

Solid Particle Emissions of HDV

Euro 3 – DPF

Euro 4 – PM-Kat

Euro 5 – SCR

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Dr. Ulrich Matter

22nd Feb 1939 – 6th Dec 2005

Questions

- **EURO 4 – PM-Kat**

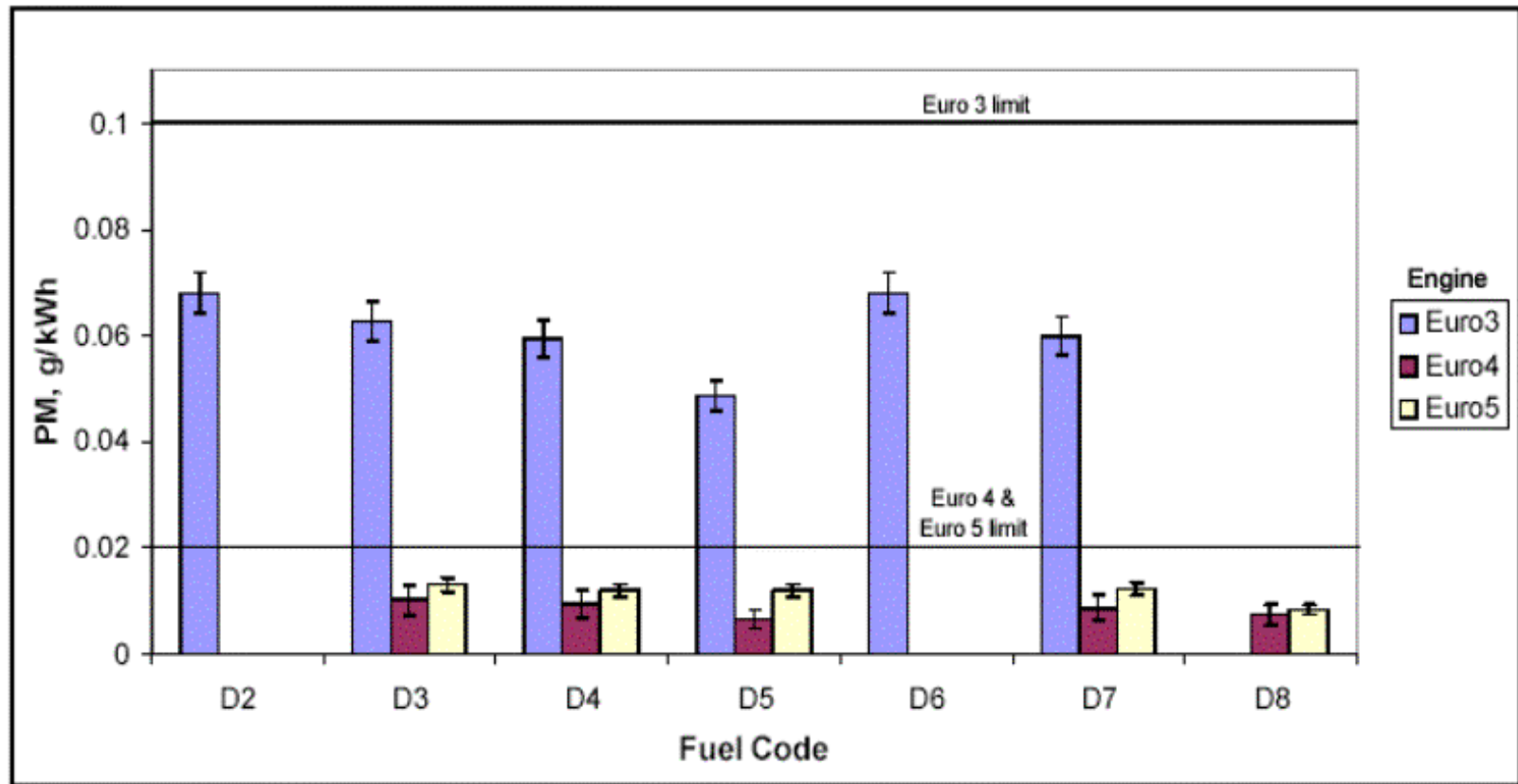
- Nanoparticle Emissions compared to Euro3/DPF
- Nanoparticle Reduction = f (Particle Size and Engine Load)
- Influence of Soot Load, Regeneration, Temperature, Transients
- Secondary Emissions: NO₂, Catalyst Metals

- **EURO 5 – SCR**

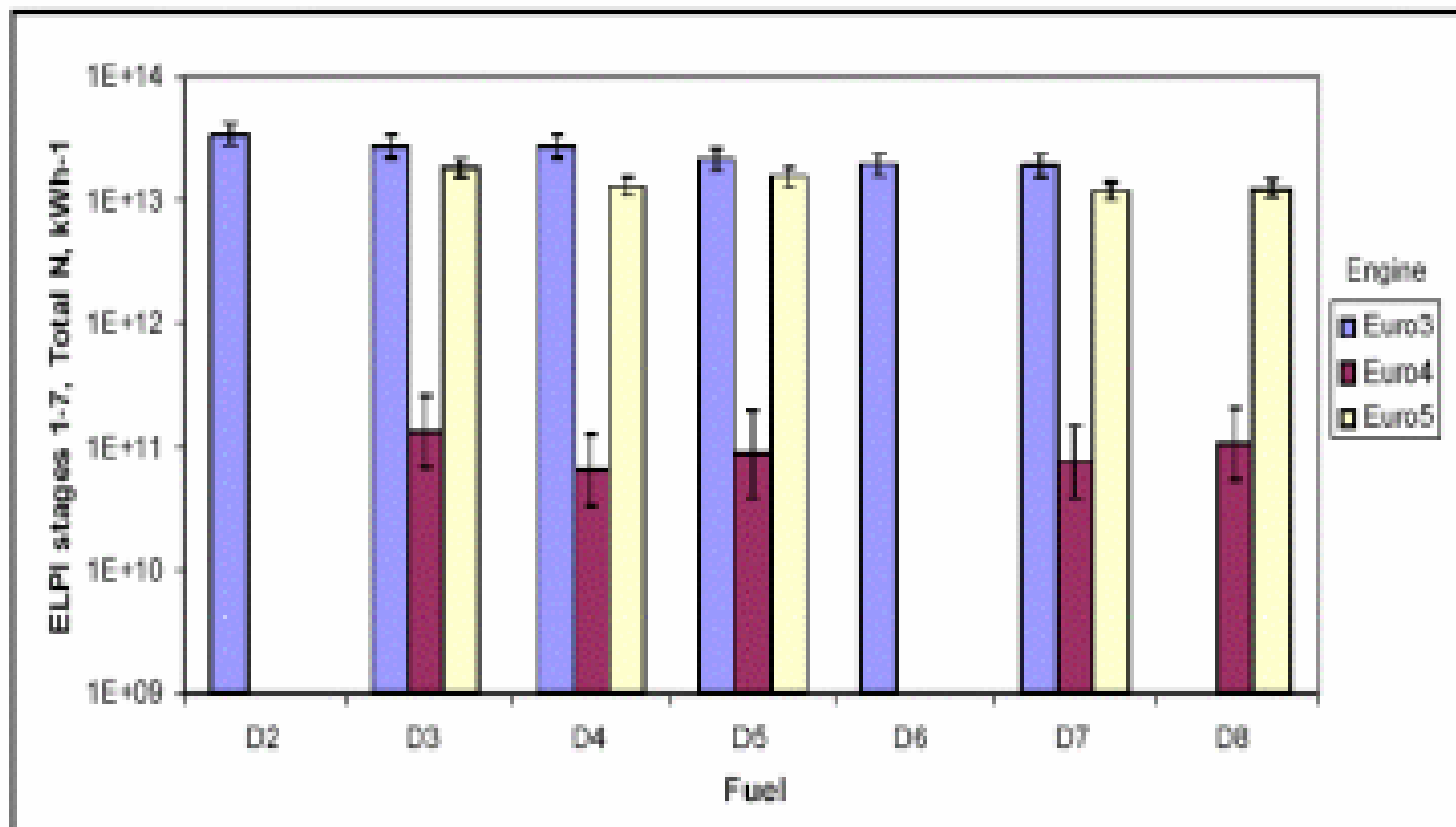
- Nanoparticle Emissions compared to Euro3/DPF and Euro4/PM-Kat
- SCR-Influence on Nanoparticle Reduction/Formation
- NO_x-Reductions at light load (bus city-driving)
- Secondary Emissions: NO₂, N₂O, NH₃, Catalyst Metals

PM : E5/4 w.DPF/3 – CONCAWE 2005

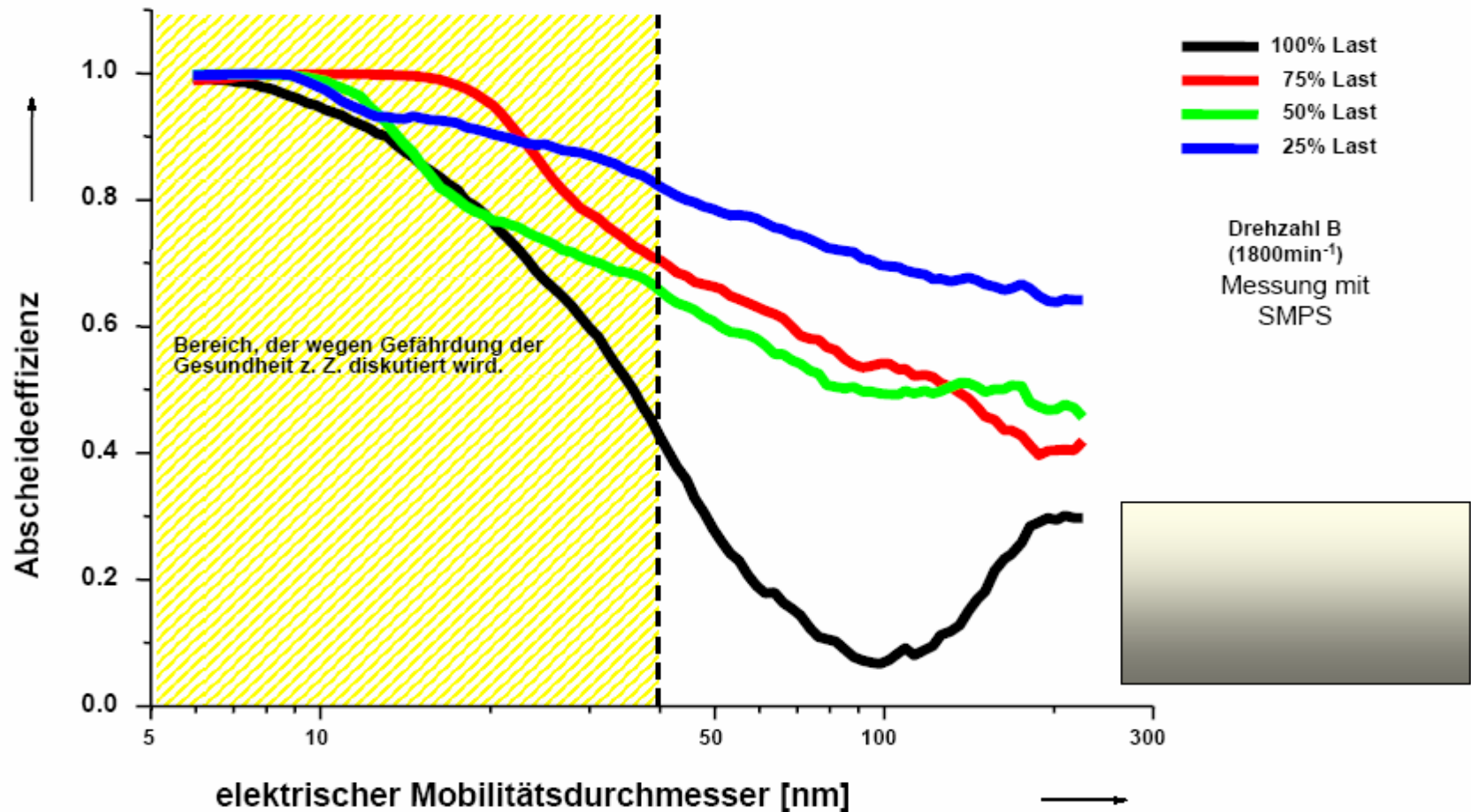
Figure 2 PM emissions - ESC



PN : E5/4 w.DPF/3 – CONCAWE 2005



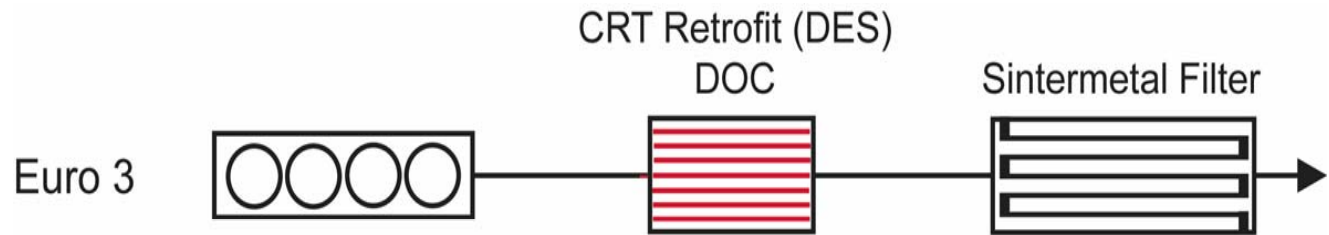
MAN-published Data of Nanoparticle Emissions with PM-Kat-System



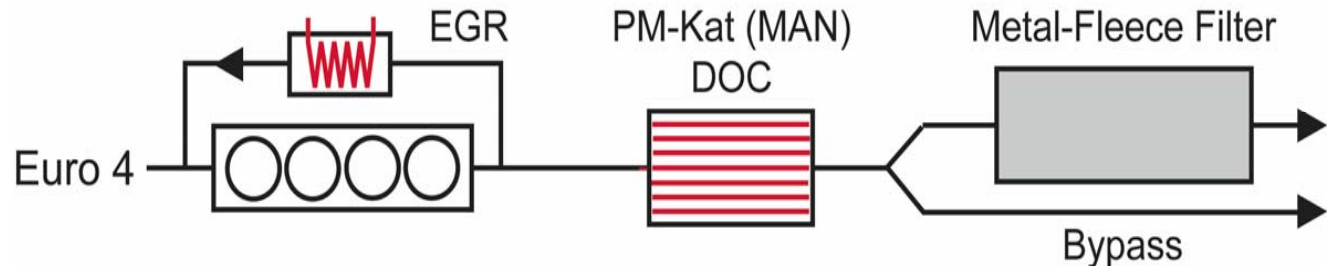
Experimental Setup

Vehicles and Exhaust Aftertreatment Concepts

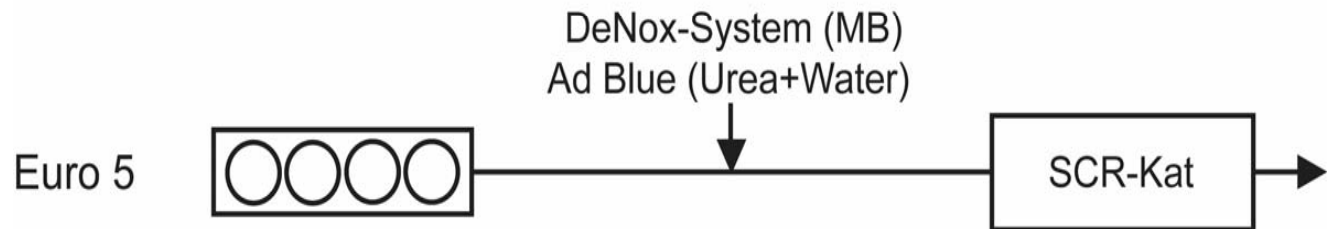
Mercedes Benz
1846-LS (49'051 km)
- 355 kW / 1695 rpm



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

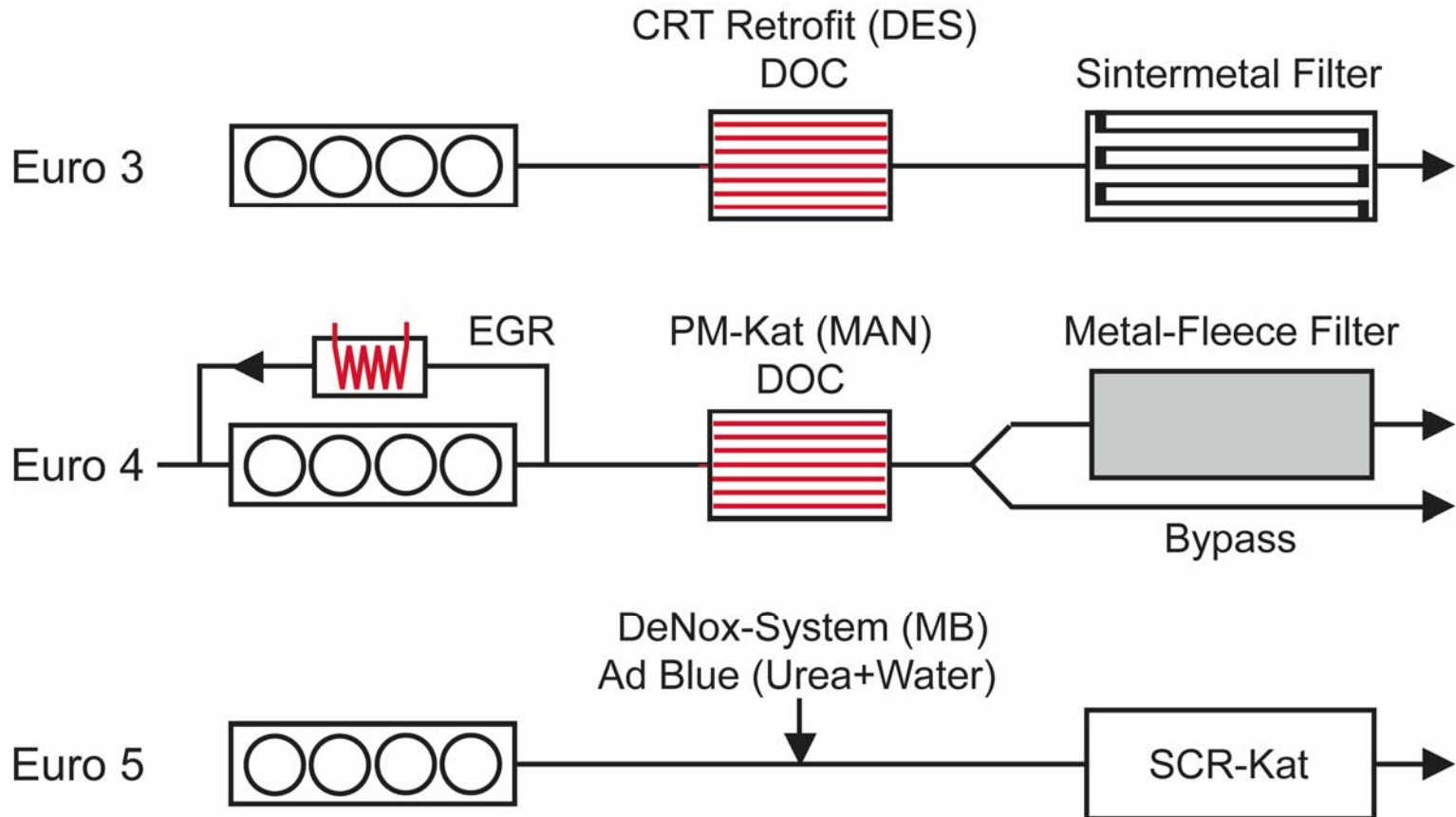
- **EURO 4 – PM-Kat**

- 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





1

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

We include our full women's line. We are
 Tostitos is women's. And we believe that
 that the old line. The technology is great. In fact,
 the line is in the line. The line is in the line.

2.

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

Als Kinetikmodelle können zwei Fälle angedacht werden, der bimolekulare Fall und der von J. Horiuti als eines limitierenden Schrittes eingestufte Fall mit einer katalytischen Induktion, bei der der katalytische Prozess in zwei Stufen abläuft. Und das ist die allgemeine Form von Reaktionen, welche gleich zu erklären sind.

3.

Nur Euro5 bietet einen langfristigen Investitionsschutz bei Neufahrzeugen.

[illegible]

4.

SCR-Technologie spart
mindestens 3% Treibstoff.

Ran-Gemüse der SCL-Technologie verfügt Schmelz- und Rumpffeld bei mindestens 25% geringeren Treibstoffverbrauch bei der SCL-Technologie sind Leistung und Verbrauch optimal angepasst. Der Motor produziert Stickoxide (NO_x), welche der SCR-Katalysator reduziert.

6.

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

Home Watergarnituren haben sich als das Herzstück der neuen Interiors für intelligente Wohnkonzepte, für die Smart-Technologie garantiert. Eine wertvolle Ergänzung kann Watergarnituren (für über 10000 Quadratmeter Wohnfläche) sein.

80

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

Thanks to her constant literary inspirations, Helen He
Muller has contributed and shared the very best of her
work. University of York

9

Mit SCR können alle Diesel- und Ölqualitäten verwendet werden.

Reinigen Sie Ihr Turbo-Erzwingen weiterhin mit dem Öl, das Ihnen am nächsten liegt. Und verwenden Sie weiterhin handelsübliche Öl. Denn bei Turbo gibt es keinerlei Einschränkungen bezüglich Diesel- und Benzinöl.

10.

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

Bei Mercedes-Benz ist es Tradition, frühzeitig mit Investitionen auf den Markt zu kommen – so auch jetzt. Das liegt vor allem daran, dass wir alle Mercedes-Infotainment-Systeme, um unsere Kunden zu einem frühen Zeitpunkt die Besten zu bieten.

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



5.

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

Im 19. Jhr. konnte durch naturhistorische Aufklärungsarbeiten die Verfügbarkeit an einem heute nicht mehr vorhandenen Zentralpunkt keine Bedeutung für die Wirtschaft und die Konzentration an der Verkehrserschließung und dem Verkehrsteilnehmern abgelesen werden. In der Zeit der Aufklärung wurde die Bedeutung der Eisen- und Stahlindustrie für die Wirtschaft und die Konzentration an der Verkehrserschließung und dem Verkehrsteilnehmern abgelesen.

7

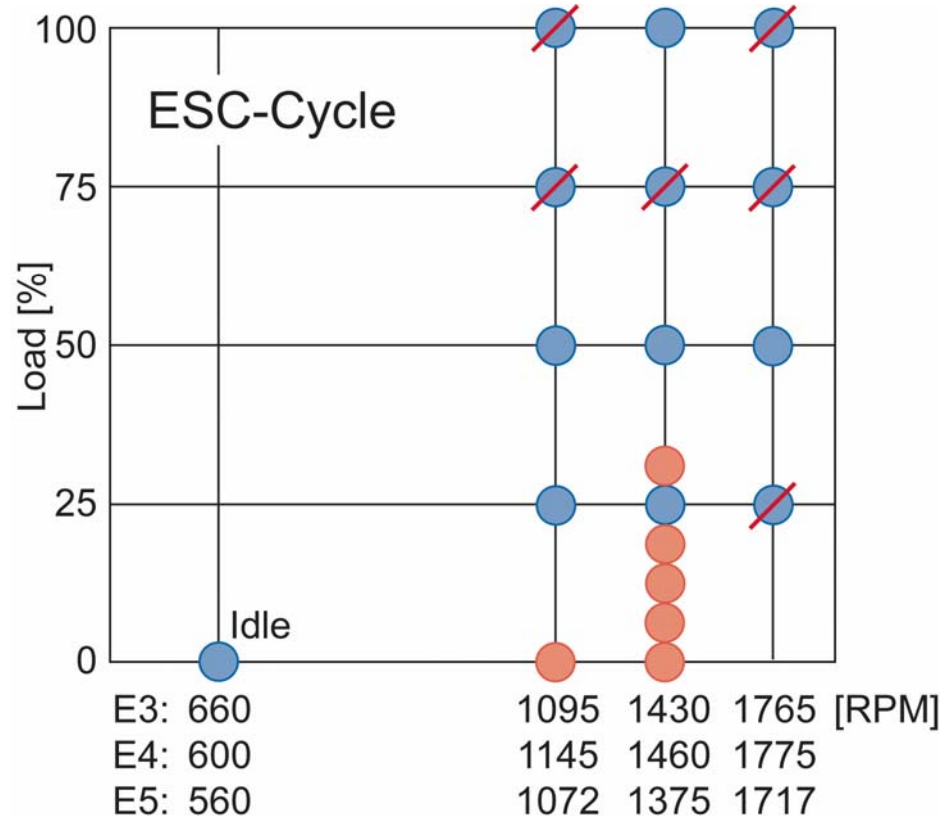
OBD I (On-Board-Diagnose)
bei Mercedes-Benz Lkw
schon jetzt an Bord.

Die Se-Richt-Diagramme wird als 1. Gliederungsstufe gemäß den vorgeschriebenen, bei Mess-Analysen und Kontrollen für CO-Luft gemessene Werte mit CO-Luft gemessen.

Certified Emissions ESC

[g/kWh]	CO	HC	NOx	PM	EC	PZ	NO ₂
EURO 3 w/o DPF <i>Limits</i>	< 2.1 2.1	< 0.7 0.7	< 5.0 5.0	< 0.1 0.1	?	?	?
EURO 4 - PM-Kat <i>Limits</i>	0.1 1.5	0.01 0.5	3.02 3.5	0.014 0.02	?	?	?
EURO 5 – SCR <i>Limits</i>	0.27 1.5	0.01 0.5	1.56 2.0	0.013 0.02	?	?	?

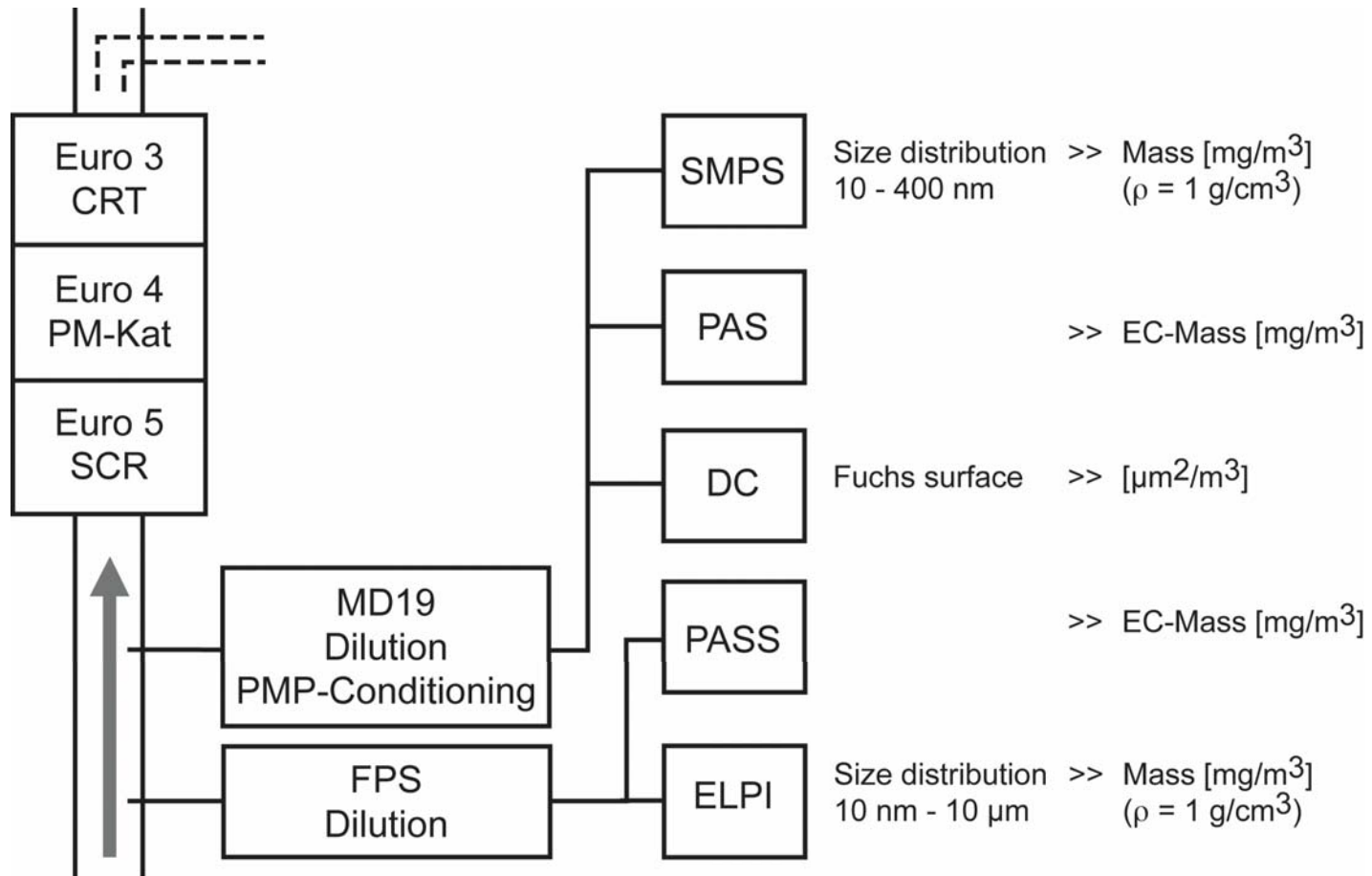
Selected Operating Points



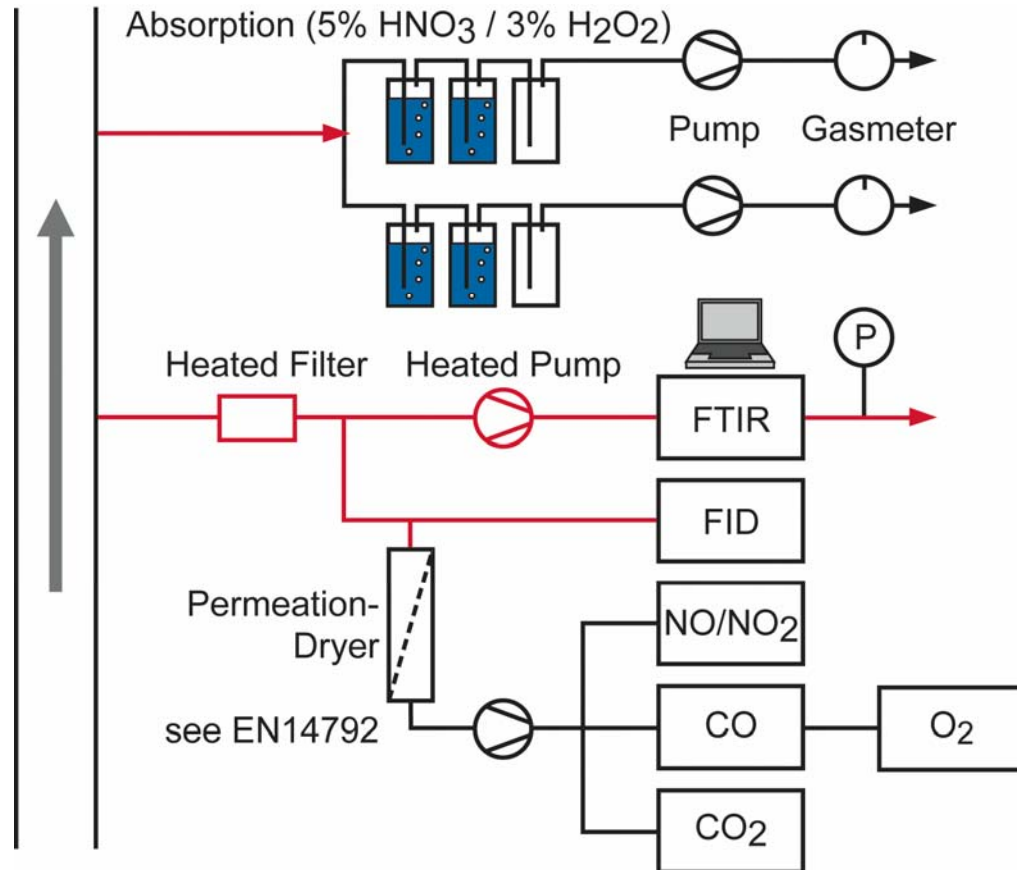
Instruments for Particle Analysis

	Product	Measurement Principle	Size Range	Result
SMPS	TSI	electric mobility 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	Photoacoustic 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)

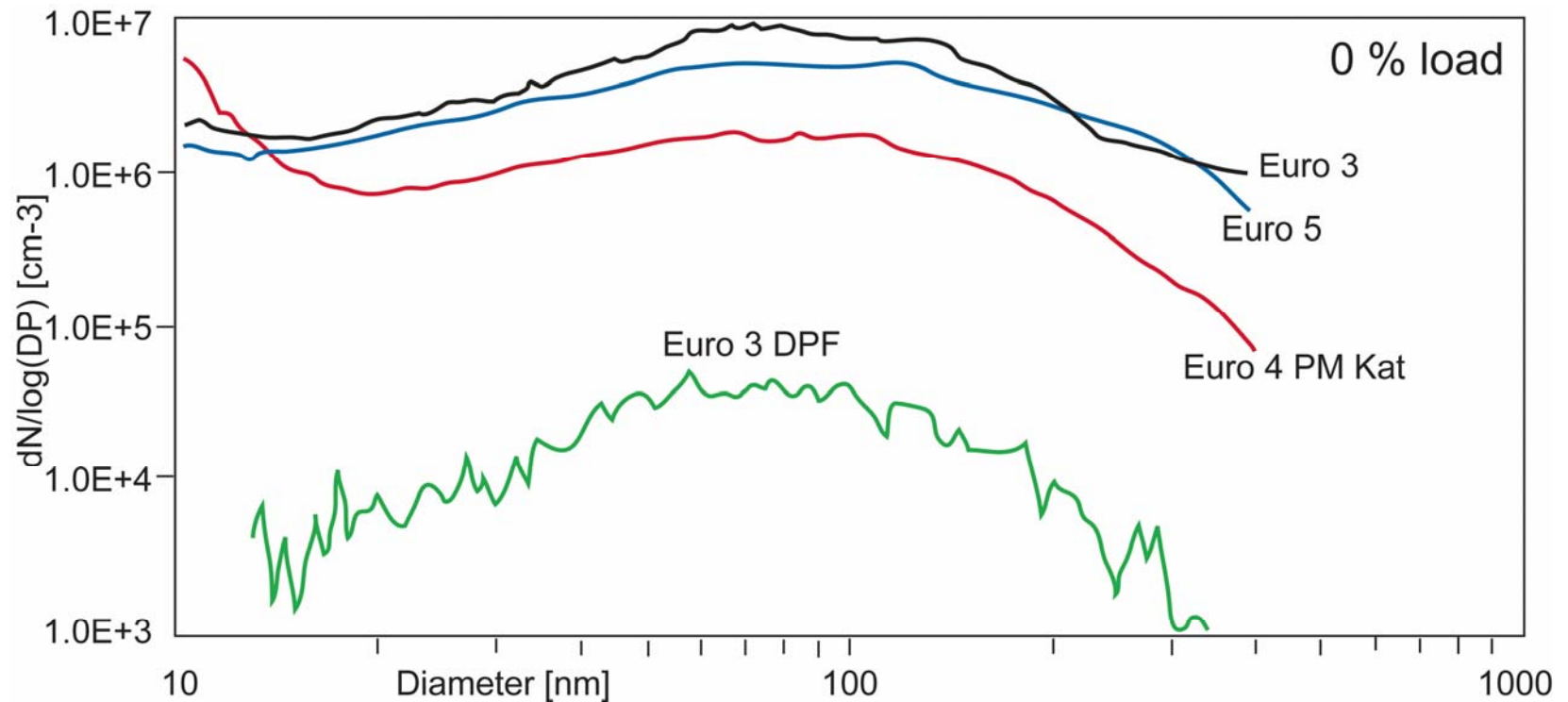
- **Measurements**

- Nanoparticle Analysis: SMPS, PAS, DC, PASS, ELPI
- Gaseous Compounds: NO, NO₂, CO, HC, N₂O, NH₃,
- Catalyst Metals: Pt, V
- Temperatures, Pressures,
- no PM-measurement - CVS-Tunnel not available

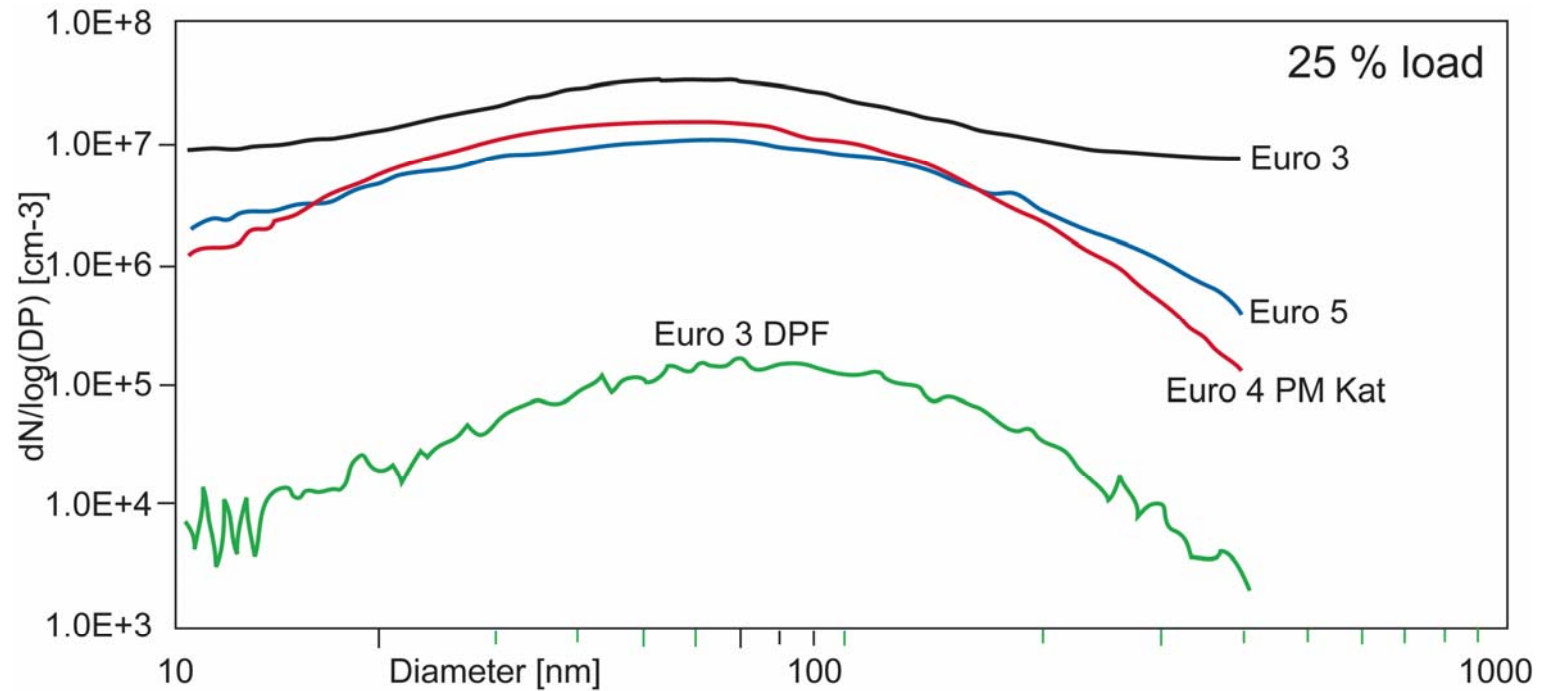
- **Fuel:** SN 181160 -1, S < 10 ppm

Particle and Gas Emissions - General

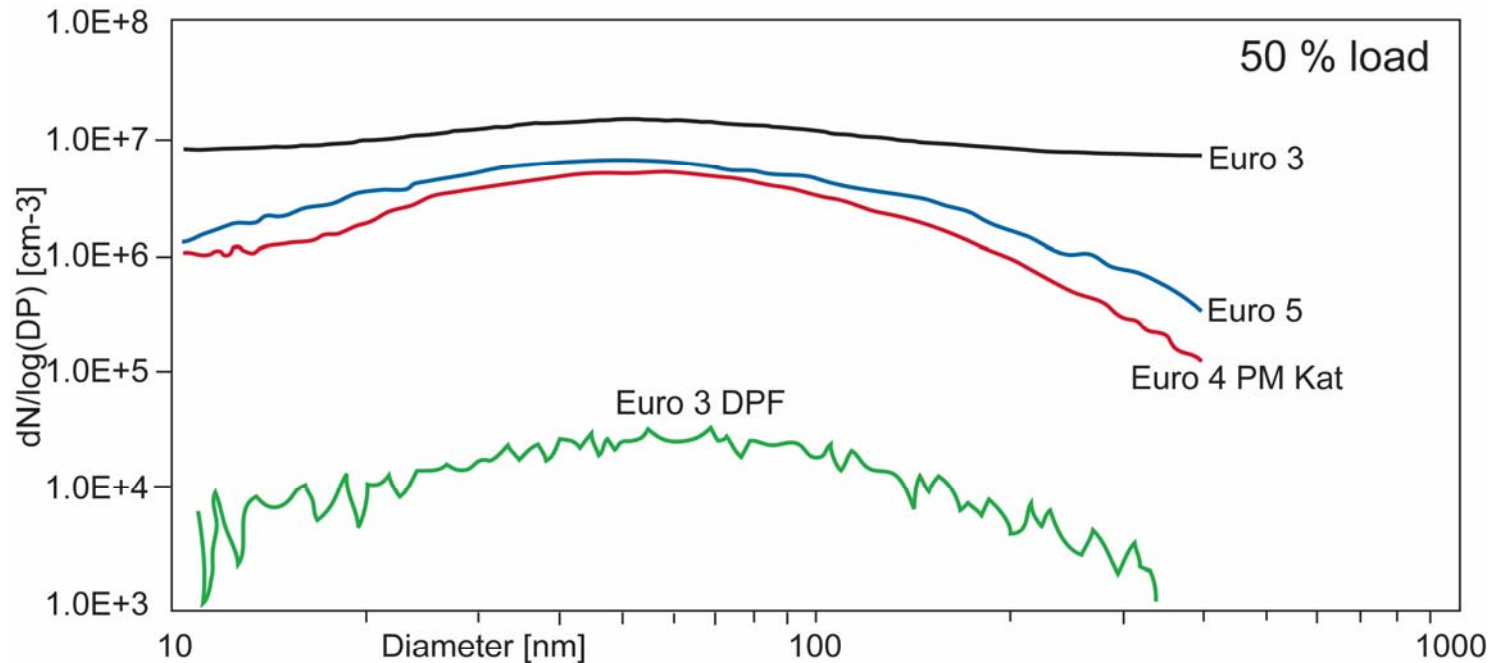
Size Distribution (SMPS) at Low Idle



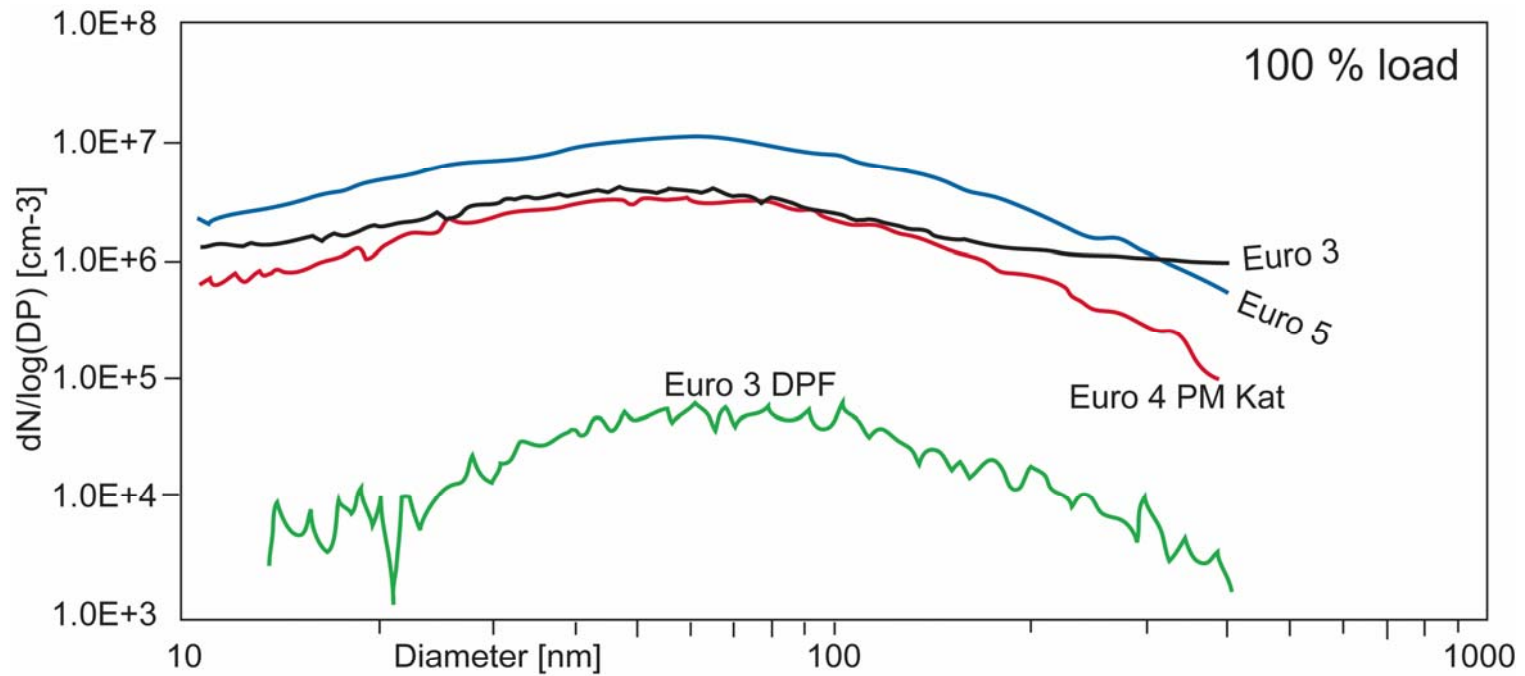
Size Distribution at 1400 rpm 25% Load



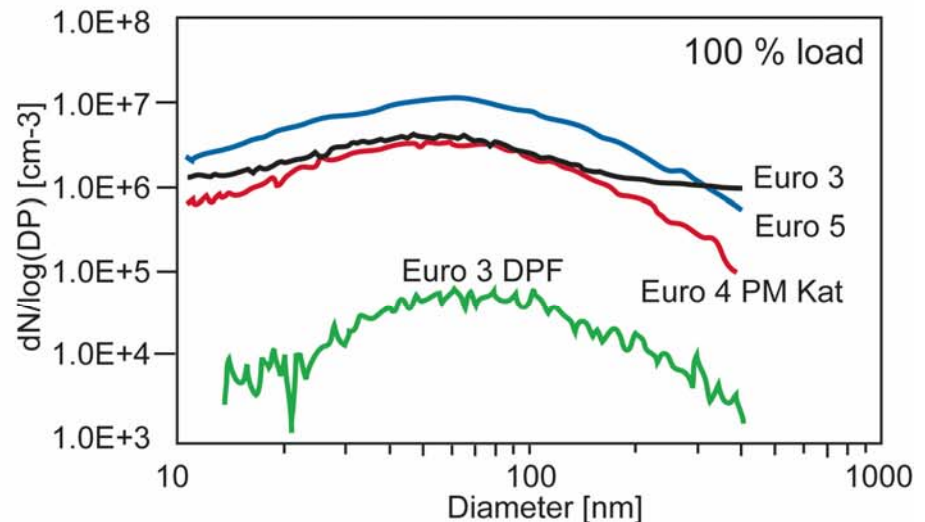
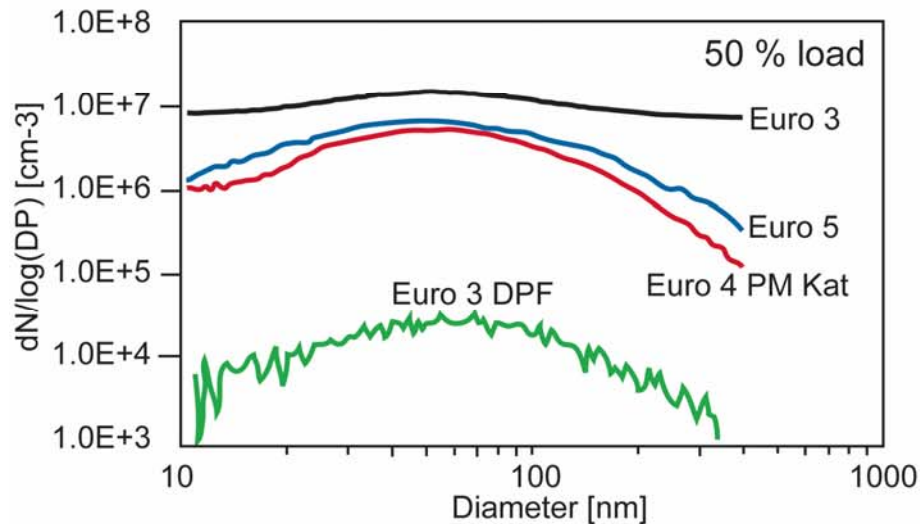
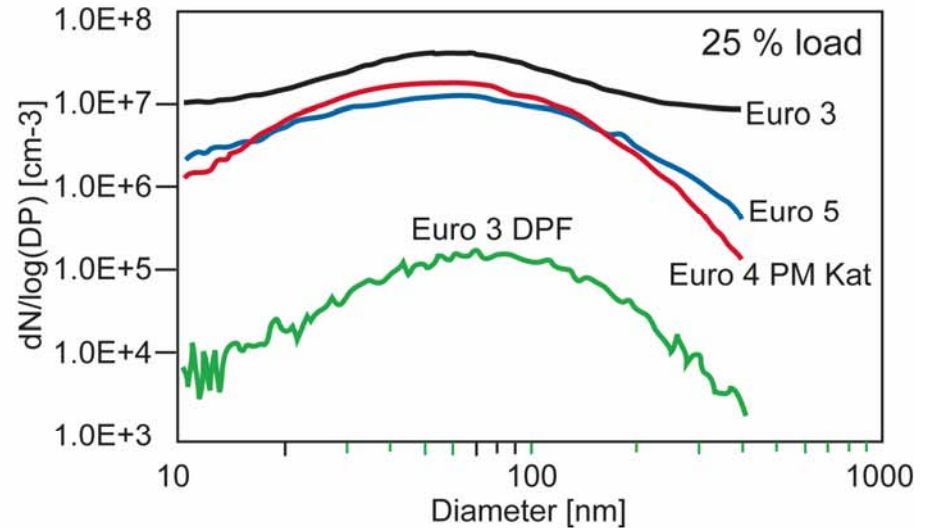
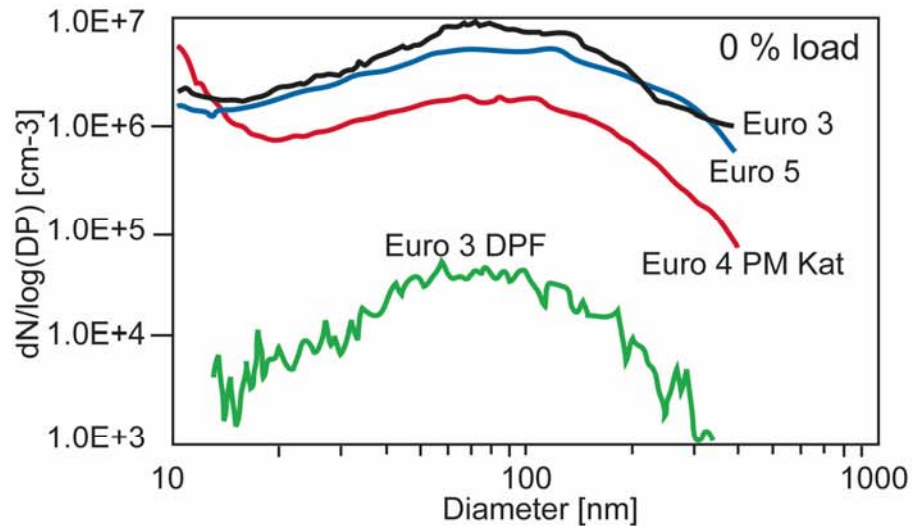
Size Distribution at 1400 rpm 50% Load



Size Distribution at 1400 rpm Full Load



Size Distributions at 1400 rpm

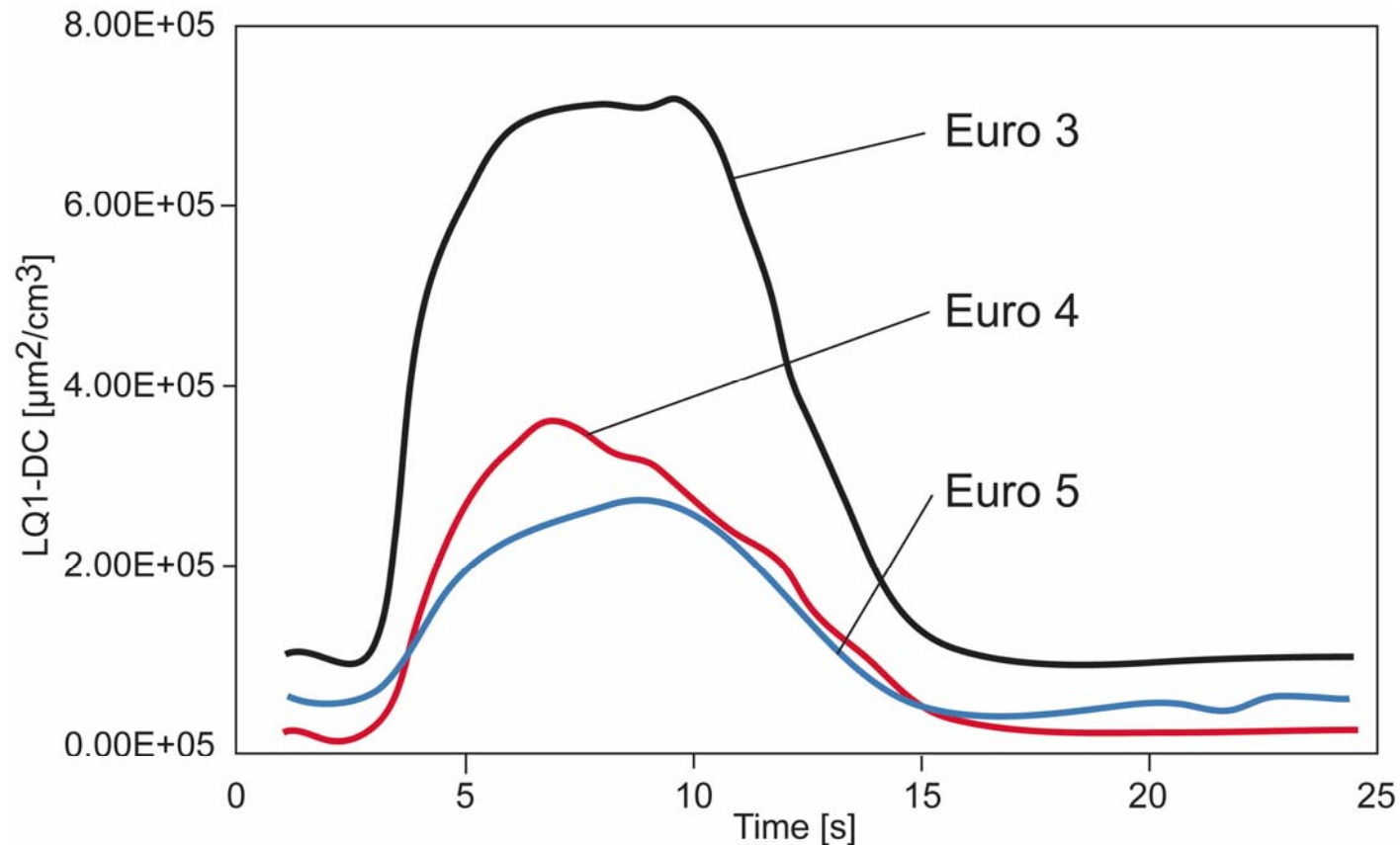


Free Accelerations, DC-Sensor

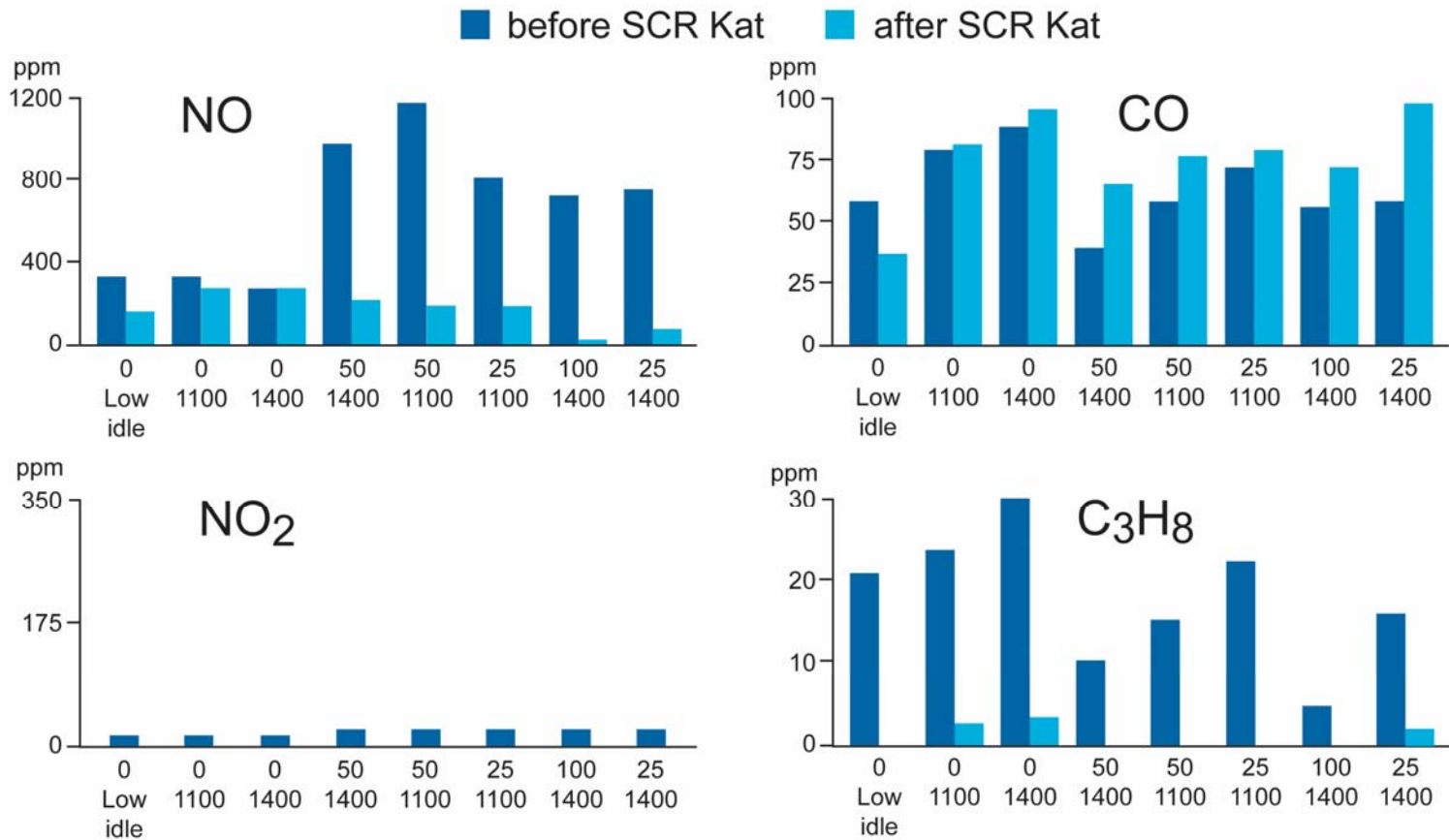
Full Load E3: 1.6×10^4

Full Load E4: 2.2×10^4

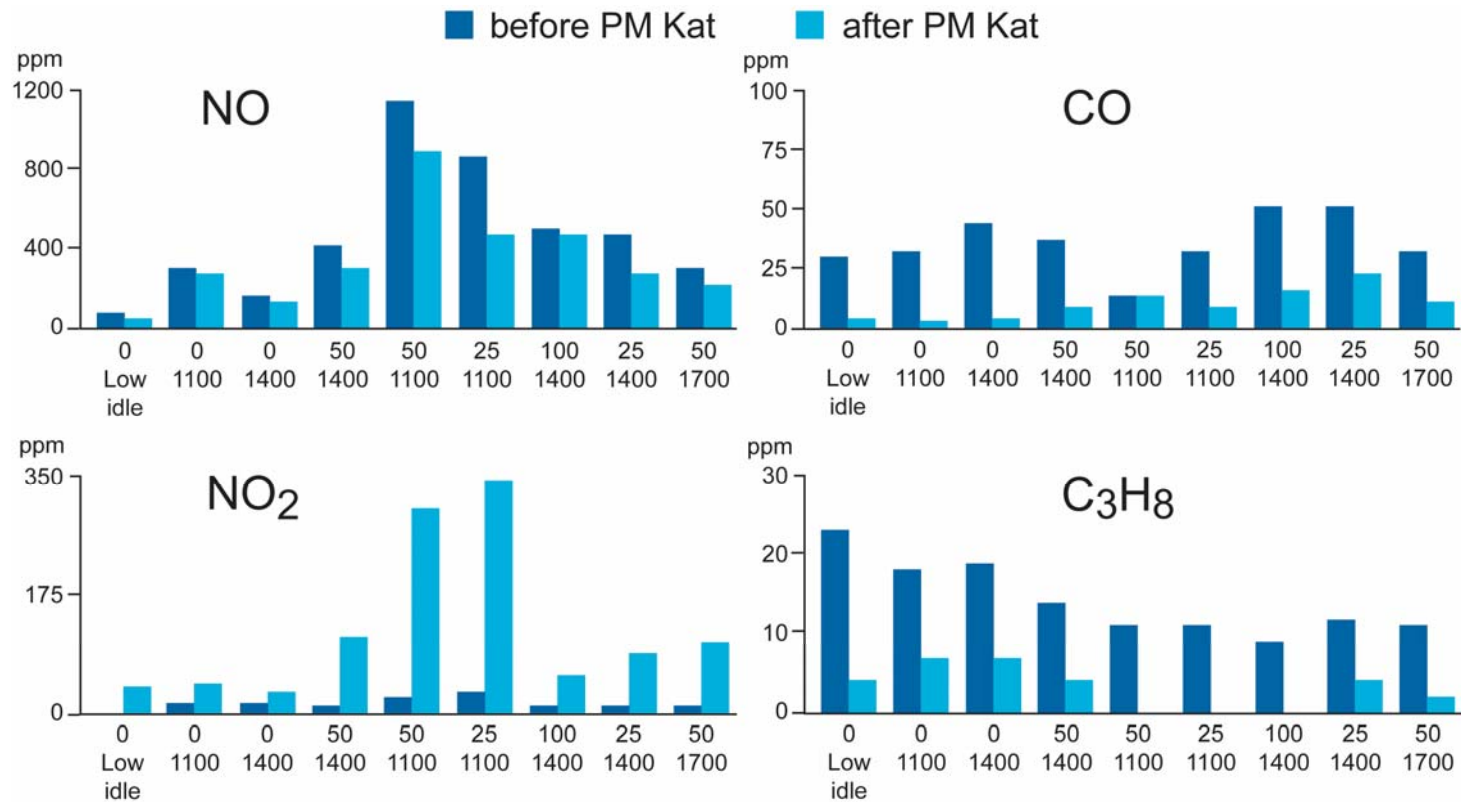
Full Load E5: 2.6×10^4



Gas Emissions Euro 5 [ppm]



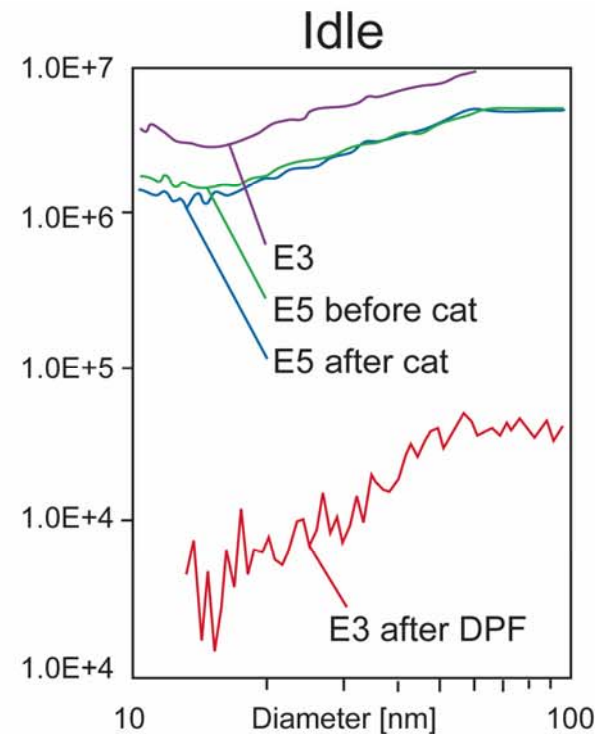
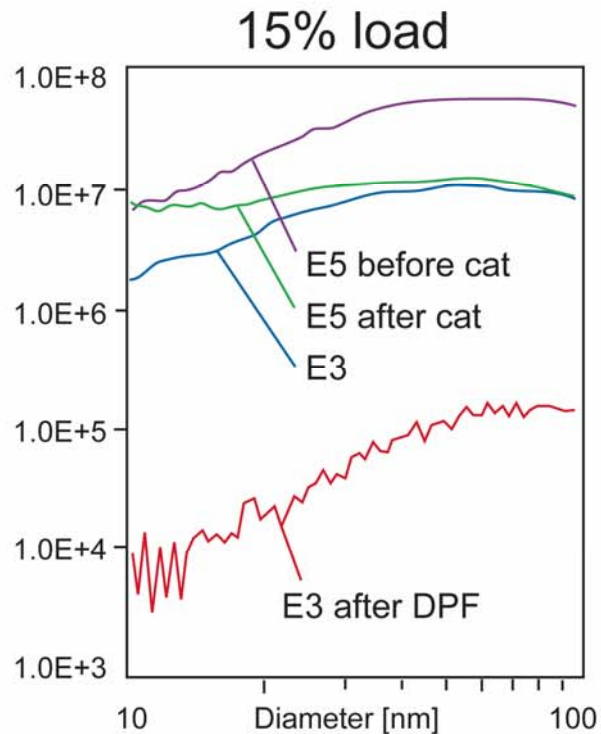
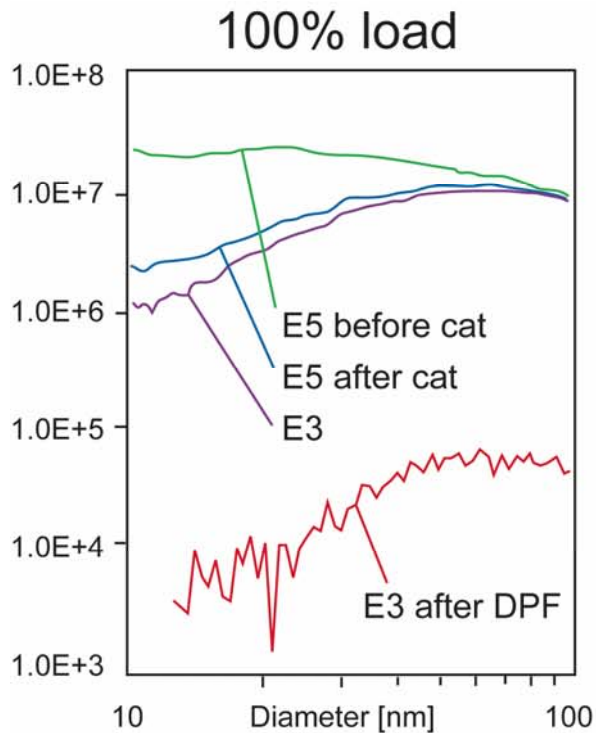
Gas Emissions Euro 4 [ppm]



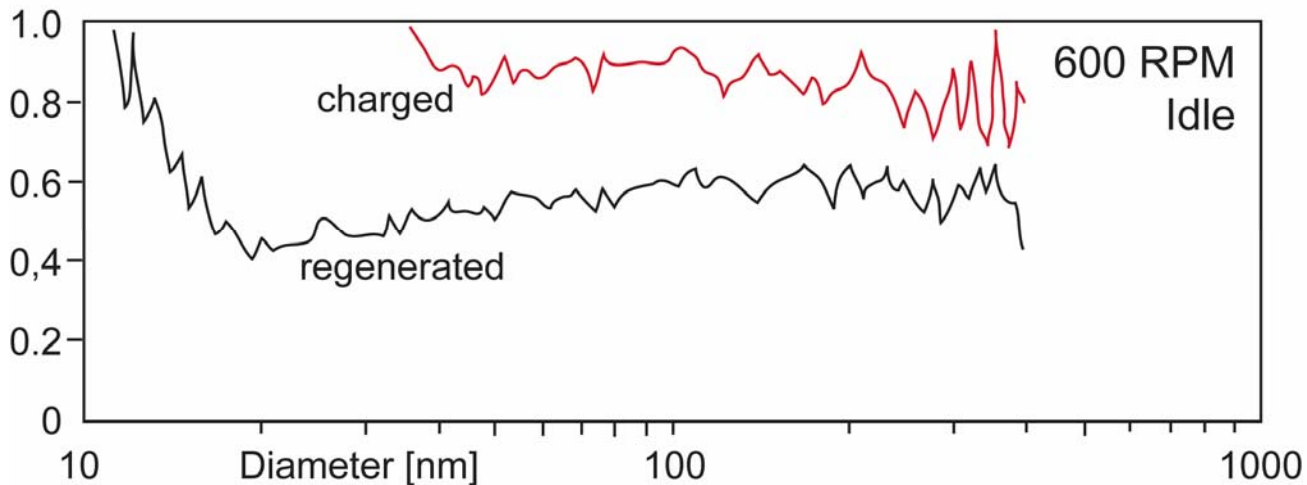
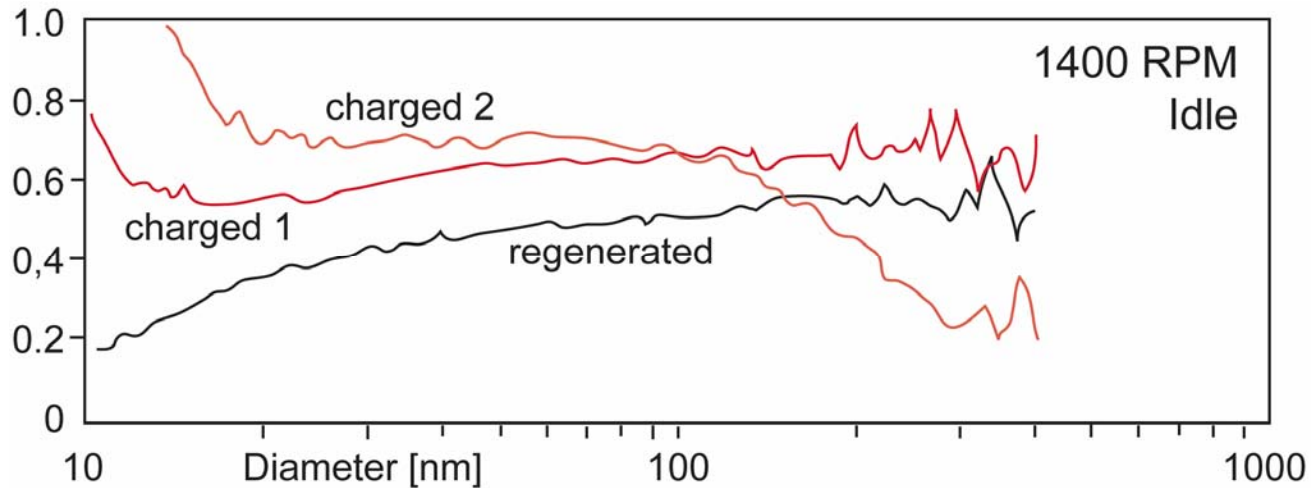
Particles:

SCR *vs* PM-Kat *vs* DPF

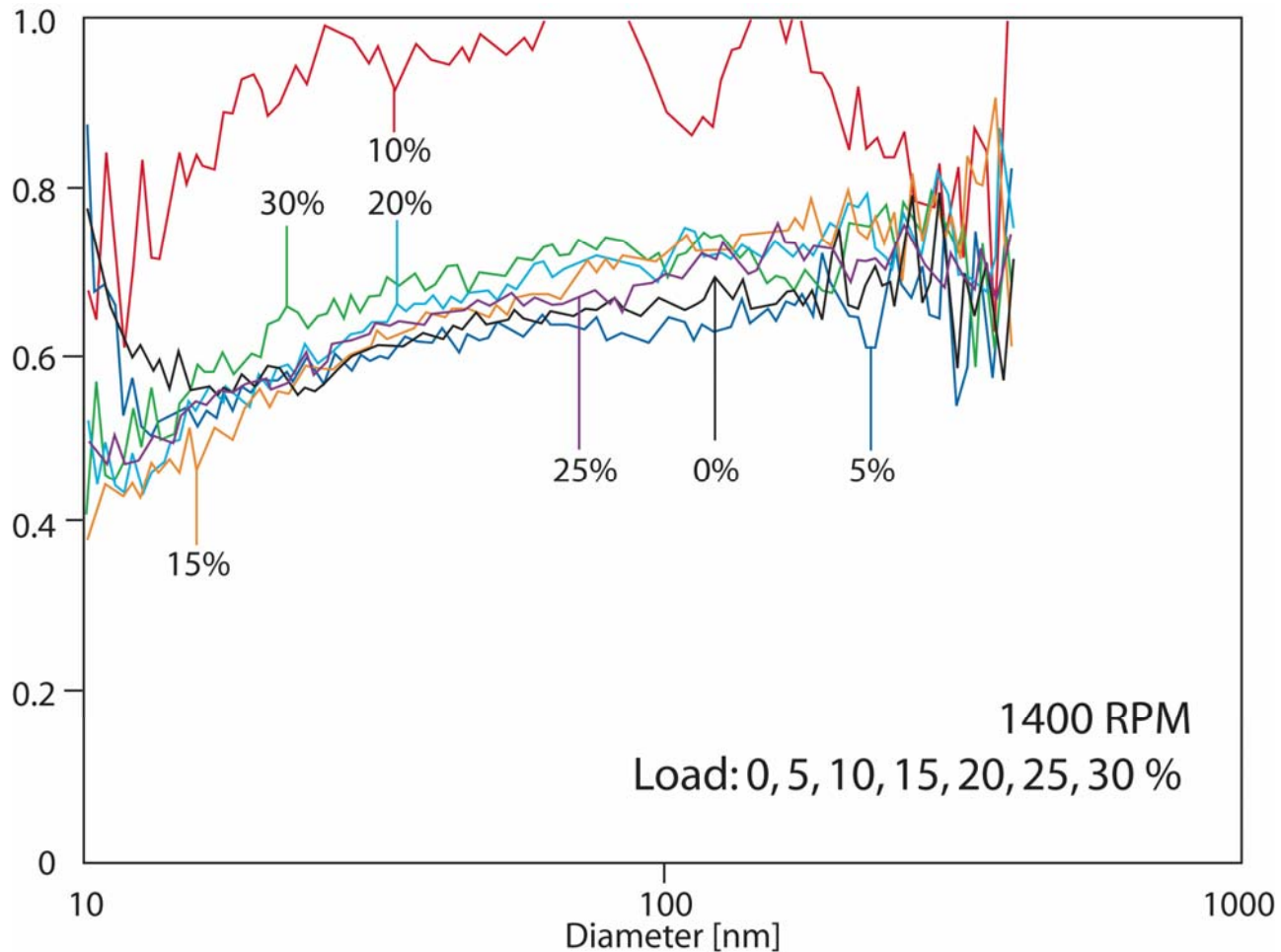
Nanoparticle Emissions with SCR



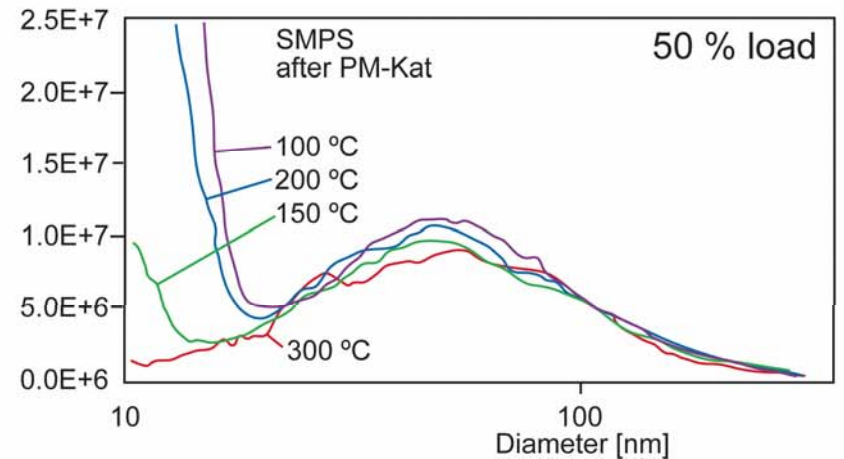
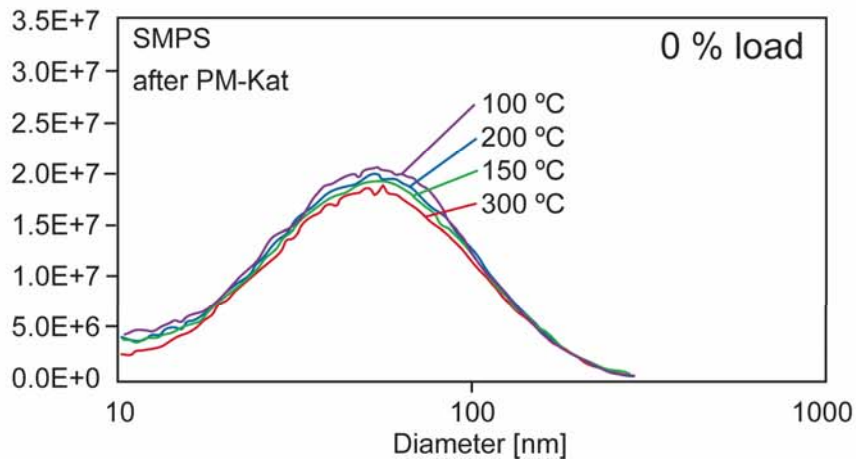
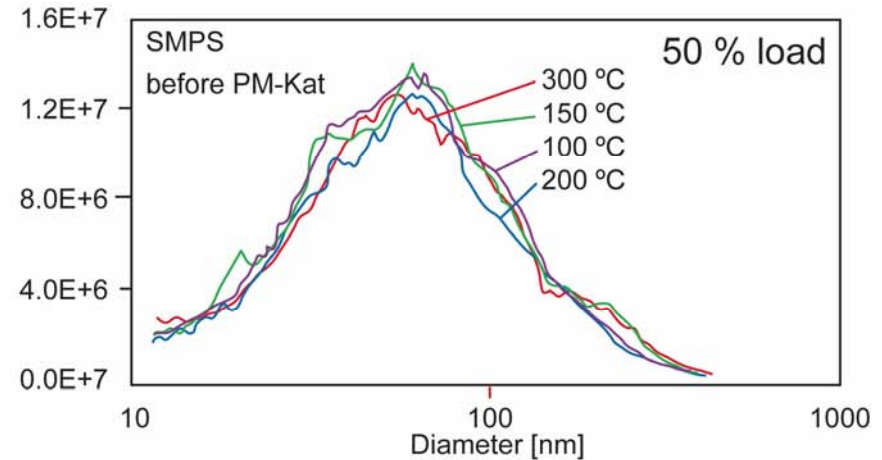
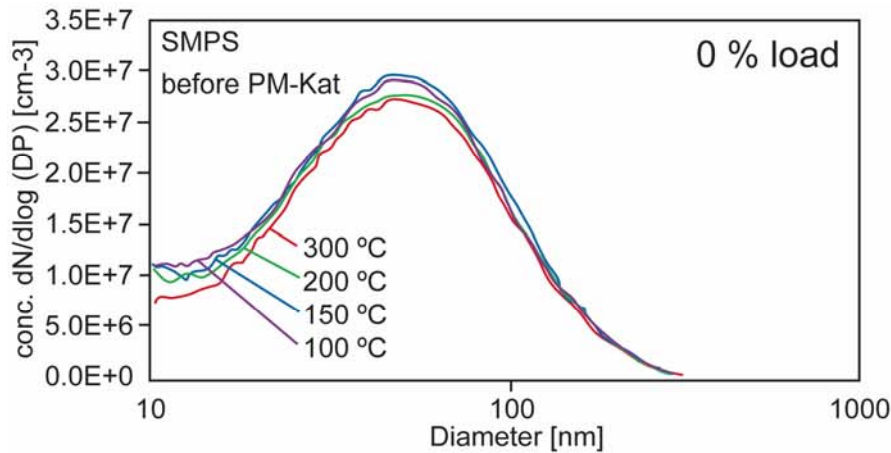
PM-Kat Regenerated and Soot Charged



PM-Kat : Penetration-Instabilities

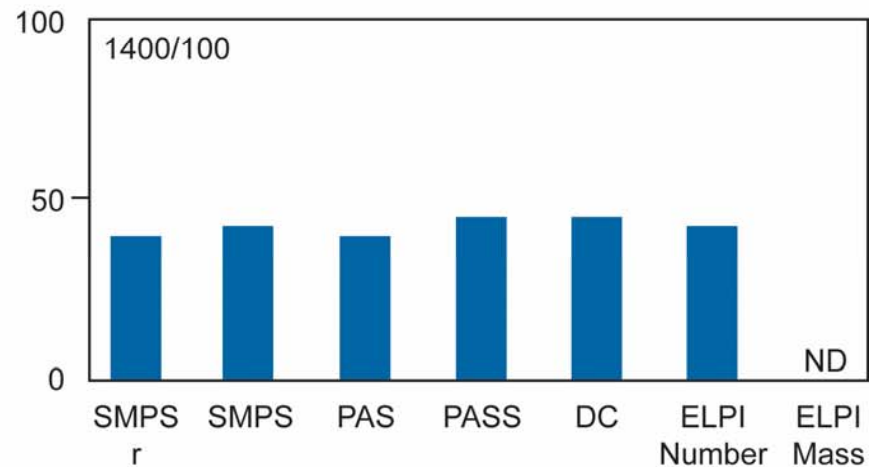
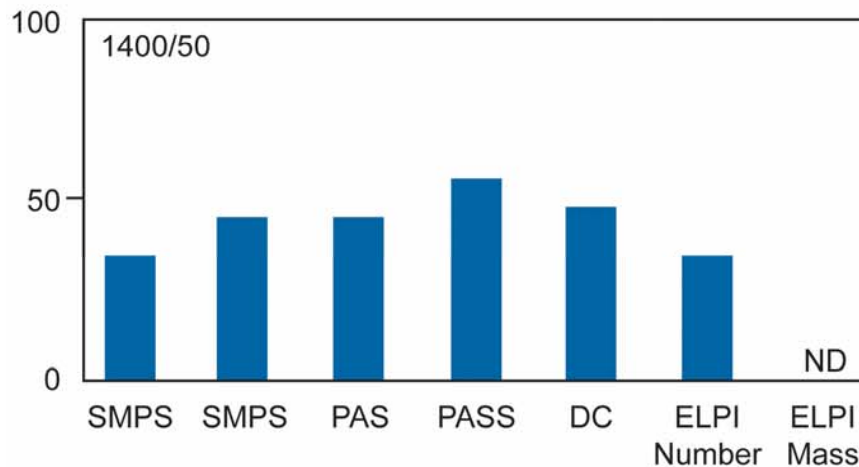
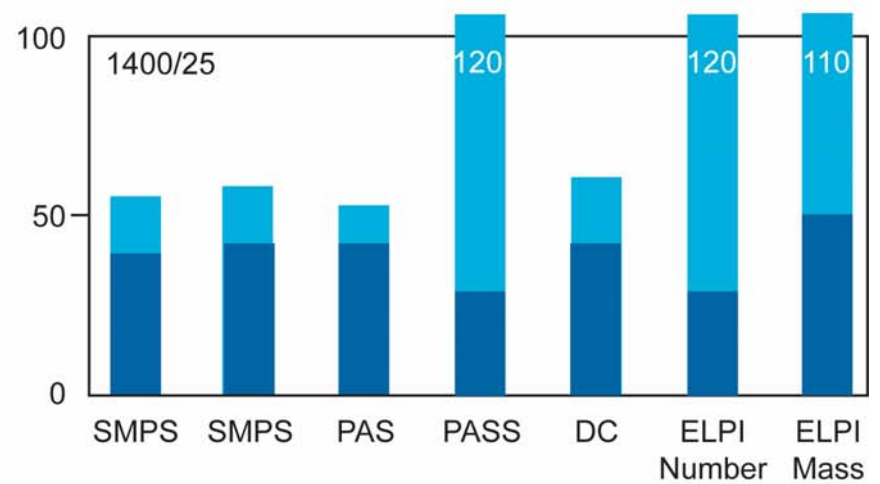
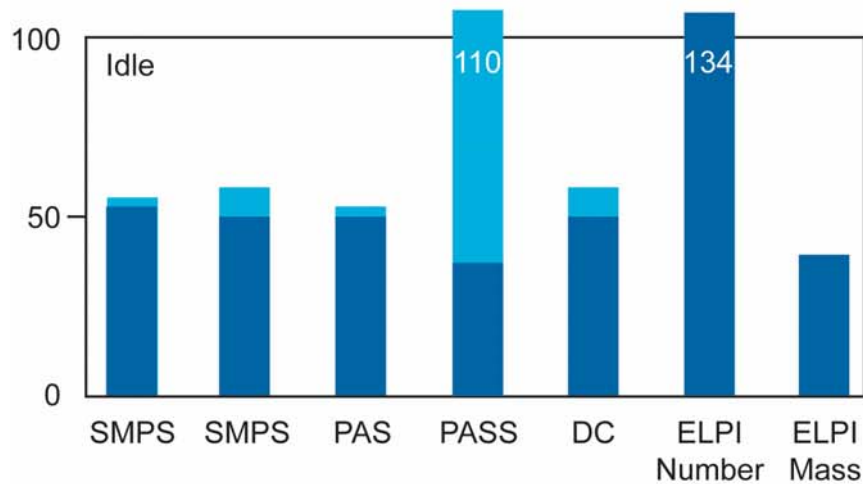


PM-Kat: Thermograms at 2 Loads



PM-Kat-Penetrations, all Instruments

not measured at exactly same time

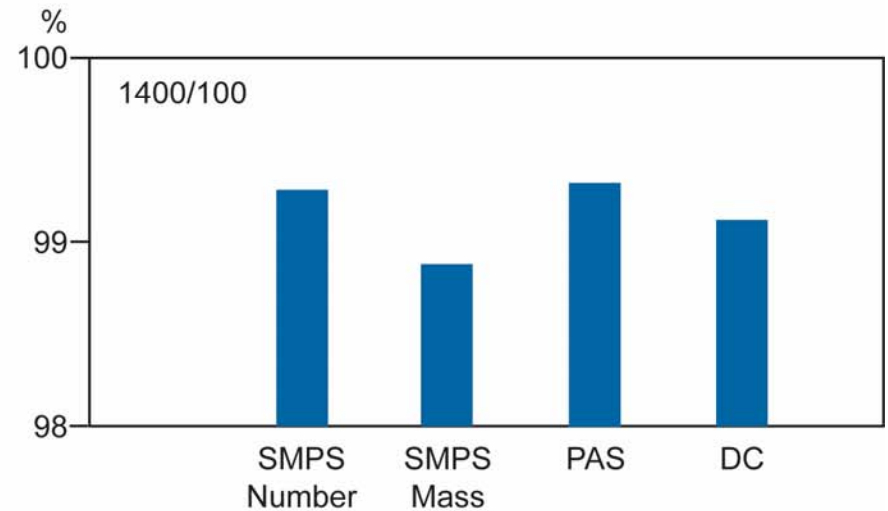
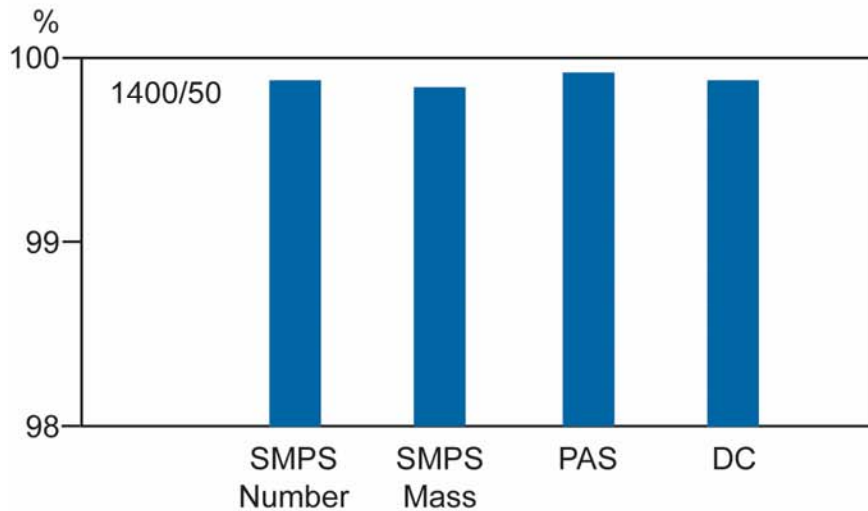
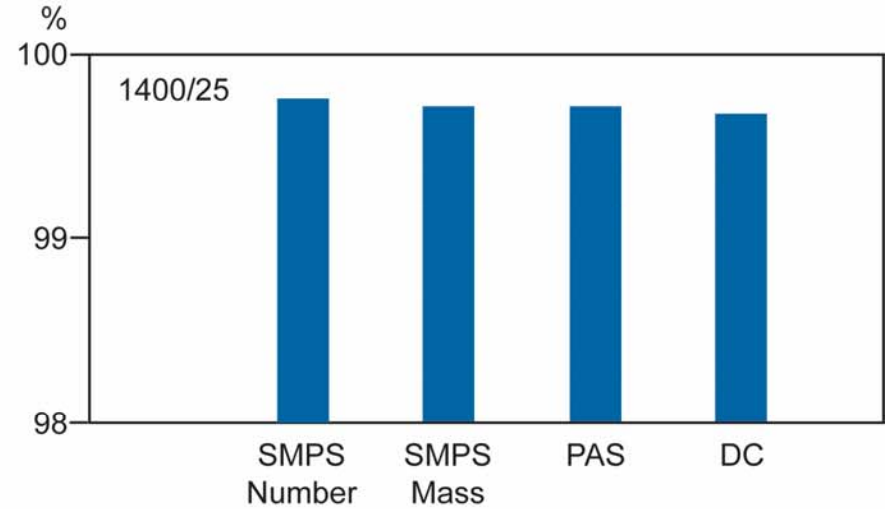
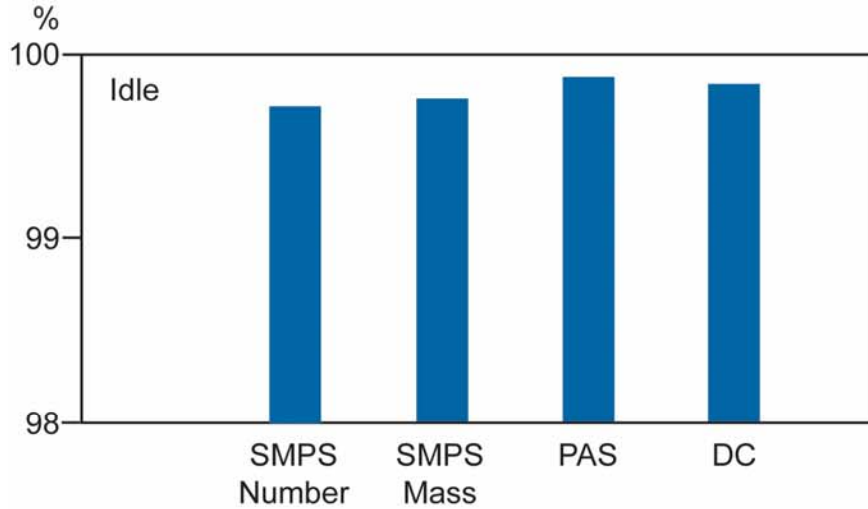


Penetration Euro 4-PM-Kat

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	0.45	0.49	0.47	0.34	0.48	0.32	0.57
25% Load	0.64*	0.69	0.59	1.20	0.69	1.20	1.10
1400 rpm	0.40	0.50	0.51	0.63	0.55	0.38	ND
50% Load							
1400 rpm	0.45	0.49	0.45	0.52	0.52	0.49	ND
100 % Load							
*) Repetition							

E3 DPF-Efficiency, all Instruments

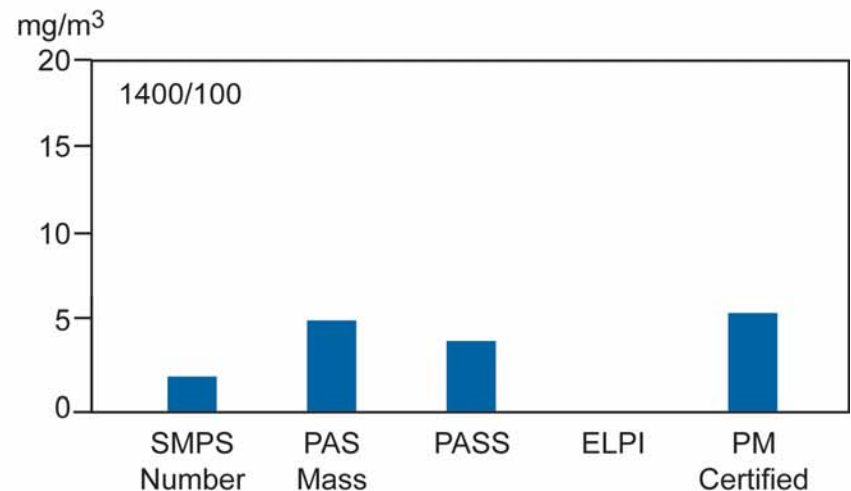
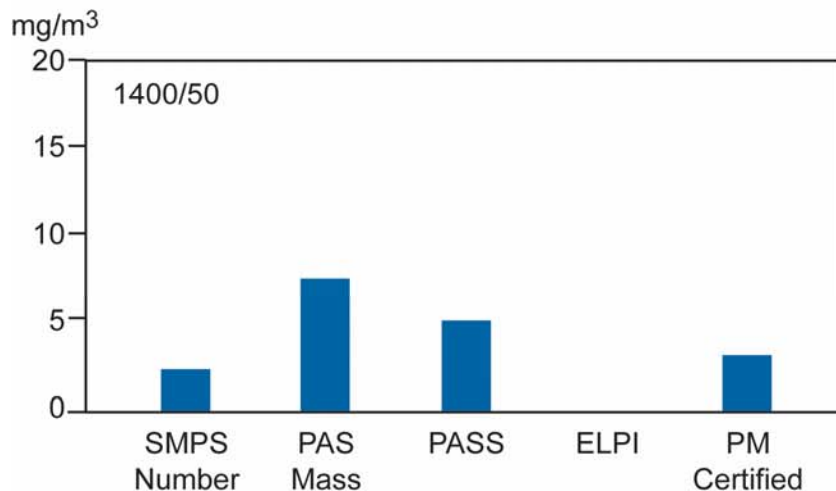
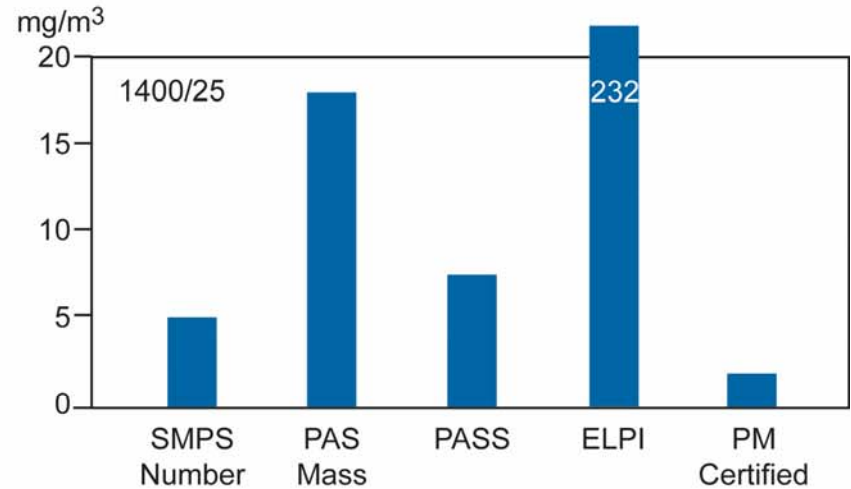
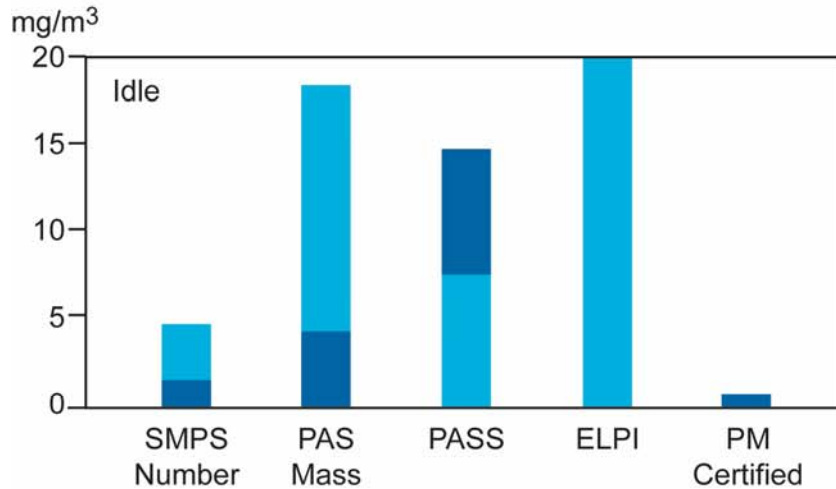


Filtration Efficiency Euro 3 – DPF

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

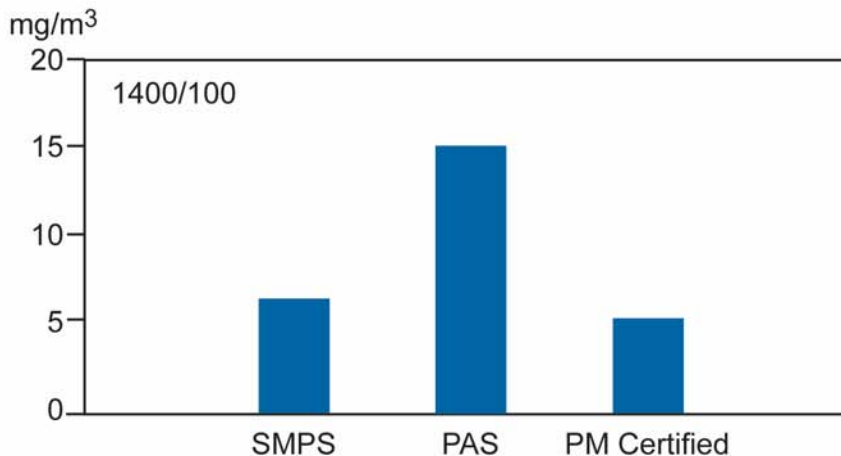
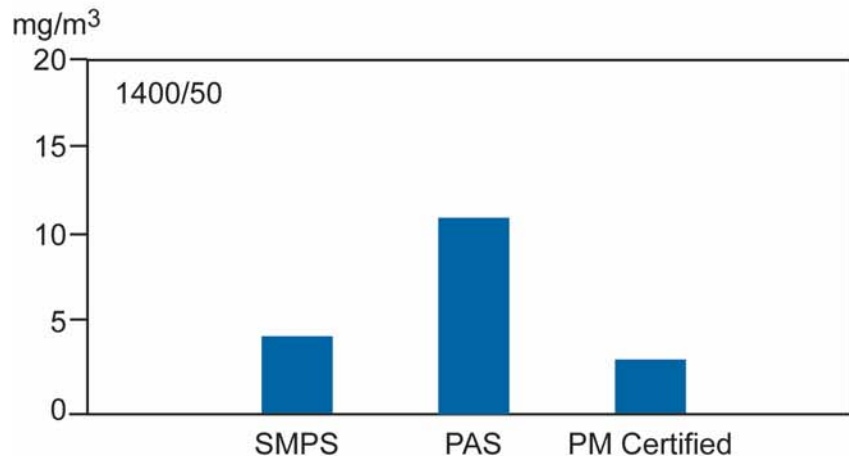
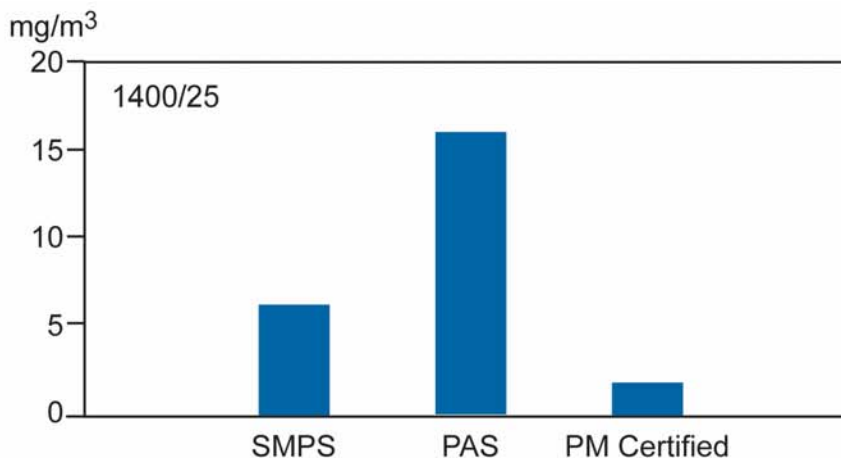
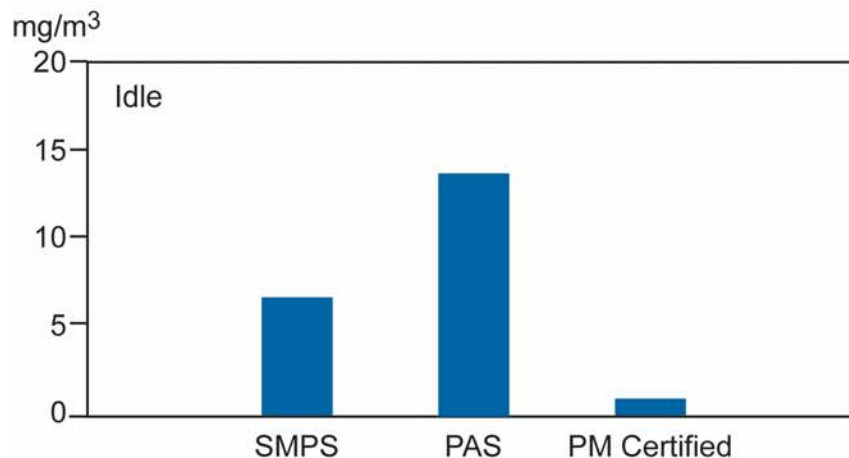
aerosol measurements compared to certified PM

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

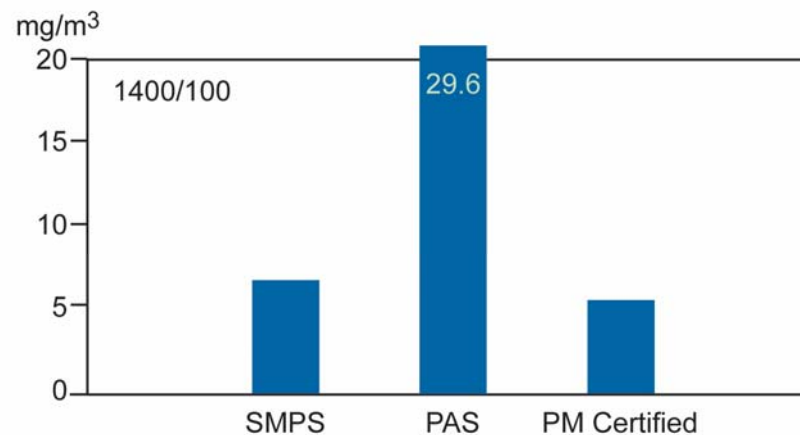
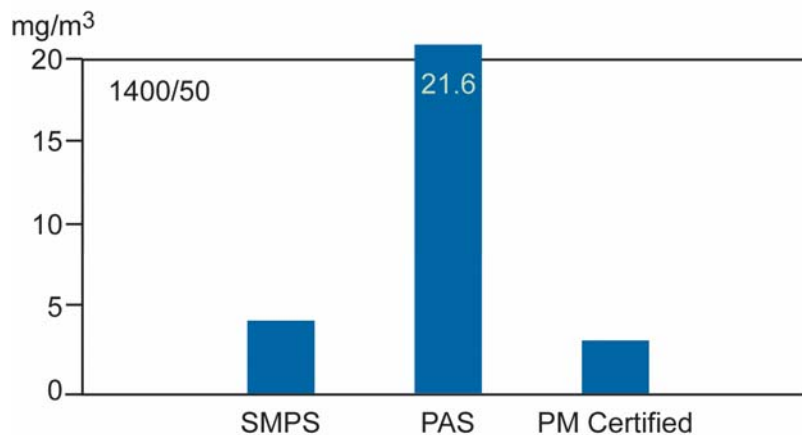
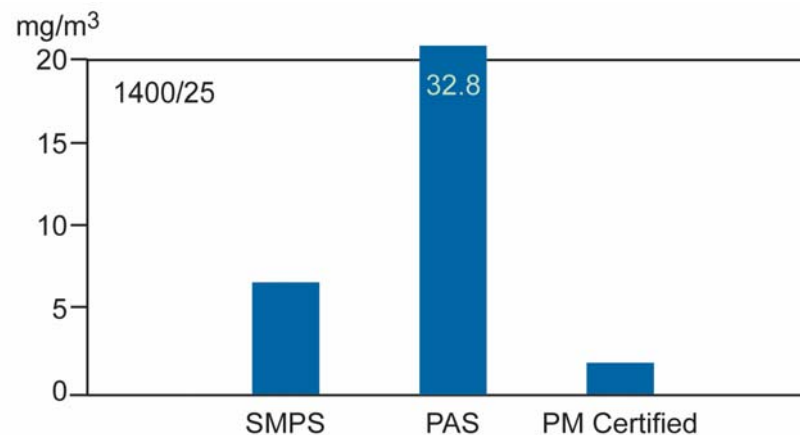
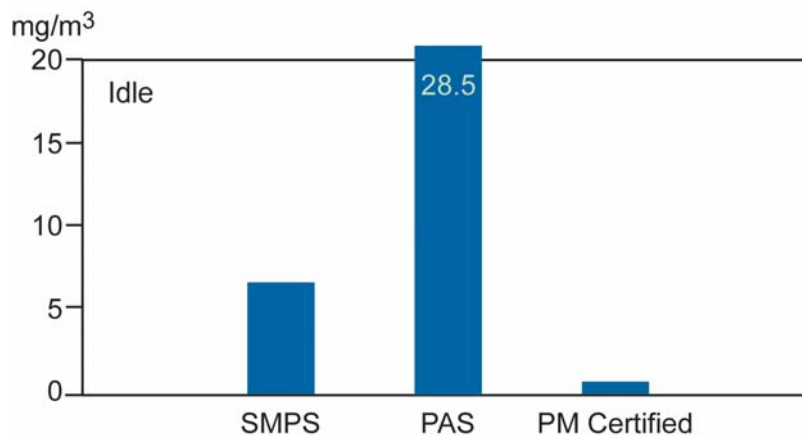
**Certified PM is given in mg/kWh per cycle
To convert into mg/m³ needs assumptions for
 λ and Be per operation point**

	αηρ περιουσια λ	fuel consumption g/kWh	air mass consumption mg/kWh	air volume consumption 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

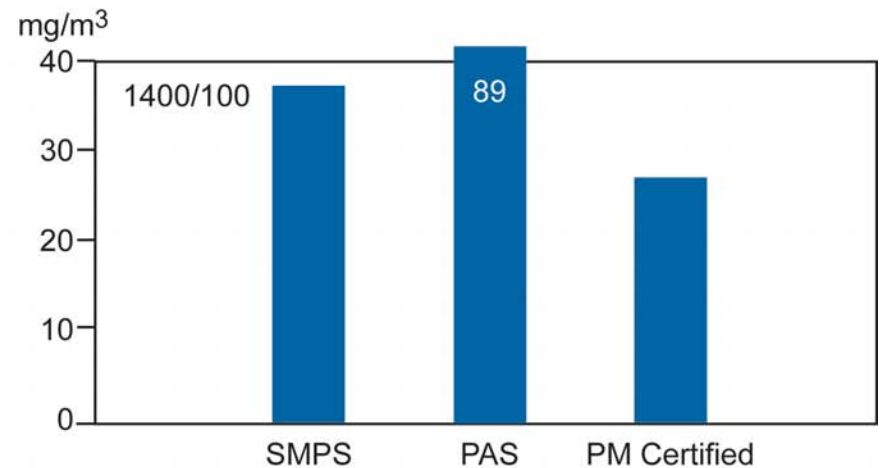
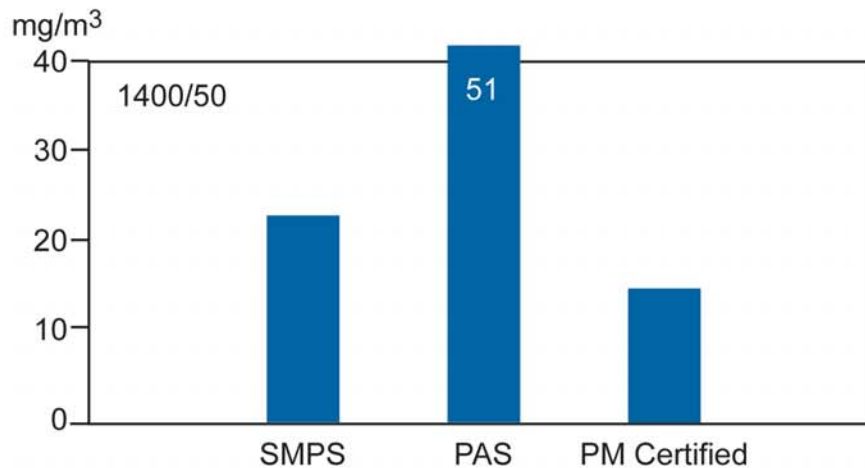
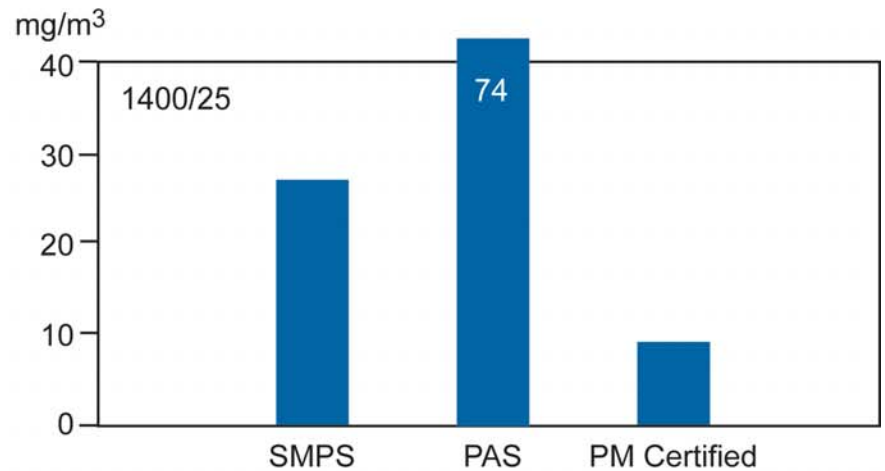
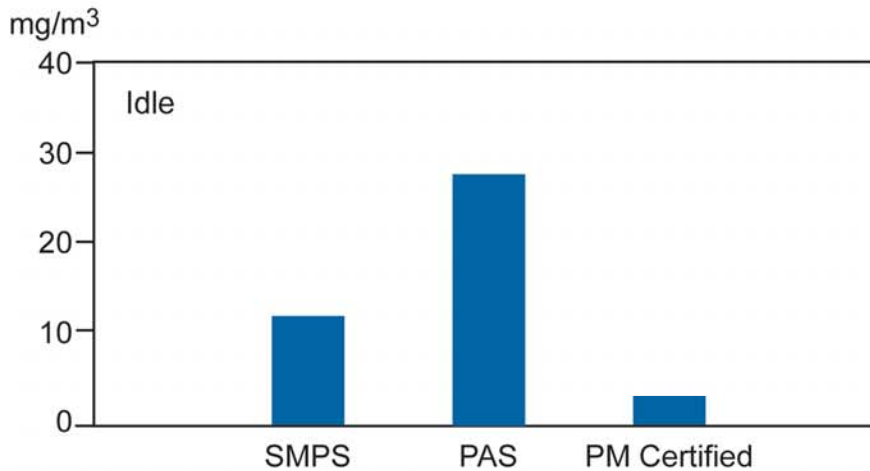


Particle Mass Emission EURO 5 - SCR

aerosol measurements compared to certified PM

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

E3 w/o DPF, Mass Emission versus certified PM

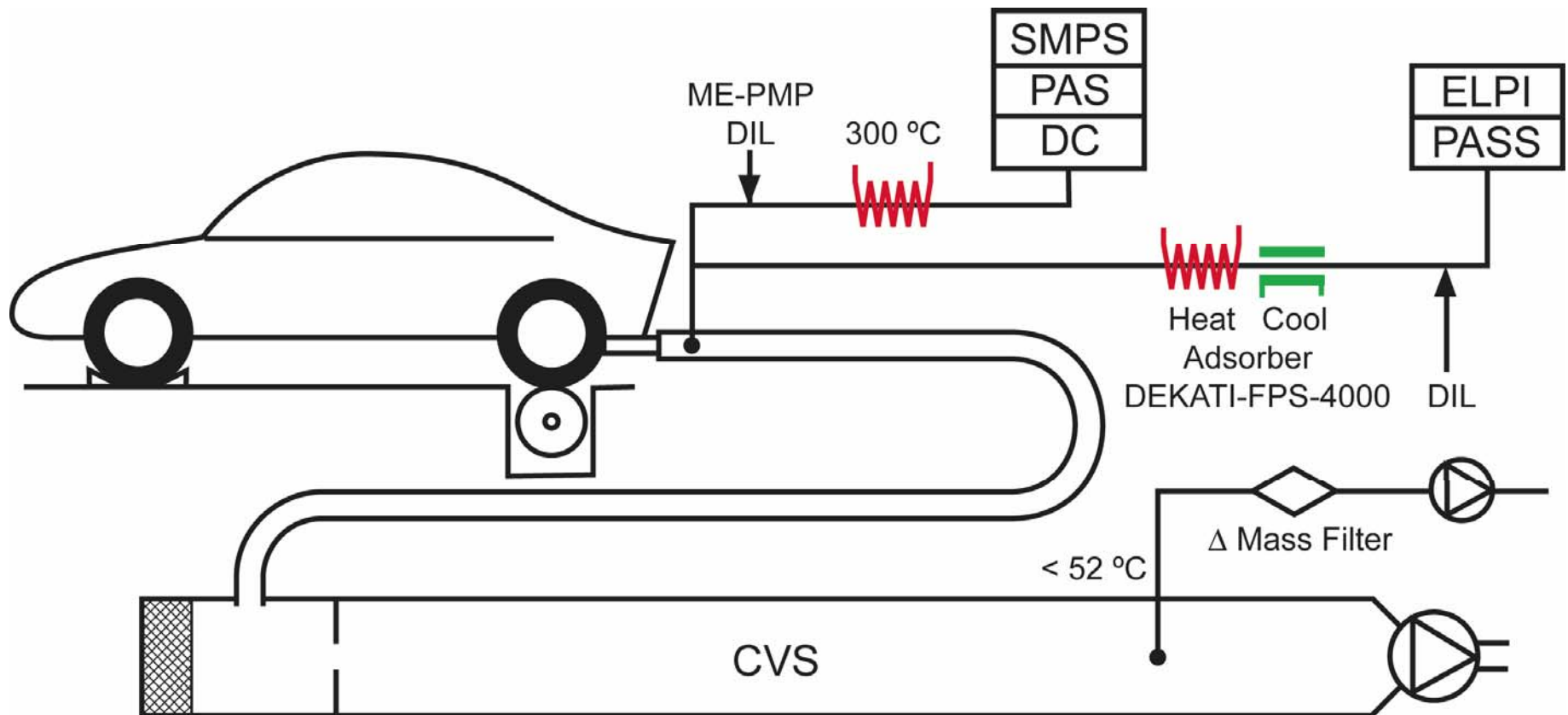


Particle Mass Emission EURO 3 w/o DPF

aerosol measurements compared to certified PM

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

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 NH₃, NO₂ or N₂O
- Euro4 - PM-Kat: Big Effort, Little Effect
 - unstable particle bypass system
 - episodes of zero efficiency; blow-off phenomena
 - creates high NO₂ 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 ≥ 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 ≥ 50 % of E3
- DPF for E4 and E5 required
- SCR reduces NO_x up to 95 % - very efficient
- SCR does not reduce NO_x below ca 225 °C
- SCR tends to increase nanoparticle emissions
- SCR - slip of NH₃, NO₂ or N₂O were below DL
- PM-Kat is an unstable bypass system with zero efficiency episodes and blow-off-phenomena
- PM-Kat creates high NO₂-concentrations
- Catalyst metal emissions were below DL