% Load	0.40	0.50	0.51	0.63	0.55	0.38	ND
1400 rpm 100 % Load	0.45	0.49	0.45	0.52	0.52	0.49	ND
*) Repetition							

E3 DPF-Efficiency, all Instruments







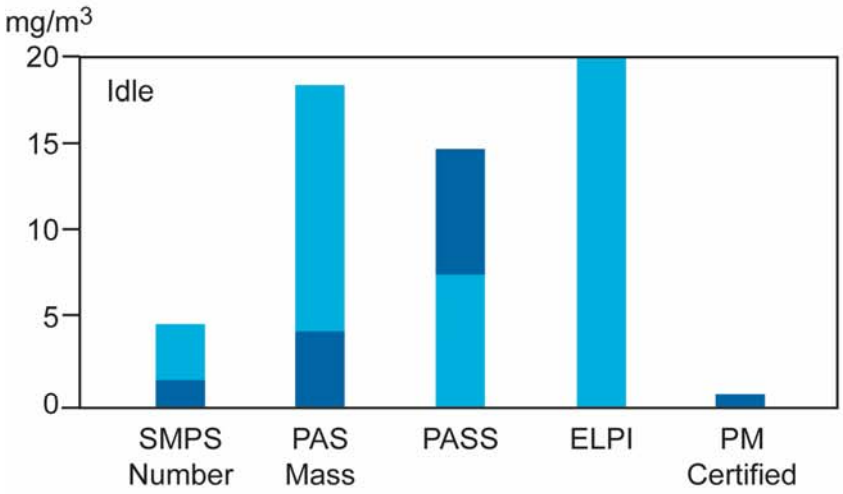


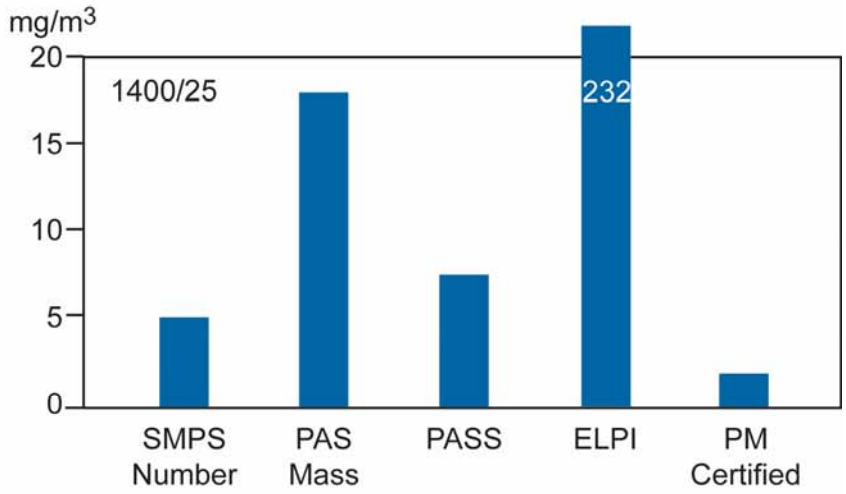
Filtration Efficiency Euro 3 – DPF

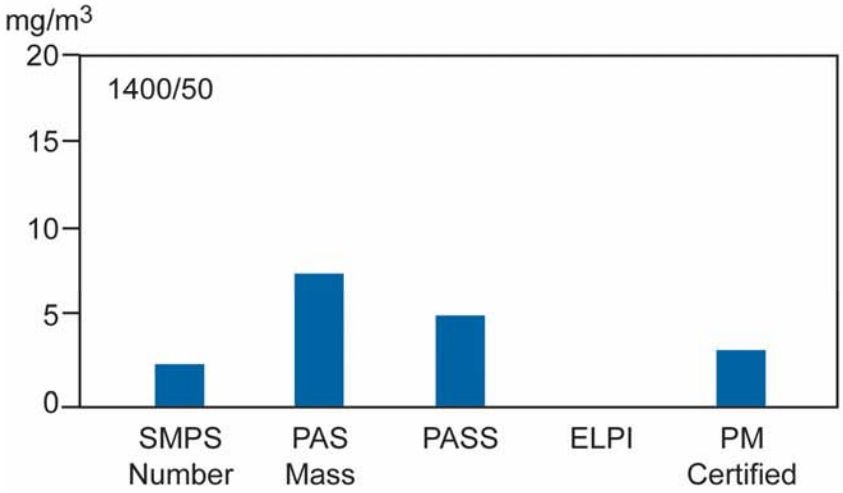
measured with different methods

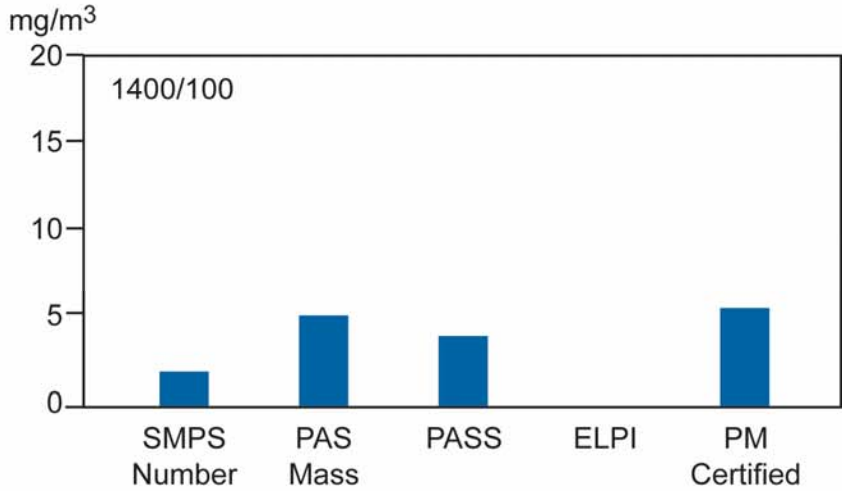
	SMPS count	SMPS mass	PAS	PASS	DC	ELPI count	ELPI mass
Idle 600 rpm 1400 rpm	99.70	99.75	99.88	ND	99.85	ND	ND
1400 rpm 25% Load	99.76	99.72	99.70	ND	99.68	ND	ND
1400 rpm 50% Load	99.87	99.82	99.90	ND	99.86	ND	ND
1400 rpm 100 % load	99.27	99.86	99.32	ND	99.12	ND	ND

E4-PM-Kat, Mass Emission versus certified PM









Particle Mass Emission EURO - 4 PM-Kat

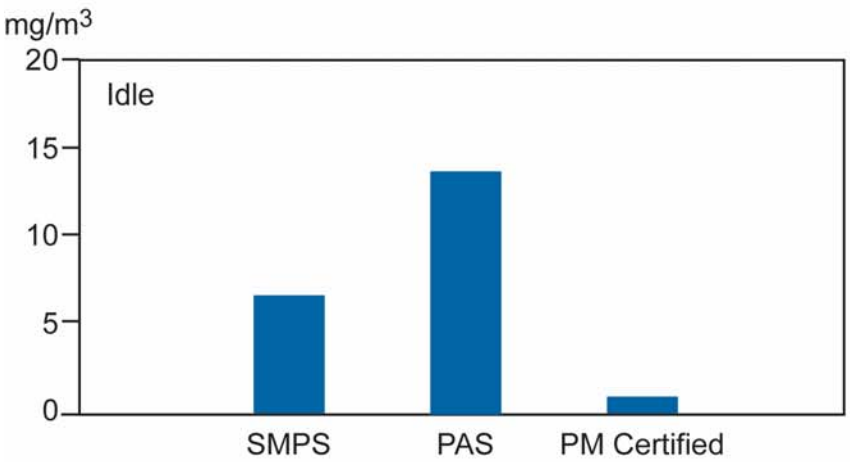
aerosol measurements compared to certified PM

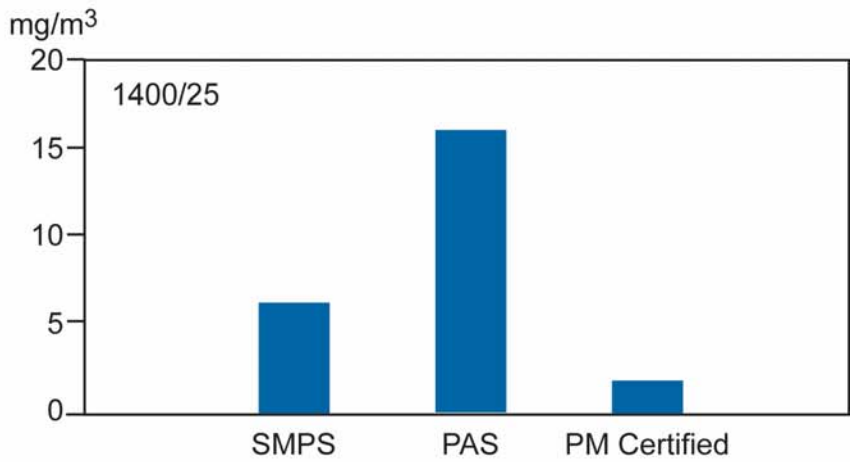
[mg/m³]	SMPS → mass	PAS EC	PASS EC	ELPI → mass	*PM certified 0.014 mg/kWh converted to mg/m³*
Idle 600 rpm 1400 rpm	1.5 4.6	4.3 18.4	14.6 7.7	ND 20.2	*0,6 (λ = 7)*
1400 rpm 25% Load	5.3	18.1	7.5	232	*1.8 (λ = 3)*
1400 rpm 50% Load	2.5	7.7	5.3	ND	*3.2 (λ = 2)*
1400 rpm 100 % load	1.8	5.1	4.1	ND	*5.4 (λ = 1.5)*

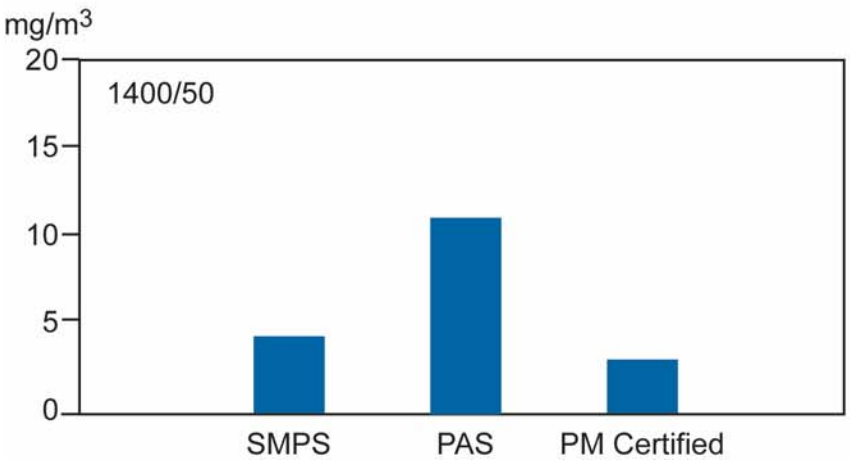
Certified PM is given in mg/kWh per cycle
To convert into mg/m3 needs assumptions for λ and Be per operation point

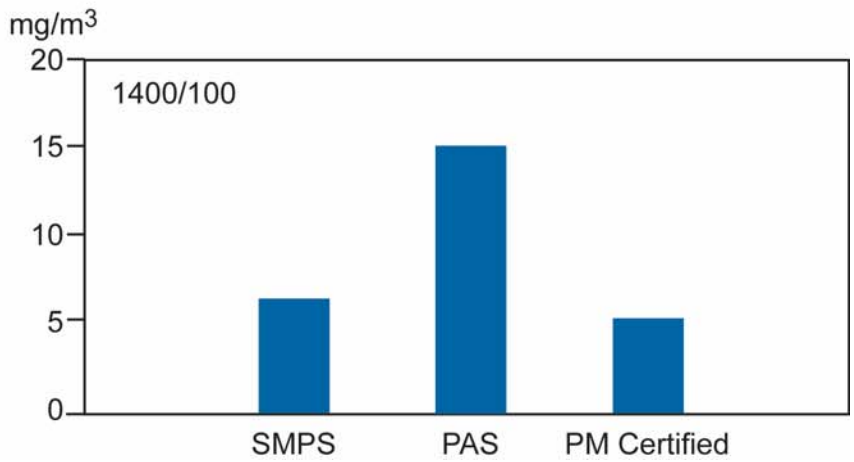
	αηρ περιουσια λ	fuel consumption g/kWh	air mass consumption mg/kWh	air volume consumtion m^3/kWh
Idle	7	400	40	34
25 % load	3	300	12.9	11
50 % load	2	250	7.2	6.1
100 % load	1.5	200	4.3	3.7

E5-SCR, Mass Emission versus certified PM

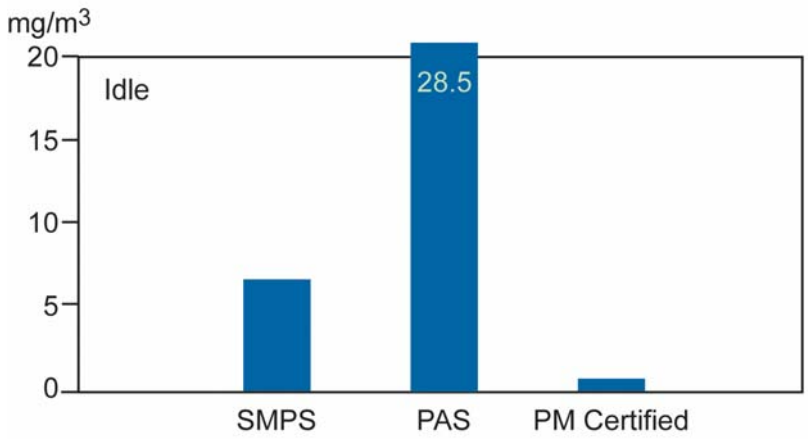


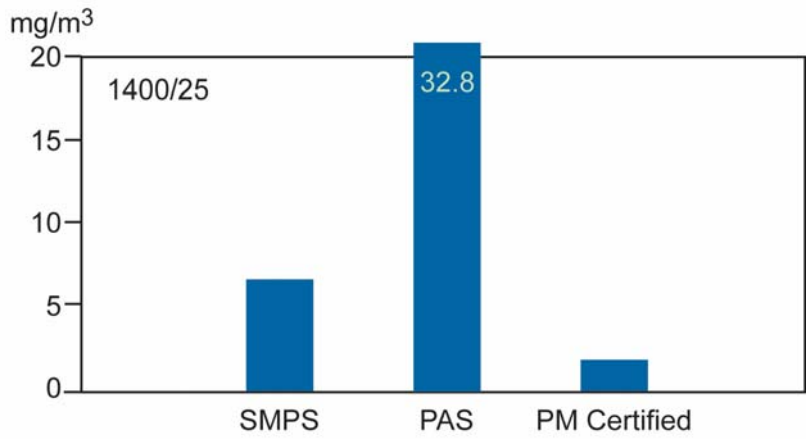


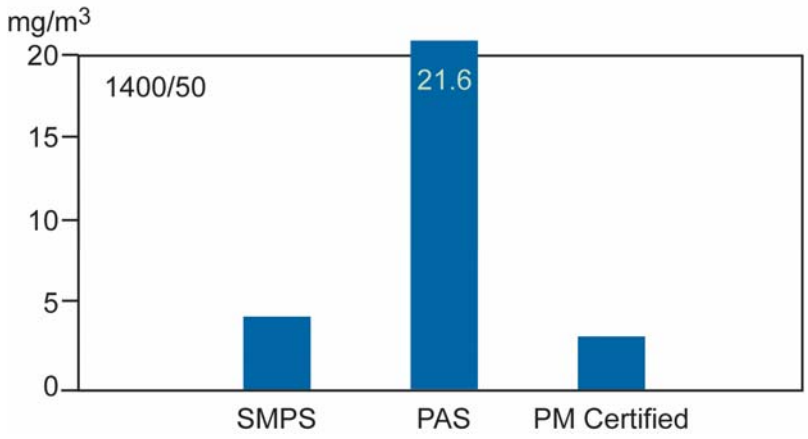


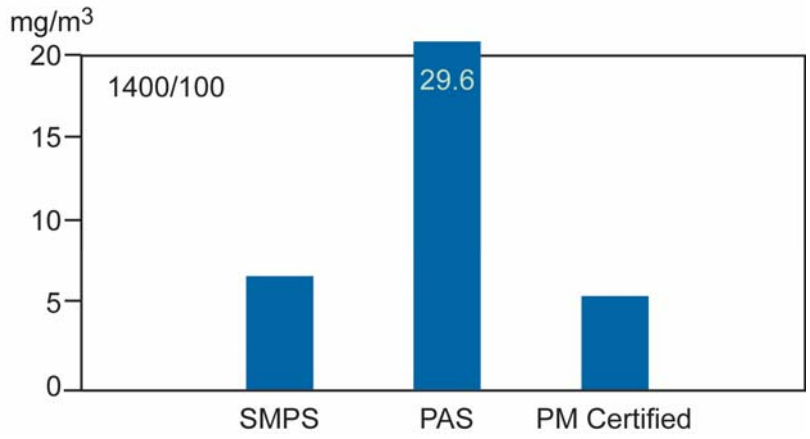


E5-SCR, Mass Emission versus certified PM







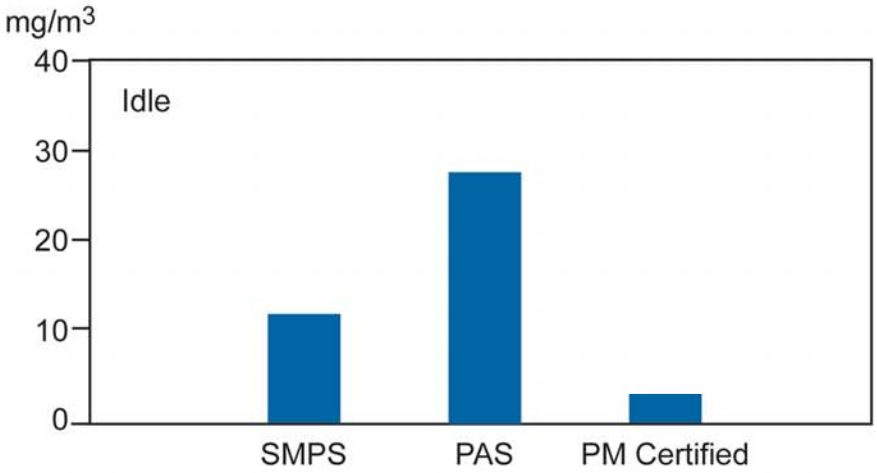


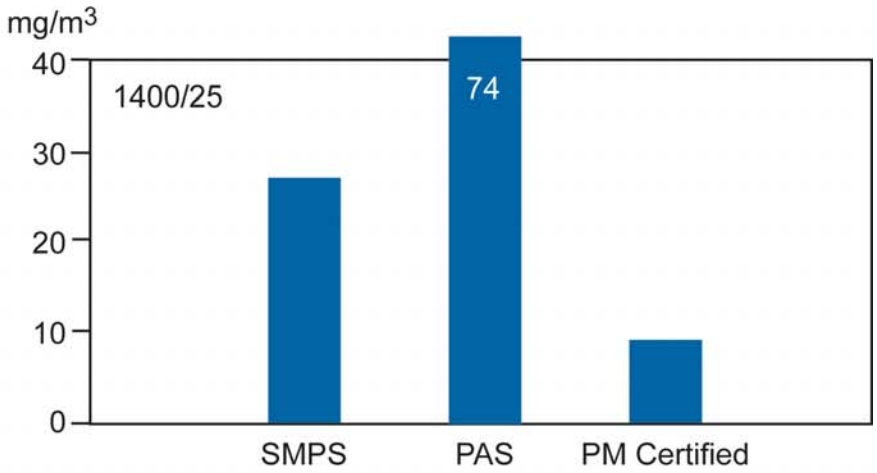
Particle Mass Emission EURO 5 - SCR

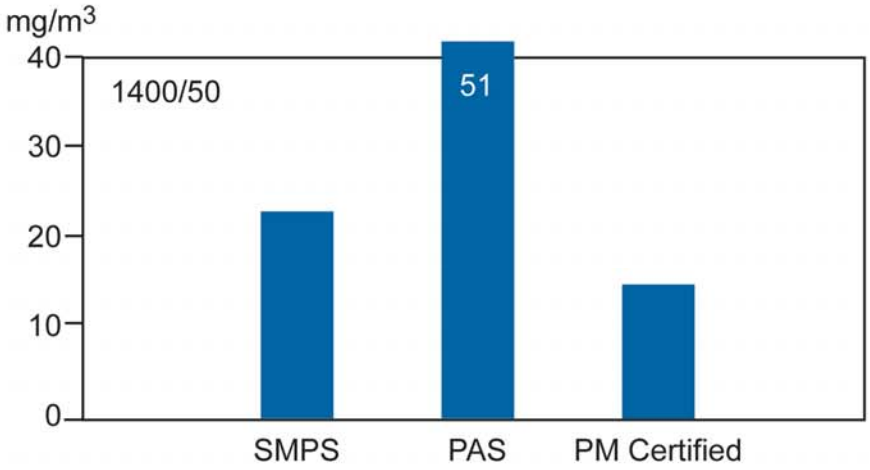
aerosol measurements compared to certified PM

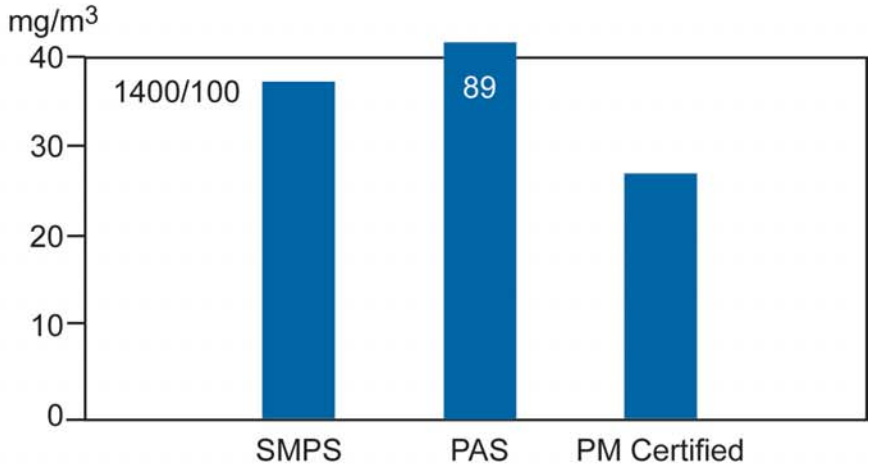
[mg/m³]	SMPS → mass	PAS EC	PASS EC	ELPI → mass	*PM certified 0.013 mg/kWh converted to mg/m3*
Idle 600 rpm 1400 rpm	6.6	14.3.6	ND	ND	*0,6 (λ = 7)*
1400 rpm 25% Load	6.7	16.4	ND	ND	*1.8 (λ = 3)*
1400 rpm 50% Load	4.5	10.8	ND	ND	*3.2 (λ = 2)*
1400 rpm 100 % load	6.7	14.6	ND	ND	*5.4 (λ = 1.5)*

E3 w/o DPF, Mass Emission versus certified PM







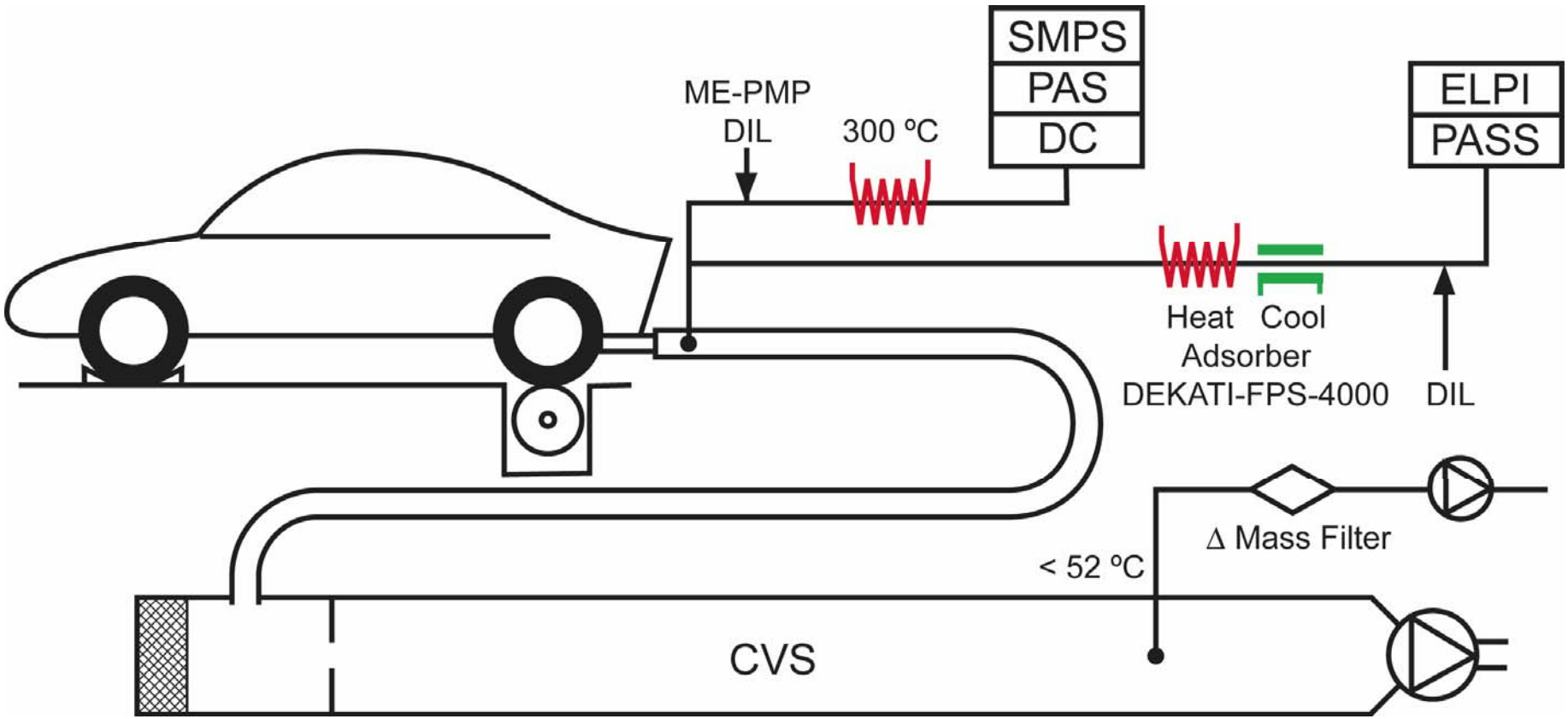


Particle Mass Emission EURO 3 w/o DPF

aerosol measurements compared to certified PM

[mg/m³]	SMPS → mass	PAS EC	PASS EC	ELPI → mass	*PM certified 0.014 mg/kWh converted to mg/m3*
Idle 600 rpm 1400 rpm	11.9	27	ND	Nd	*3.0 (λ = 7)*
1400 rpm 25% Load	28.8	70.4	ND	ND	*9.0 (λ = 3)*
1400 rpm 50% Load	22.5	51.0	ND	ND	*16 (λ = 2)*
1400 rpm 100 % load	37	86.5	ND	ND	*27 (λ = 1.5)*

Aerosol Analysis compared to gravimetric CVS-PM-Measurement



Wrap Up

Summary

- Particle Measurement Technology
  - high consistency of various measurement methods
- Euro5 - SCR: The NO_x Eater
  - NO_x reduction up to 95% - very efficient
  - may increase engine-out nanoparticle emissions
  - no detectable slip of NH_3, NO_2 or N_2O
- Euro4 - PM-Kat: Big Effort, Little Effect
  - unstable particle bypass system
  - episodes of zero efficiency; blow-off phenomena
  - creates high NO_2 concentrations
  - no detectable metal emissions from catalyst
- Euro3 - DPF: The Particle Benchmark
  - PN downstream of DPF is < 0.2 % of upstream
  - PN at Euro4 and Euro5 is $\geq$ 50 % of Euro3 (engine out)

Conclusions = Outlook

- Combine Advantages of DPF and SCR:
- **=> SCRT**
- commercially available from Jan 2007
  - for limited fleets, e.g. buses
  - IVECO, DaimlerChrysler

Summary and Conclusions

- PN downstream DPF is < 0.2 % of upstream
- PN downstream E4 and E5 is $\geq$ 50 % of E3

→ DPF for E4 and E5 required

- SCR reduces NOx up to 95 % - very efficient
- SCR does not reduce NOx below ca 225 °C
- SCR tends to increase nanoparticle emissions
- SCR - slip of NH_3, NO_2 or N_2O were below DL
- PM-Kat is an unstable bypass system with zero efficiency episodes and blow-off-phenomena
- PM-Kat creates high NO_2-concentrations
- Catalyst metal emissions were below DL