

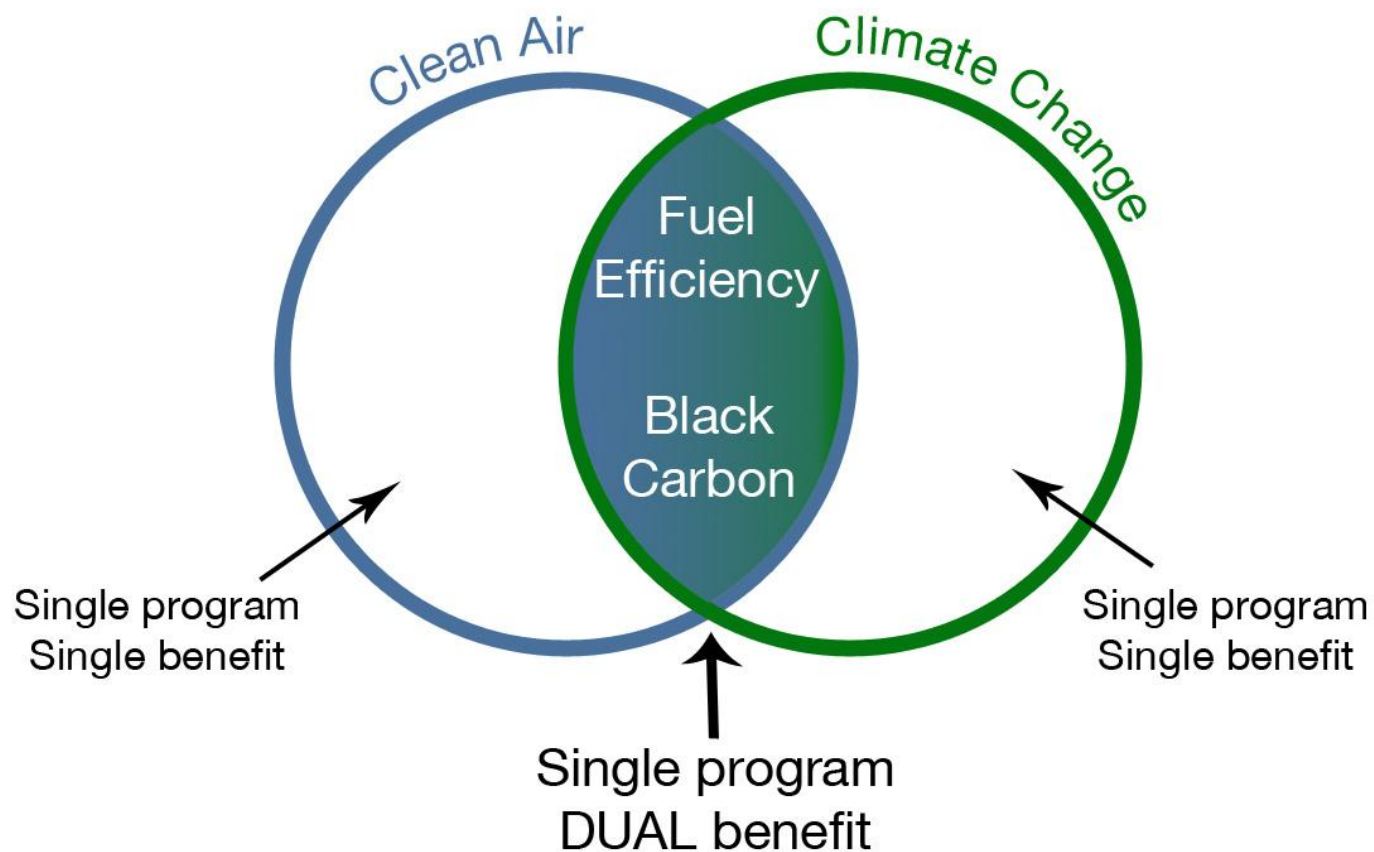
7. VERT-Forum – EMPA Dübendorf – 18. March 2016

BCEMS
SINO Swiss & VERT
Final Meeting Oct. 15./16.2015

DPF-Technology Transfer
via Pilot Fleets and Bench Tests

A.Mayer

The Problem is Health and Climate
The Solution
is the VERT Diesel Particle Filter



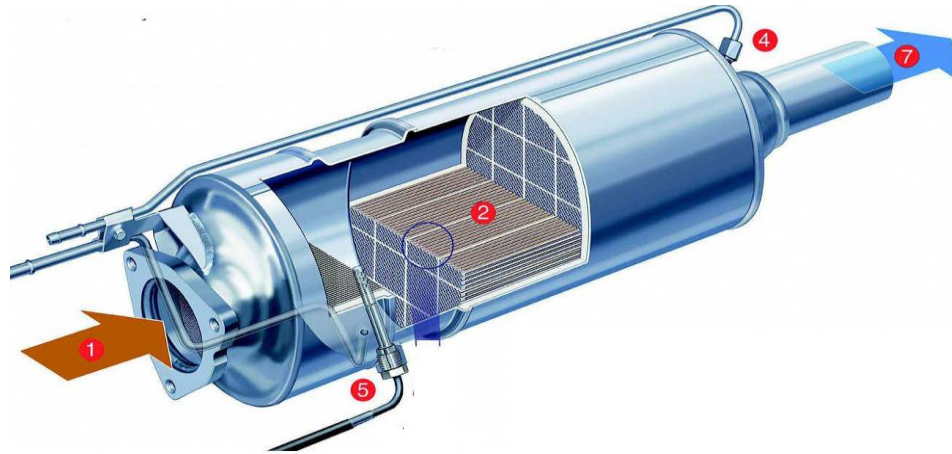
Large and Difficult but Successful Project

- Starting in October 2009
- 13 Missions to China and Switzerland
- Technology Demos and Instructions in Europe
- Pilot Fleet Tests in Nanjing, Xiamen, Beijing 2013/15
- 3 Lab Test Series Xiamen, Jinan and Biel 2010 - 14
- VERT: Dinex, HJS, Puritech, Matter, CPK, Innospec, AFHB
- 3 public workshops in Beijing 2010/11/15, 3 exhibitions
- publications in 6 international conferences
- 35'000 technical documents on PC-TTM – project leader
- DEZA support: 2'400'000 CHF – did by far not cover all
- VERT-Consortium overall cost estimate: 2'000'000.- CHF
- Final Meeting 15/16.October 2015

Starting with high Challenges

- Fuel Sulfur still very high: > 1200 ppm at Xiamen !
- Vehicles very old: all Nanjing buses > 2 Mio km
- Very high mileage: > 80'000 per year
- Low Quality lubrication oils – high sulfated ash
- No filter cleaning infrastructure available
- No filter obligation yet → no market perspective
- BAT required to eliminate BC for health and global warming

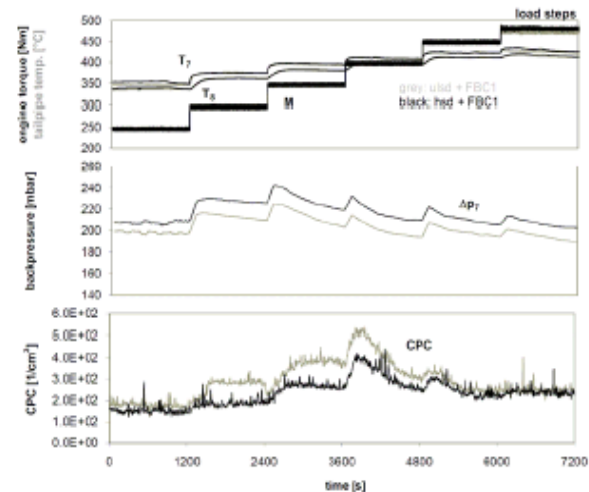
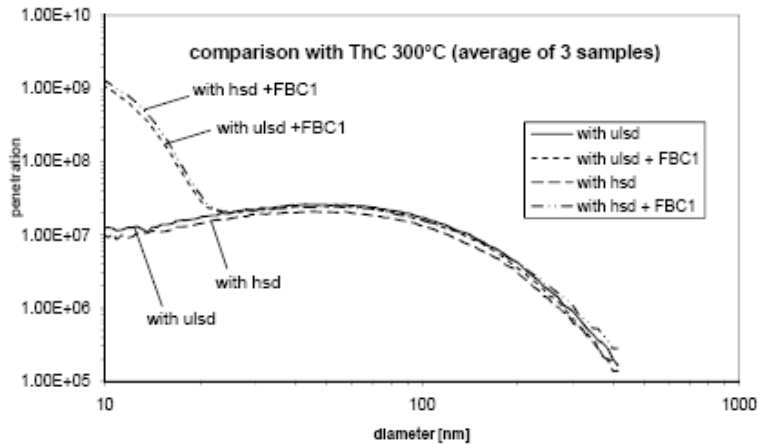
Standard CRT-Filters as used in 90 Mio. EU and US vehicles **are not applicable**



- with high fuel sulfur (>10ppm) regeneration problems
- with high fuel sulfur sulfuric acid production+emission
- with low sulfur NO₂ formation and emission
→ the big problem in European low emission zones

STEP-1: find Sulfur tolerant DPF

- 9 VERT certified DPF tested with fuel sulfur 1200 ppm
7 fuel sulfur tolerant: mainly FBC and TM-coatings



SAE 2011-01-0605

DPF Systems for High Sulfur Fuels

A. Mayer, J. Mooney
TTM, Switzerland, LLC, USA

J. Czerwinski, P. Bonsack
AFHB, Switzerland

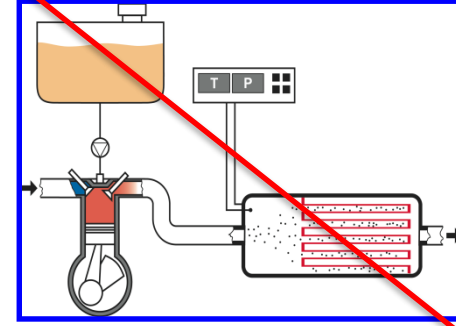
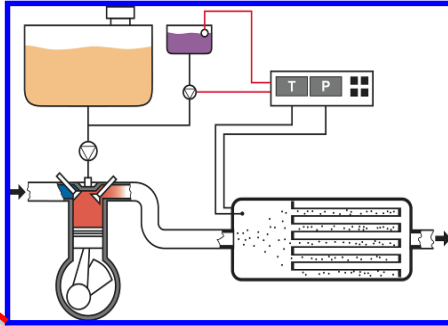
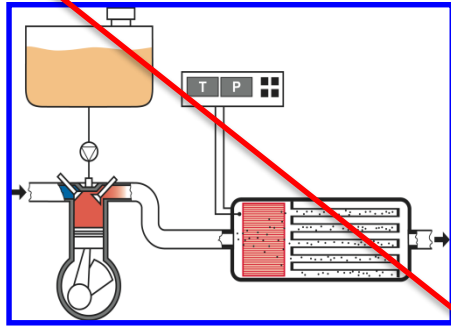
L. Karvonen
EMPA, Switzerland

Liu Xian
VEMC Beijing

***DPF-Technology is possible
and very efficient even at very
high fuel sulfur content***

Adaqueate Filter Systems are available

Passive
Filters

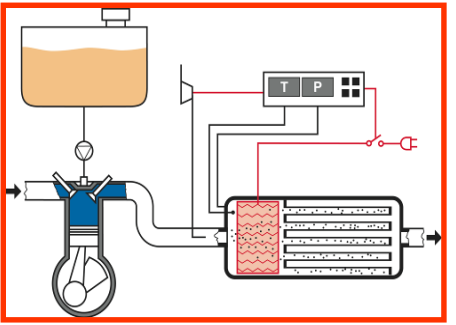
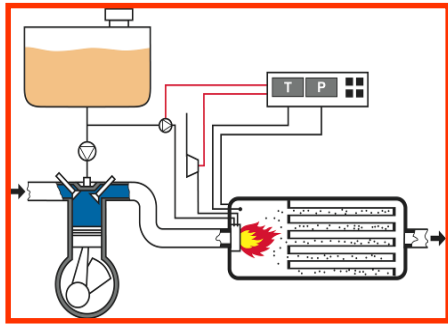
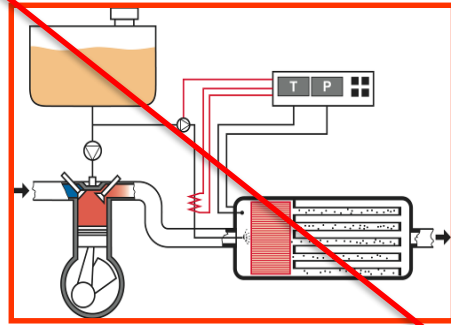


CRT >260°C

FBC >340°C

CAT Coating > 240 °C

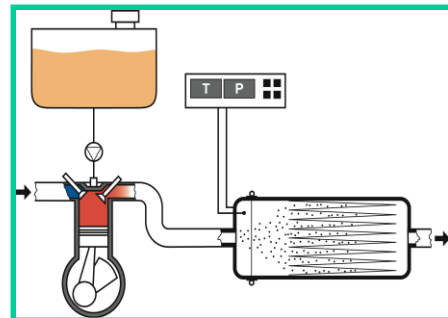
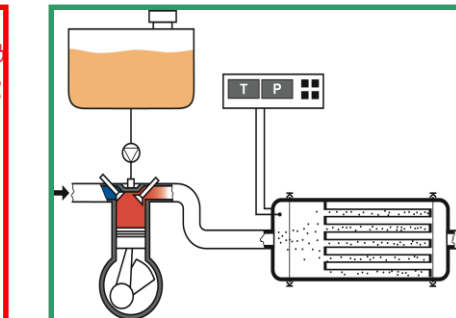
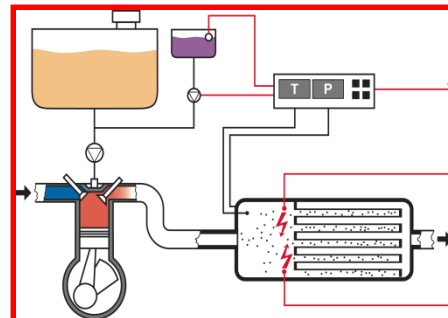
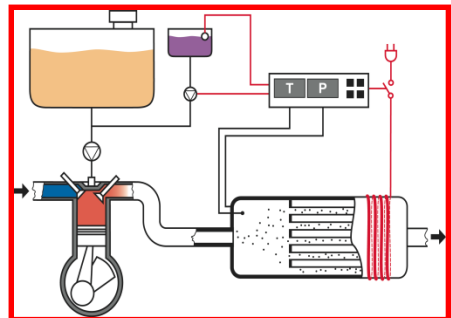
Active
Filters



Cat.Burner > 260 °C

Burner ambient

Electr.Heater ambient



FBC active > 250 °C

FBC active > 200 °C

Offline Regeneration

Disposable Element

STEP-2: Selection of Filter Systems and establish Project Partnership

DINEX:

- passive: SiC coating ($>240\text{ }^{\circ}\text{C}$) or FBC ($>350\text{ }^{\circ}\text{C}$)
- active: SiC HC-dosing / $>220^{\circ}\text{C}$)

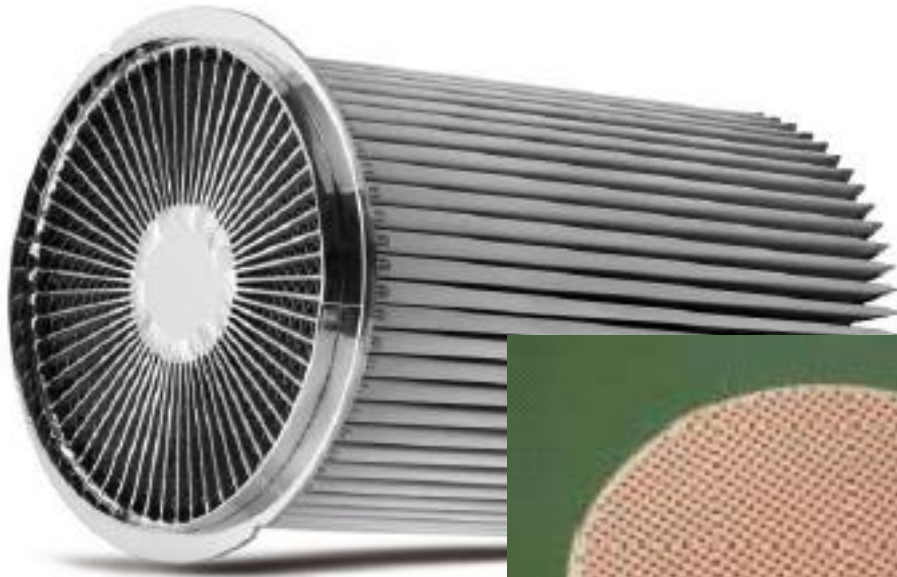
PURltech:

- passive: SiC-CCRT ($> 250\text{ C}$)
- active: DAS coated ($>190\text{ }^{\circ}\text{C}$)

HJS:

- passive: SMF-CRT ($> 240\text{ }^{\circ}\text{C}$)
- active:SMF-AR any temperature

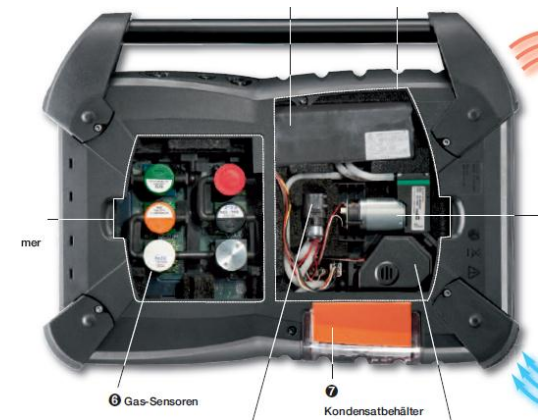
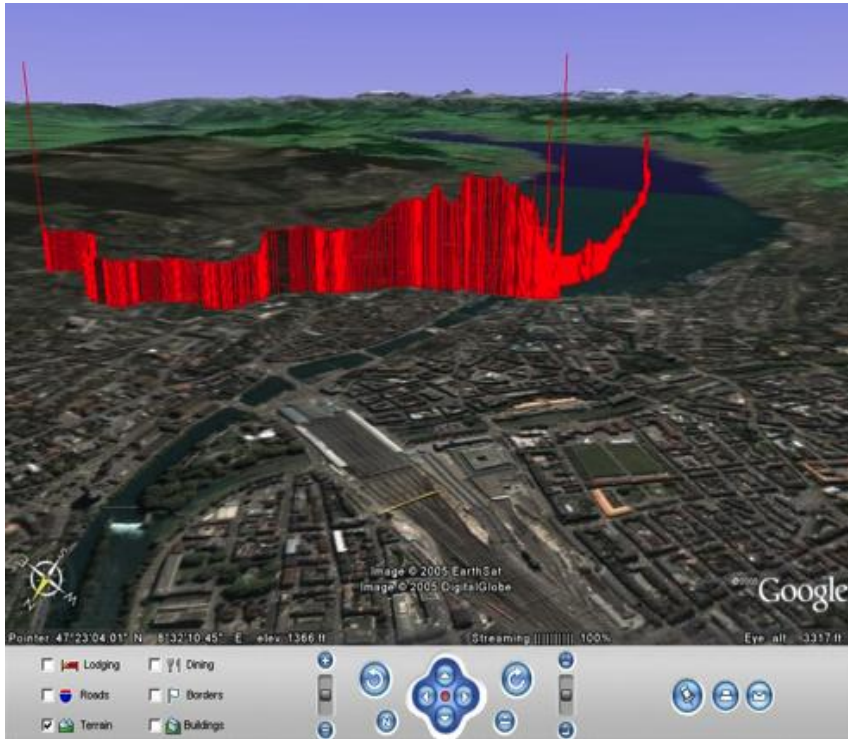
Extruded Cordierite and Silicon Carbide honeycomb filters used by DINEX and Puritech but also Sintermetal Structures by HJS



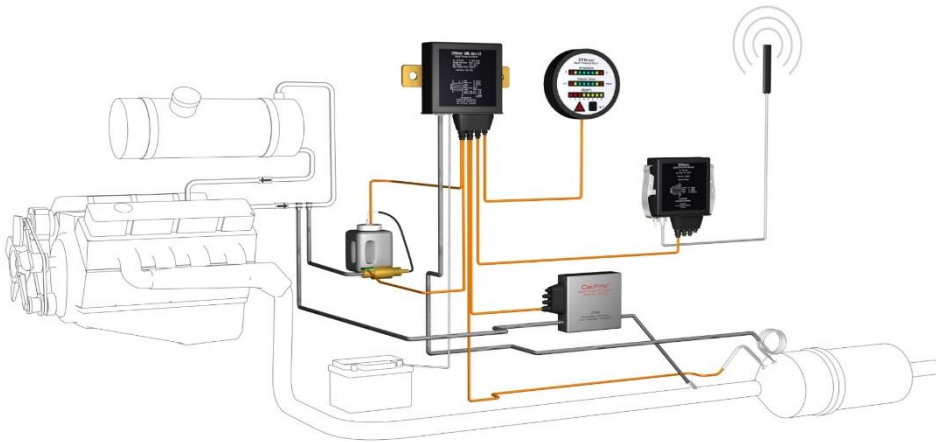
STEP-3: Selection of candidate vehicles to be representative

- Vehicle Characterisation
 - Engine Characterisation
 - Fuel Analysis
 - Lubrication Oil Analysis
 - Drive Cycle analysis by Datalogging
 - Reporting and Infrastructure
- **Select the appropriate filter for a given vehicle, available fuel and dominant drive cycle**

STEP-4 Switzerland donated top modern nanoparticle instruments and performed instruction courses in CH and China

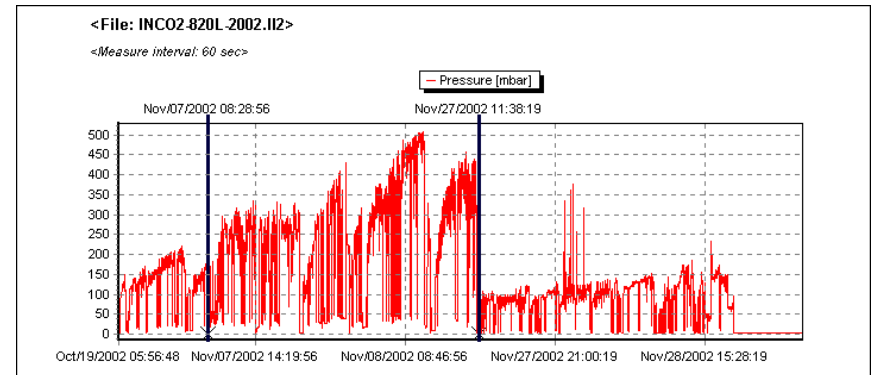
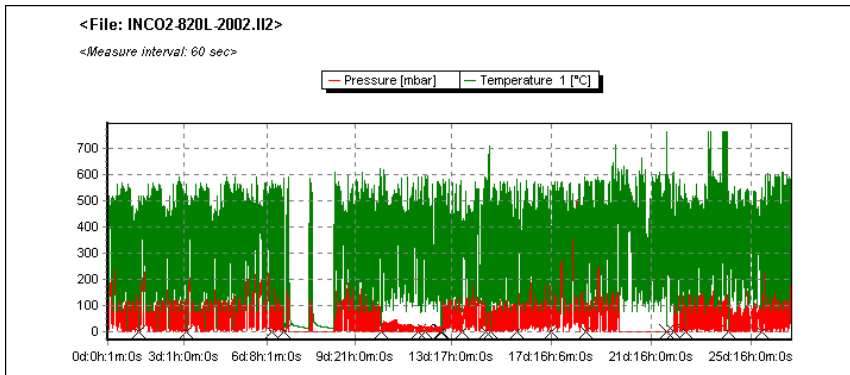


STEP-5 Switzerland donates top-modern DPF-monitors for wireless data transfer via Internet and performs instruction



CPK-Automotive
VERT-certified Datalogger

PNE-Data Evaluation



STEP-6 Learning by Doing

- 4 Emission Labs receive instruction, filters and instrumentation and continuous mentorship by TTM and AFHB → 8 excellent reports
- Installation of DPF-Monitors by VECC and BIT and continuous mentorship by TTM and CPK → data download and interpretation
- Filter allocation and installation with local support and continuous mentorship by filter manufacturers and TTM → fast learning and no damages

STEP-7 Monitoring and Supervision

- Second by second measurement
- Download locally and remote via Internet
- Very close communication
- Immediate action if filter cleaning needed

Weekly analysis and statistical results

Every week for every retrofitted vehicle

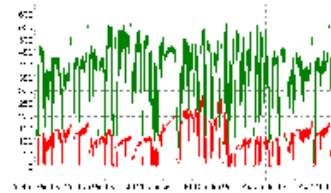
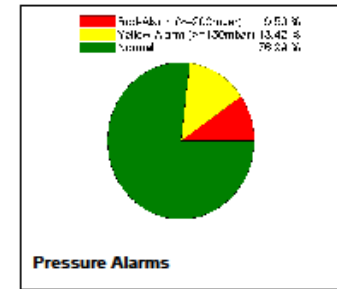
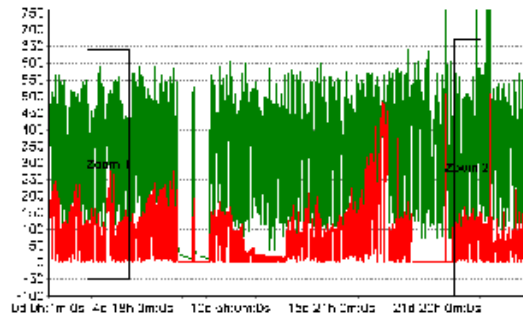
9500 DL-files

INCO2 - 820L
08.04.2002 (dd.mm.yyyy)

Description: Total 2002/3
Trap: Yes

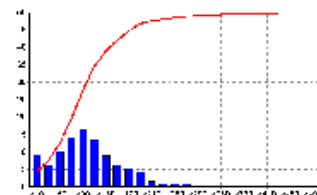
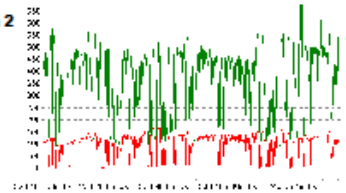
Start of measurement: 08.04.2002 08:27:48
Duration of measurement: 27d 6h:59m:0s

Interval: 60 sec.
Counts: 30298
Usable: 29610(75 %)



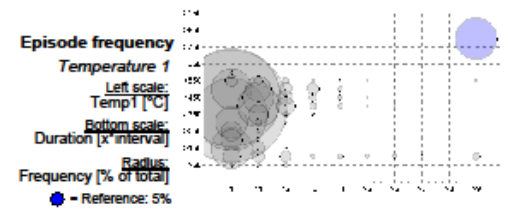
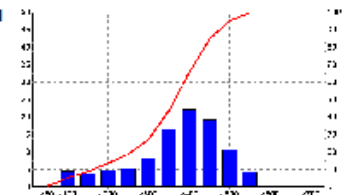
Zoom 1 **Zoom 2**

- Pressure [mbar]
- Temp. 1 [°C]
- Temp. 2 [°C]
- RPM [1/min]



Pressure **Temperature 1**

right scale: — Sum of events [% of total]
left scale: ■ Frequency [% of total]

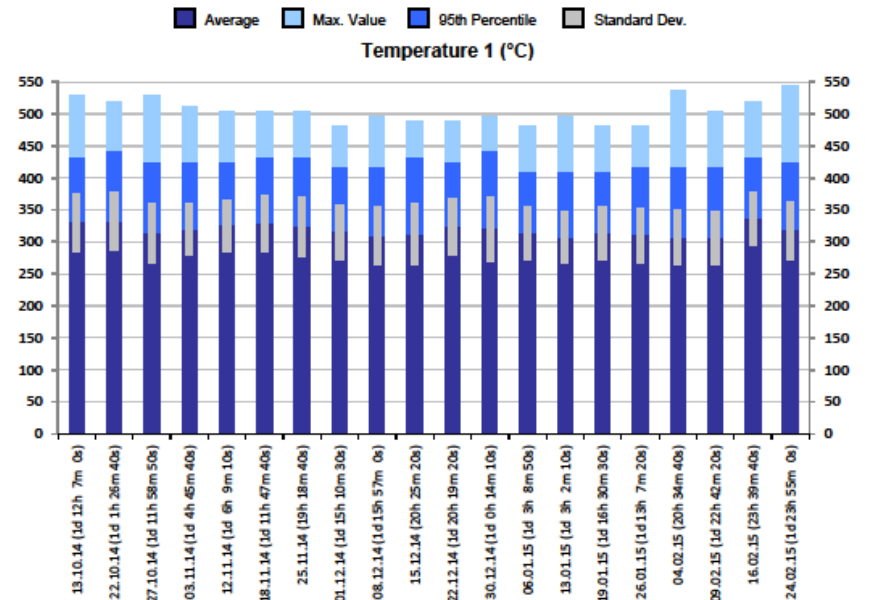
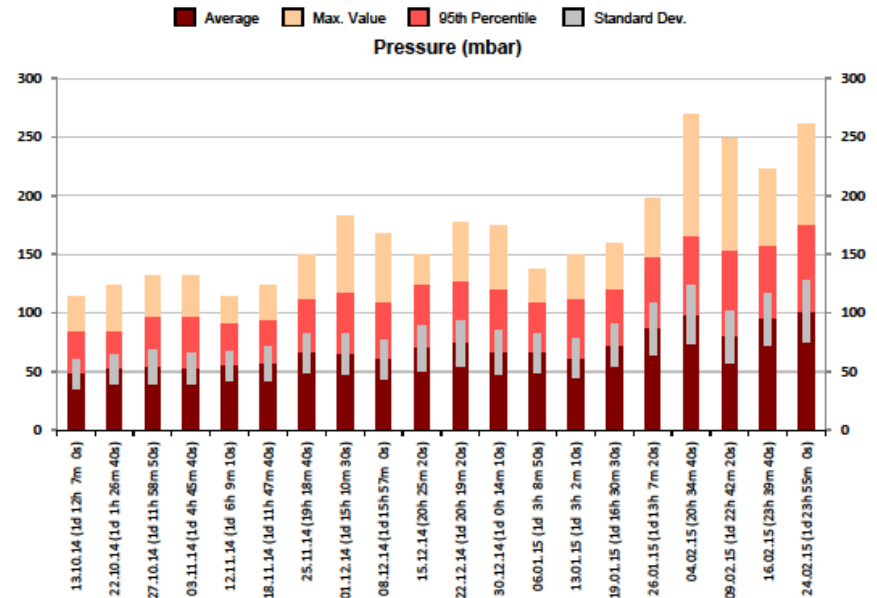


	Pressure [mbar]	Temp. 1 [°C]	Temp. 2 [°C]	RPM [RPM]
Max. value	508	747	-	-
Min. value	10	60	-	-
Average	110.71	393.74	-	-
Standard dev.	73.34	113.73	-	-
95th percentile	200	500	-	-

Trend Analysis

shows change of the operation profile from week to week

Cleaning was needed from time to time because of the dirty lube oil and high oil consumption but preventive maintenance can be planned in time using this fleet monitoring



STEP-8 Filter Installation

- Allocation of Filter to Vehicle in a common decision process
- Installation by manufacturer personal with local support by fleet workshops
- Installation of OBD and VERT-monitor for remote control
- Instruction of fleet workshops
- Establish communication and emergency rules
- Organize reporting

STEP-9 Alarms after Filter Installation

1. Red light at the drivers panel
2. GSM/GPS to TTM, Filter manufacturer and VECC / B-EPB
3. SMS Alarm information to TTM and filter manufacturer usually *in the middle of the night*

GSM LOGGER 1456
reports following errors D36
T:356C; P:201 mbar
GPS Pos 32052862N, 118490720E

→ *immediate info to local supervisor*

Pilot Test Nanjing

Pilot Fleet Nanjing – Fuel sulfur < 350 ppm

Status 06.10.2014

NoI	Vehicle Licence No.	Vehicle Kind	Year Mileage [km]	Vehicle Brand & Model	VIN	Engine Brand & Model	Power [kW]	Displacement [dm ³]	Opacity [1/m]	Emiss. Class	DPF installed	DL Number	DL Status based on internet data until September 30.2014 Latest correct data set on Internet
	A32292	long distance Coach	2001 2 Mio +331731	XiAn / VOLVO B10M	LKDG421 771G053 444	VOLVO THD102	210	9,6	0,81	China II	Dinex 25.7.2014	1454	17.12.2013
	A33751	long distance Coach	2002 2 Mio +106343	XiAn / VOLVO B10M	LKDG421 782G054 099	VOLVO THD102	210	9,6	0,7	China II	Dinex 25.7.2014	1448	18.12.2013
	A34568	long distance Coach	2002 2 Mio + 61034	XiAn / VOLVO B10M	LKDG421 712G054 218	VOLVO DH 10	210	9,6	0,42	China II	Dinex 26.7.2014	1450	17.08.2014 OK ?
	A31695	long distance Coach	2001 2 Mio + 265342	XiAn / VOLVO B10M	LKDG421 771G052 858	VOLVO TH102	210	9,6	1,39	China II	Dinex 26.7.2014	1452	01.06.2014
	A33377	long distance Coach	2001 2 Mio +225117	XiAn / VOLVO B10M	LKDG421 742G053 855	VOLVO THD102	210	9,6	1,57	China II	Dinex 24.7.2014	1446	07.09.2014 OK ?
	A33742	long distance Coach	2002 1.95 Mio	XiAn / VOLVO B10M	LKDG421 732G054 107	VOLVO THD102	210	9,6	1,56	China II	PURltech 30.7.2014	1456	01.09.2014 OK ?
	A33694	long distance Coach	2002 2.17 Mio	XiAn / VOLVO B10M	LKDG421 772G054 109	VOLVO THD102	210	9,6	1,23	China II	PURltech 30.7.2014	1447	11.05.2014
	A33753	long distance Coach	2002 2.23 Mio	XiAn / VOLVO B10M	LKDG421 732G054 101	VOLVO THD102	210	9,6	1,33	China II	PURltech 23.7.2014	1402	24.08.2014 OK ?
	A33755	long distance Coach	2002 2.21 Mio	XiAn / VOLVO B10M	LKDG421 782G054 152	VOLVO THD102	210	9,6	1,45	China II	PURltech 30.7.2014	1451	24.08.2014 OK ?
	A39358	long distance Coach	2003 1.81 Mio	XiAn / VOLVO B10M	LKDG421 732G054 808	VOLVO THD102	210	9,6	0,25	China II	PURltech 30.7.2014	1445	16.12.2013

Pilot Test Xiamen

Pre-Datalogging Pilot Fleet Xiamen - Fuel Sulfur < 350 ppm

Status 06.10.2014

No. I	Vehicle Licence No.	Vehicle Kind	Year Mileage [km]	Vehicle Brand & Model	Engine Brand	Power [kW]	Displacement [dm ³]	Opacity [1/m] PN [#/cc]	Emissi Class	Filter Installed	DL Number	DL Status based on Internet data until September 30.2014 Latest correct data file on Internet
1	D59289	City-Bus	2010 193286	Suzhou HIGER KLQ 6856E3	YUCHAI YC4G 200-30	147	5.2	0.19 2.9 x 10 ⁶	China 3	DINEX active 2.8.2014	1458	24.11.2013
2	D88987	City-Bus	2010 249623	King Long LKQ 8656	YUCHAI YC4G 180-30	132	5.2	0.16 2.9 x 10 ⁶	China 3	DINEX active 3.8.2014	1462	19.01.2014
3	D59293	City-Bus	2010 85711	Suzhou HIGER KLQ 6856E3	YUCHAI YC4G 200-30	147	5.2	0.35 2.9 x 10 ⁶	China 3	DINEX active 3.8.2014	1461	29.09.2014 OK
4	D59281	City-Bus	2010 145929	Suzhou HIGER KLQ 6856E3	YUCHAI YC4G 200-30	147	5.2	0.45 2.9 x 10 ⁶	China 3	DINEX active 4.8.2014	1464	28.06.2014
5	D88957	City-Bus	2010 140507	King Long LKQ 8656	YUCHAI YC4G 180-30	132	5.2	0.33 2.9 x 10 ⁶	China 3	DINEX active 4.8.2014	1466	25.06.2014
6	D89330	City-Bus	2010 148709	King Long LKQ 8656	YUCHAI YC4G 180-30	132	5.2	0.25 2.9 x 10 ⁶	China 3	Puritech active 21.8.2014	1459	24.06.2014
7	D89336	City-Bus	2010 121535	King Long LKQ 8656	YUCHAI YC4G 180-30	132	5.2	0.22 2.9 x 10 ⁶	China 3	Puritech active 23.8.2014	1460	29.06.2014
8	D89331	City-Bus	2010 155383	King Long LKQ 8656	YUCHAI YC4G 180-30	132	5.2	0.14 2.9 x 10 ⁶	China 3	Puritech active 22.8.2014	1468	27.07.2014
9	D59290	City-Bus	2010 147140	King Long LKQ 8656	YUCHAI YC4G 180-30	132	5.2	???? 2.9 x 10 ⁶	China 3	Puritech active 24.8.2014	1457	23.06.2014
10	D59283	City-Bus	2010 202543	King Long LKQ 8656	YUCHAI YC4G 180-30	132	5.2	???? 2.9 x 10 ⁶	China 3	Puritech active 25.8.2014	1469	27.07.2014

Pilot Test Beijing

Construction Machine Pilot Test Beijing

NO.	Datalogger NO.	DPF	Vehicle type	Vehicle brand	Engine displacement (L)	Nominal power (kW)	Overall weight (kg)	sulfur (ppm)	smoke intensity	Owner (operator) company	installation day
1	1404	HJS	loader	XGMA	9.0	162	16500.00		0.23	XINSHI	2013.9
2	1409	HJS	road roller	BOMAG	4.8	98	13200.00		1.46	XINSHI	2013.9
3	1385	HJS	road roller	XCMG	8.0	136	22000.00		2.32	XINSHI	2013.9
4	1410	PURITECH	road roller	ingersoll rand	5.9	125	15000.00		1.71	XINSHI	2013.9
5	1406	PURITECH	paver	volvo	7.2	182	17550.00		0	XINSHI	2013.9
6	1435	PURITECH	paver	ingersoll rand	7.2	182	17550.00		1.5	XINSHI	2013.9
7	1442	PURITECH	paver	ingersoll rand	7.2	182	17550.00		0.26	XINSHI	2013.9
8	1434	PURITECH	pavemill	HME	15.0	448	32000.00		0.32	XINSHI	2013.9

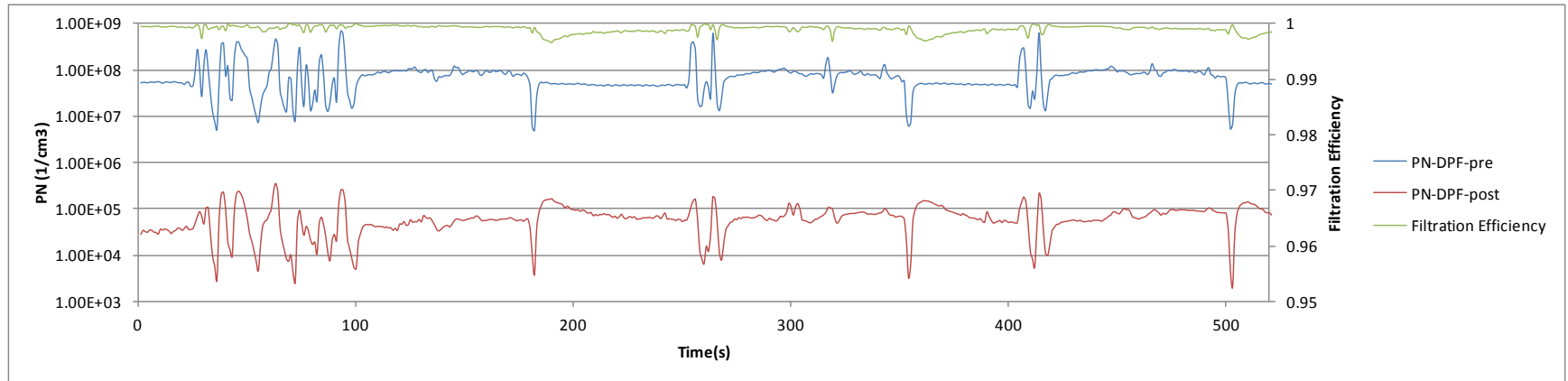
XINSHI = Beijing XINSHI Road&Bridge Construction Co., LTD.

南京改造车辆 Transformed Vehicles in Nanjing



加载减速典型实验结果

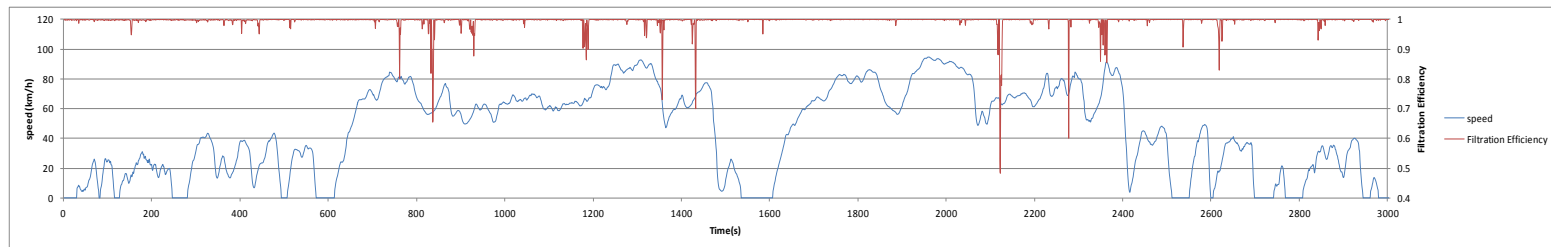
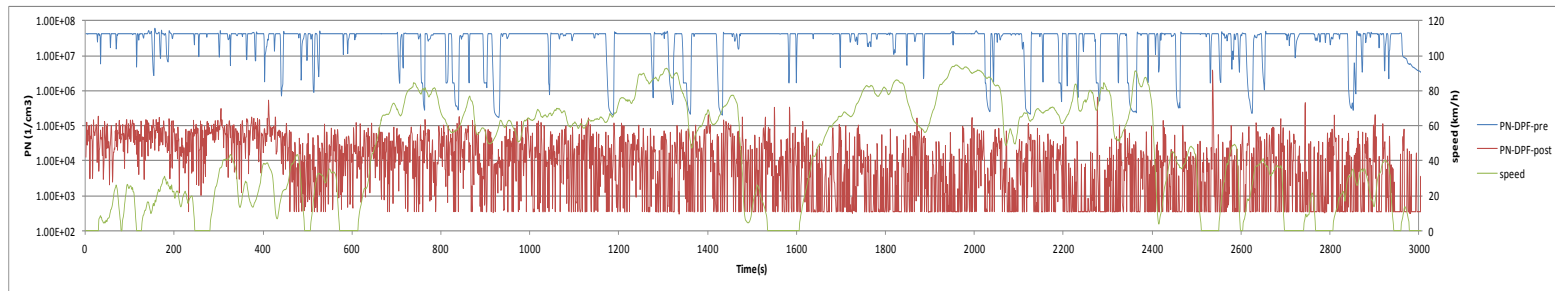
Typical Test Results of Lug-down Test



- DPF后颗粒物数量平均浓度: $7.07E+04/cm^3$
Average Particulate Number Concentration after DPF:
 $7.07E+04/cm^3$
- DPF平均过滤效率: 99.91%
Average Filtration Efficiency of DPF: 99.91%
- DPF前颗粒物数量平均浓度: $8.20E+07/cm^3$
Average Particulate Number Concentration before DPF:
 $8.20E+07/cm^3$

道路行驶实验结果

Test Results of Road Driving



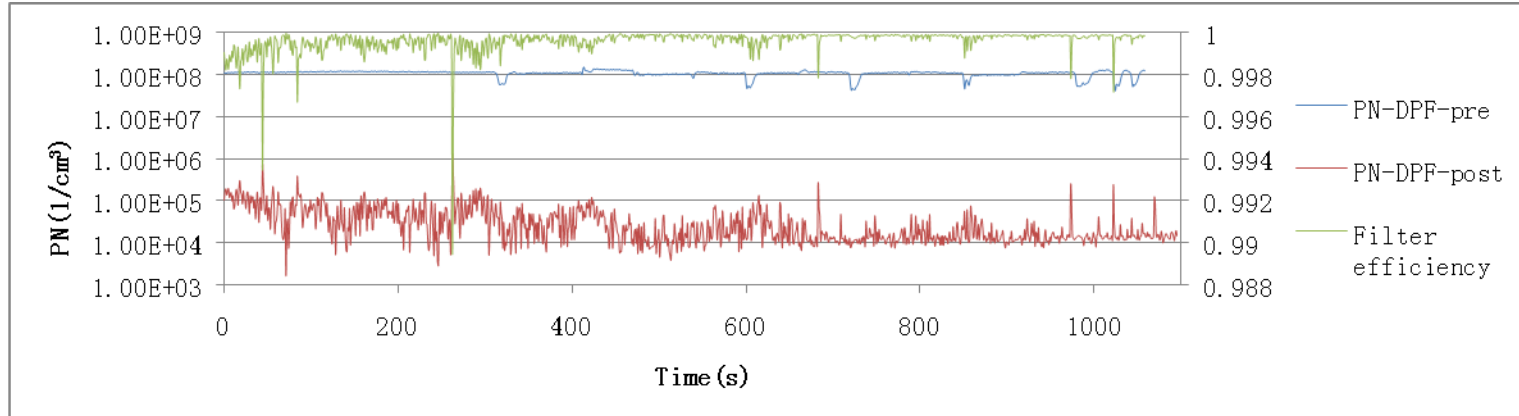
- DPF前颗粒物数量平均浓度: $3.48E+07/cm^3$
Average Particulate Number Concentration before DPF:
 $3.48E+07/cm^3$
- DPF后颗粒物数量平均浓度: $2.77E+04/cm^3$
Average Particulate Number Concentration after DPF:
 $2.77E+04/cm^3$
- DPF平均过滤效率: 99.92%
Average Filtration Efficiency of DPF: 99.92%

北京市非道路改造 Non-road Machines in Beijing



#1385 压路机

#1385 steam-roller



- DPF前颗粒物数量平均浓度: $1.11E+08/cm^3$

Average Particulate Number Concentration before DPF:
 $1.11E+08/cm^3$

- DPF后颗粒物数量平均浓度: $3.86E+04/cm^3$

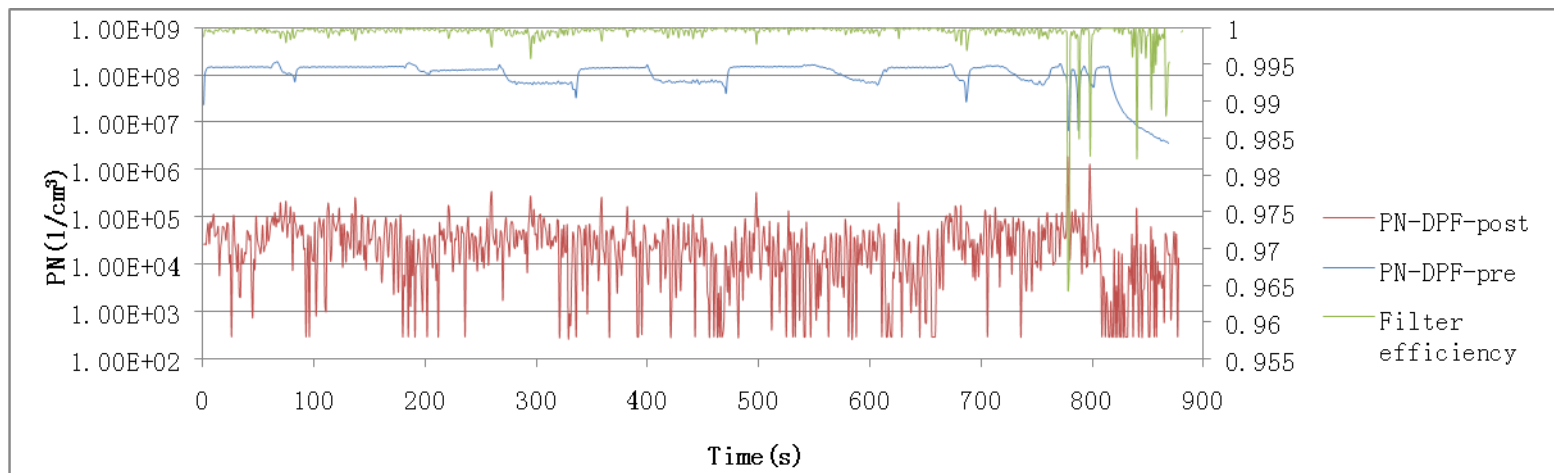
Average Particulate Number Concentration after DPF: $3.86E+04/cm^3$

- DPF平均过滤效率: 99.97%

Average Filtration Efficiency of DPF: 99.97%

#1404 装载机

#1404 wheel loader



- **DPF前颗粒物数量平均浓度: $1.16\text{E}+08/\text{cm}^3$**

**Average Particulate Number Concentration before DPF:
 $1.16\text{E}+08/\text{cm}^3$**

- **DPF后颗粒物数量平均浓度: $4.11\text{E}+04/\text{cm}^3$**

Average Particulate Number Concentration after DPF: $4.11\text{E}+04/\text{cm}^3$

- **DPF平均过滤效率: 99.94%**

Average Filtration Efficiency of DPF: 99.94%

STEP-10 Emission Measurements by BIT

Nanjing and Xiamen Start and End

Test Results Nanjing / PN-Efficiency from Reports BIT

Vehicle	1 A34568 DINEX	2 A31695 DINEX	3 A32292 DINEX	4 A33377 DINEX	5 A33751 DINEX	6 A33694 Puritech	7 A33742 Puritech	8 A33753 Puritech	9 A33755 Puritech	10 A39358 Puritech
1 - Dyno	99.91	99.94	-	99.91	90.39	-	91.45	-	99.45	99.86
1 - Road	99.96	99.38	99.94	99.92	86.00	99.81	97.76	-	99.95	99.15
2 - Dyno	58.43	69.65	99.35	97.12	96.93	79.48	83.01	97.82	95.56	95.72
2 - Road	99.78	48.83	99.11	82.85	93.22	21.85	63.01	99.14	97.44	79.20

Measurement with 2 NanoMet3 in parallel

Measurement 1: August 2014 after 3-4 weeks of installation

Measurement 2: January 2015 after about 100'000 km of operation

Test Results Xiamen / PN-Efficiency from Reports BIT

Vehicle	1 D59281 DINEX	2 D59289 DINEX	3 D59293 DINEX	4 D88987 DINEX	5 D88957 DINEX	6 D89330 Puritech	7 D89331 Puritech	8 D89336 Puritech	9 D59290 Puritech	10 D59283 Puritech
1 - Dyno	98.76	99.50	99.08	98.85	96.96	97.20	98.67	97.42	94.17	91.03
1 - Road	99.20	99.82	98.34	97.65	99.54	98.06	98.47	98.97	96.76	-
2 - Dyno	94.98	98.20	85.92	91.11	94.75	99.14	95.60	93.91	93.72	77.93
2 - Road	99.55	99.78	97.92	80.92	94.05	99.91	99.57	99.24	95.02	62.48

Measurement with 2 NanoMet3 in parallel

Measurement 1: September 2014 after 4-6 weeks of installation

Measurement 2: January 2015 after about 30'000 km of operation (estimate)

- First test on average 98.5%
15 F > 98%
- Second test on average 85.6 %
11 F > 98 %

STEP-10 Emission Measurements by BIT

Beijing Construction in the Middle of the Test

Test Results Beijing Construction / PN-Efficiency from Reports BIT

Vehicle	1 DL1385 HJS active	2 DL1404 HJS active	3 DL1410 Puritech passive	4 DL1406 Puritech passive	5 DL1442 Puritech passive	6 DL1434 Puritech passive	7 DL1435 Puritech
1 - Dyno	-	-	-	-	-	-	-
1 - Road	-	-	-	-	-	-	-
2 - Dyno	-	-	-	-	-	-	-
2 - Road	99.72	97.07	99.88	95.09	99.10	99.25	no data

Measurement with 2 NanoMet3 in parallel

Measurement 1: not performed

Measurement 2: March 2015 after 2-3 month of operation

Machine with DL 1435 was transferred to outside Beijing at very high sulfur content; not measured



Diesel Particle Retrofit in China

Regulations

- **The China Action Plan** on Air Pollution Prevention and Treatment 2013: ...by 2017 reduce inhalable particulates concentration of cities by over 10% .. cut PM_{2.5} concentration by 25% .. annual average PM_{2.5} concentration in Beijing shall be 60 microgram per cubic meter.
- **Beijing Clean Air action** plan 2013: .. by the end of 2014, Euro V standard will be applied to all new heavy diesel vehicles, and the heavy diesel vehicles used within the city shall install DPF.
- **PRC Law on Air Pollution** Prevention and Control – August 2015: Article 59: existing heavy duty diesel vehicles and non-road mobile machinery that lack pollution control devices or those with devices that do not conform to requirement, shall install necessary pollution control devices or be replaced by vehicles that conform to regulations

Manufacturers – see also emission control association under CATARC

- Pirelli, Yinlun PURltech, Dinex, Twintec, Corning – all VERT certified
- Huangdi – VERT-certification in process
- Lotusfairy, Actblue – canning
- KaiLong – VERT-member
- Sichuan Zongzhi
- Beijing 2008: Yantai Hualong, SK, Shanghai Tenneco, Zhonghedacheng, Rijin, Pirelli
- Manufacturing announced by Panasonic, Liqtech and NGK – both VERT-members

Retrofit Numbers

- 2008: 10'000 buses retrofitted in Beijing for the Olympics
- 2009: 200 buses retrofitted in Hongkong, some hundreds in Shanghai
- 2013: 2'000 buses retrofitted in Nanjing
- 2015: 30'000 buses and trucks retrofitted mainly in Shandong Province
- 2016 >100'000 retrofits are expected in Beijing, Shenzhen and other cities and in mines

Next Steps

- Cooperation with CATARC- CVEC (kick-off 18.12.15)
- 3 VERT-certifications for Chinese Technology in process
- KAILONG – first VERT-member
- VERT-members participate in the Nanjing LEZ
- VERT-members participate in the ShenzhenProject
- many other projects will come soon
- VERT-Video in Mandarin available

How can Switzerland and VERT assist for next Steps ?

- **Continuation BCEMS-DEZA**
- **Provide Filter Technology**
- Certify Filters
- Supply Particle Metrology
- Instruct Retrofit Approval
- **Inspection and Maintenance**
and at a later stage
- **DeNOx Retrofit – VERT SDPF**

