

VERT Iran Workshop

UFP Health Effects and Diesel Exhaust Detoxification by Particle Filters

Diesel Particle Filter Technologies

January 13th 2016 | 23. Dei 1394

Iran, Tehran
Volker Hensel

Diesel Particle Filter Technologies

Agenda

- Introduction
- Technical Concept of a Diesel Particulate Filter
- Filtration of Soot
- Soot Conversion Techniques in the Filter (Regeneration)
- Electronically Control of Filter Systems
- Summary

○ What does VERT® stand for?

- Non-profit organization to eliminate particles and harmful substances from internal combustion engines
- Certification of diesel particle filters with Best Available Technology (VERT® filterlist)
- International membership out of manufacturers of DPF and SCR systems, testing devices, substrate producers, chassis builders, engine manufacturers and others
- Acting as partner of Megacities to support and execute pollution reduction programs from road traffic and nonroad

VERT® is a Trade Mark

for Particle Filters based on Best Available Technology



○ Take Home Message

- Small particles (UFP) have to put in focus due to their health effects
- Diesel particle filtration is a well known and reliable technology since more than 20 years with more than 85 Million applications ww
- Diesel Particle Filters are systems to fulfill
 - filtration efficiency
 - Regeneration (soot burning)
 - electronically control
 - noise reduction
- Diesel particulate filters are used for first fit, option fit and retrofit
- There is no known alternative technology to reduce small particles from combustion engines to avoid heavy health effects

Introduction | Mobility

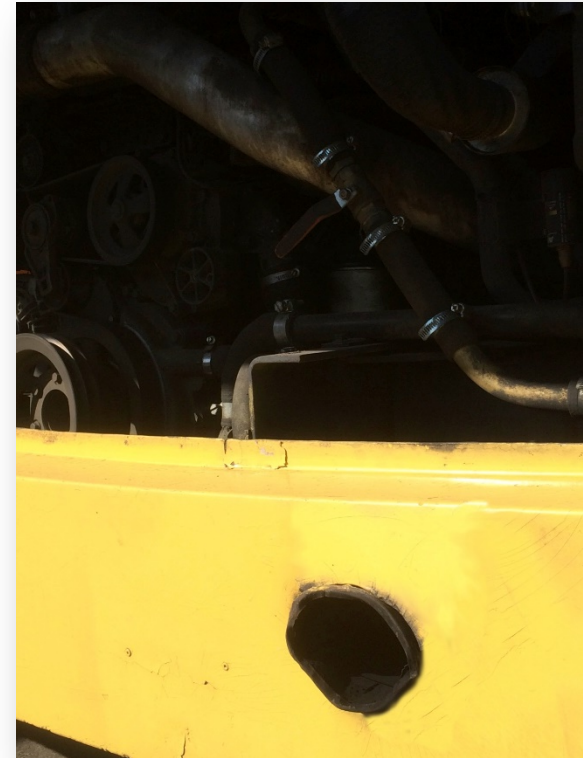
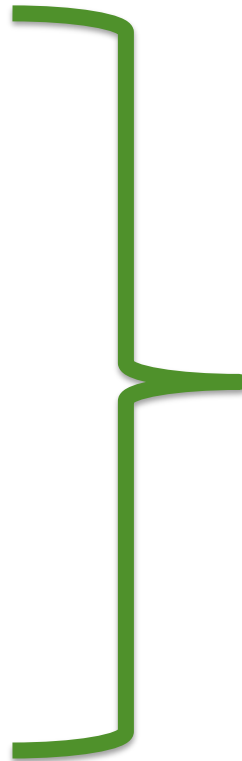
The Challenge is increasing

- World population is growing
- Need for mobility is increasing
- Total emissions are increasing
- Combustion engines will be used for decades
- No alternative for Best Available Emission Control Technologies

○ Introduction | Substances of Diesel Exhaust

Substances of Diesel Exhaust

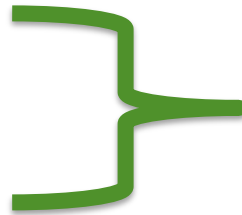
- Solid particles:
 - Soot particles
 - Ash particles
- Liquid droplets
- Gases:
 - O₂, HC, NO, NO₂
 - PAH, Nitro-PAH
- Many trace substances



○ Substances of Diesel Exhaust

Substances of Diesel Exhaust

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 - Ash particles
- Liquid droplets
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 - O₂, HC, NO, NO₂
 - PAH, Nitro-PAH
- Many trace substances

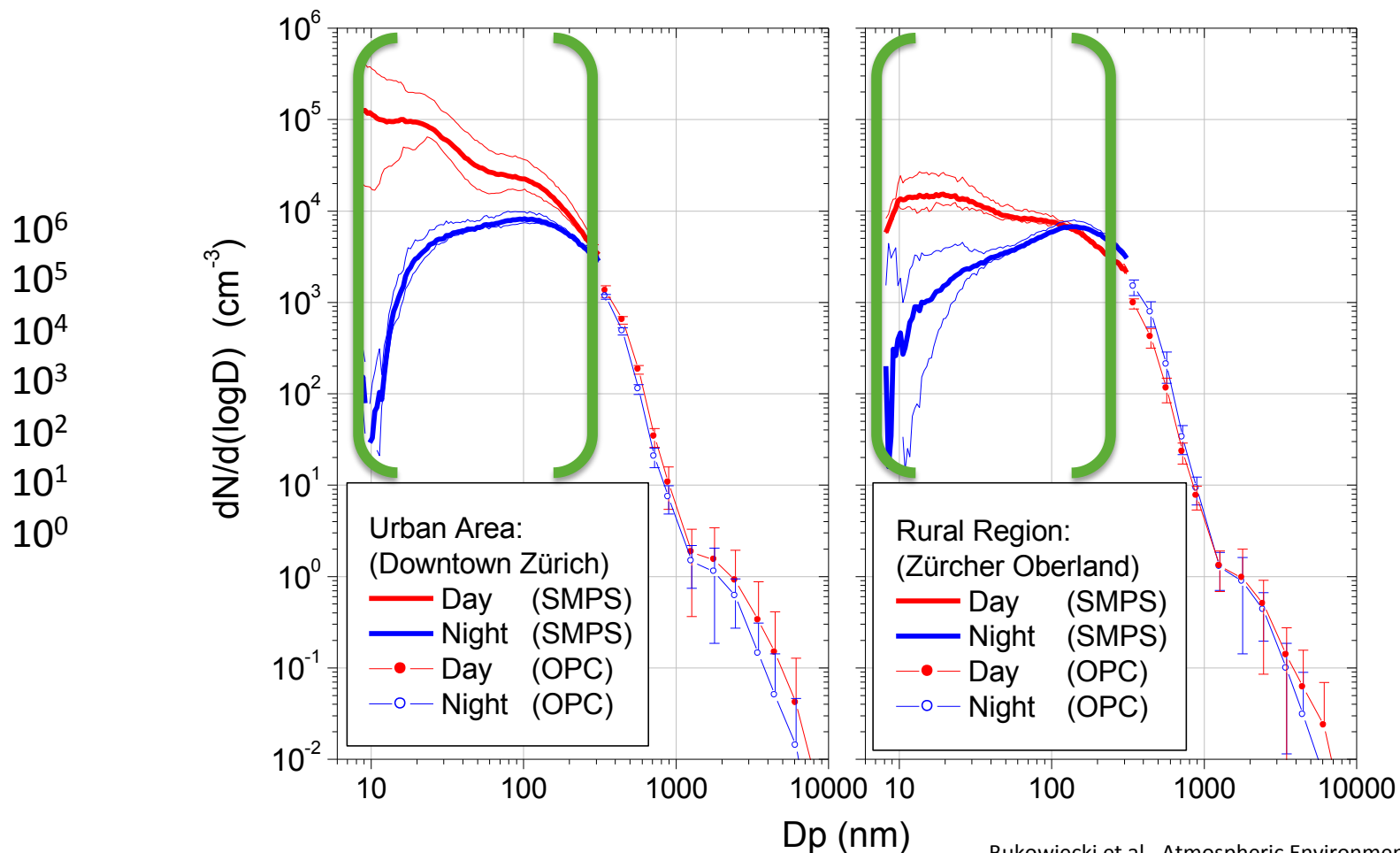


- Very small 20 ... 500 nm
- High surface > 100 m²/g
- Transporting toxics persistent in organism
- Carcinogenic
- Black colour | global warming effect

Long life toxic aerosol (weeks to month)

Defined by WHO since 2012 as evidenced carcinogenic (class 1 like asbestos)

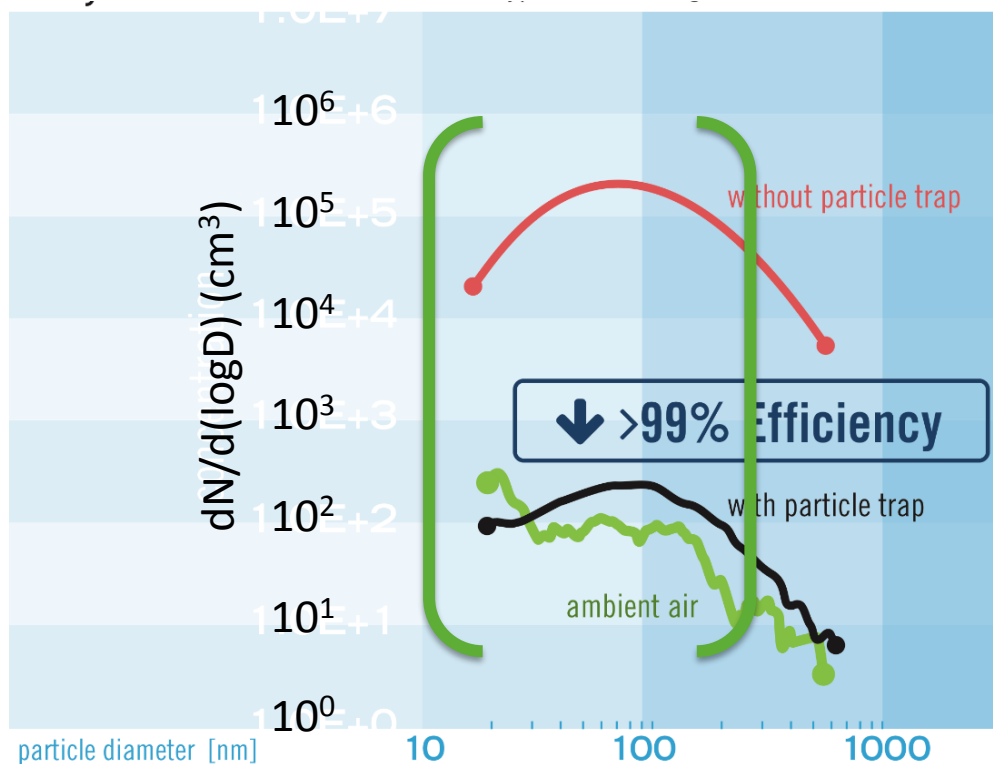
Introduction | Road Traffic Effects to Urban Air Pollution



Bukowiecki et al., Atmospheric Environment, 2002

Introduction | Road Traffic Effects to Urban Air Pollution

Size distribution of an typical diesel engine w and w/o closed DPF

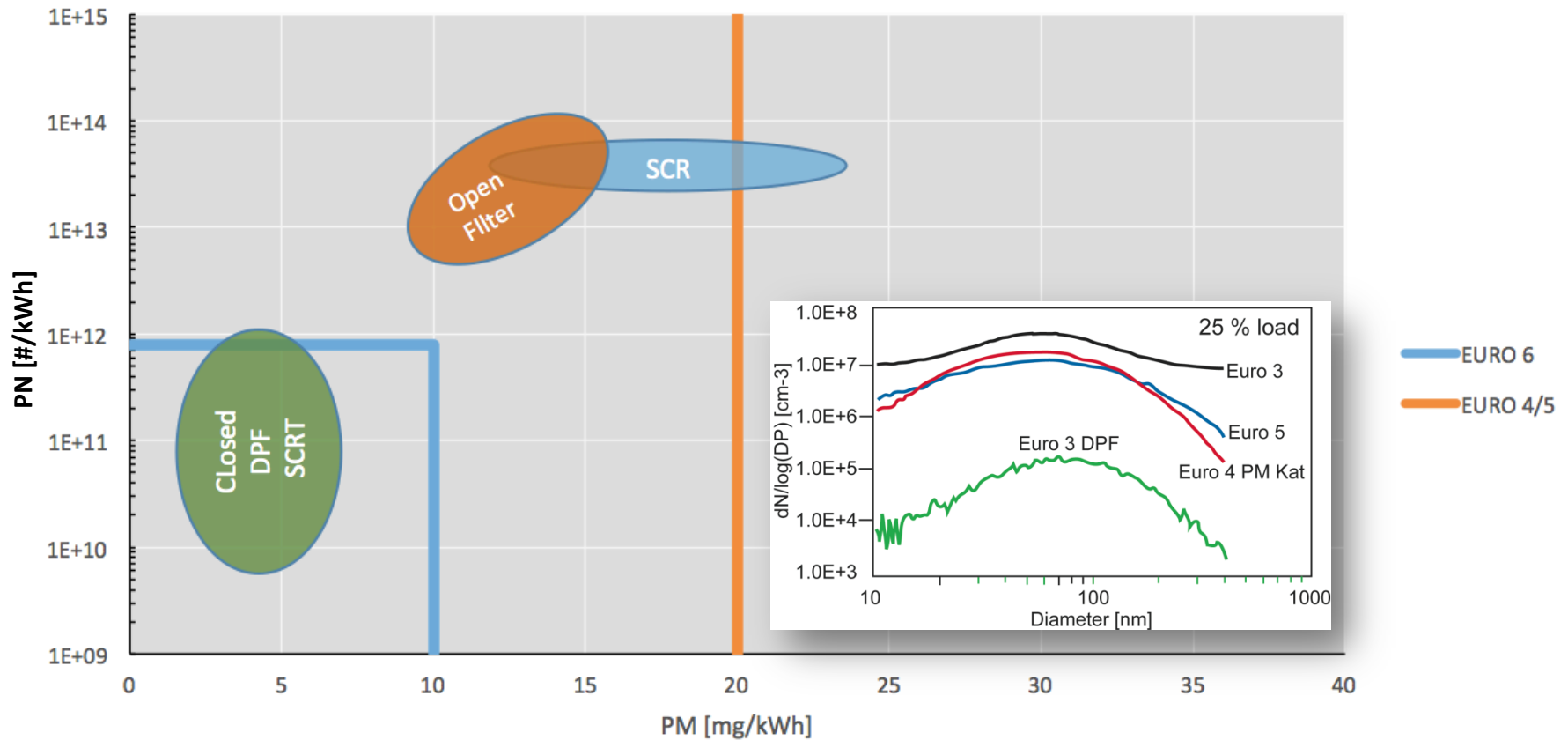


- DPF remove 99.99% of engine generated particles
- Only 0.01 % released to the environment
- DPF removes all particles



Introduction | Technology Assessment

Limits of different Exhaust Aftertreatment Technologies

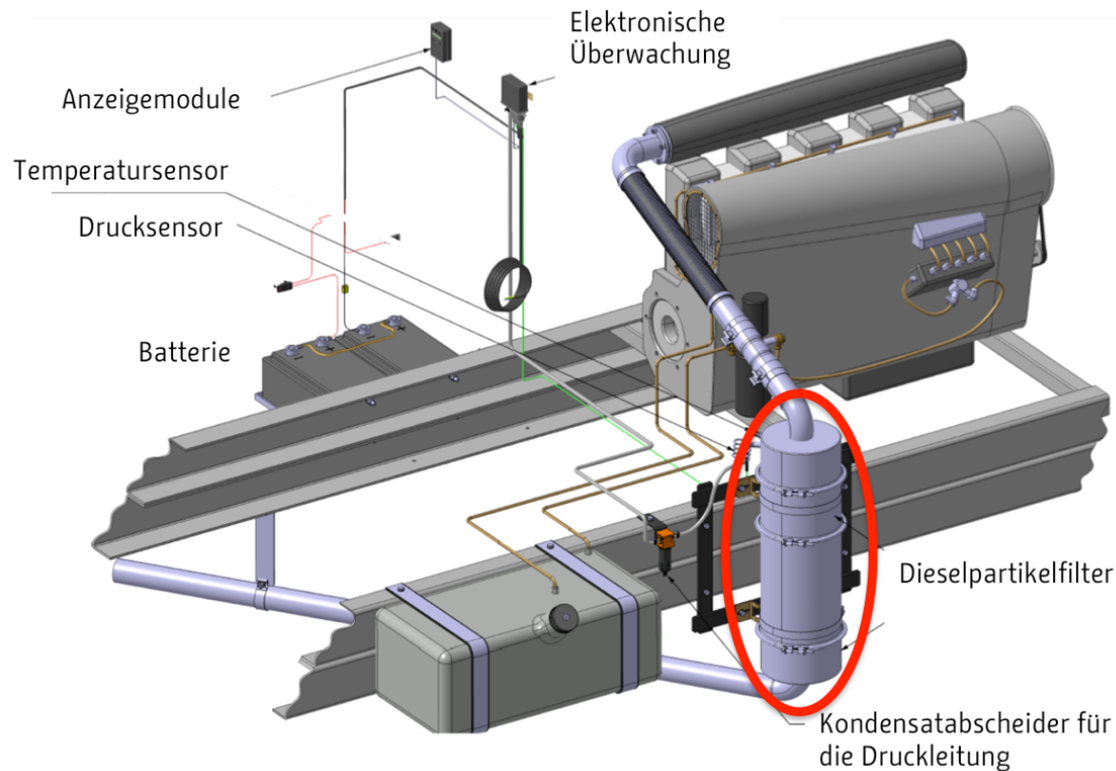


Diesel Particle Filter Technologies

Agenda

- Introduction
- Technical Concept of a Diesel Particulate Filter
- Soot Conversion Techniques in the Filter (Regeneration)
- Electronically Control of Diesel Particulate Filter Systems
- Cleaning and Service of Diesel Particle Filters
- Summary

Technical Concept of a Diesel Particulate Filter



○ Technical Concept of a Diesel Particulate Filter

- Particle filters substitute the original muffler



○ Technical Concept of a Diesel Particulate Filter

- Particle filters substitute the original muffler



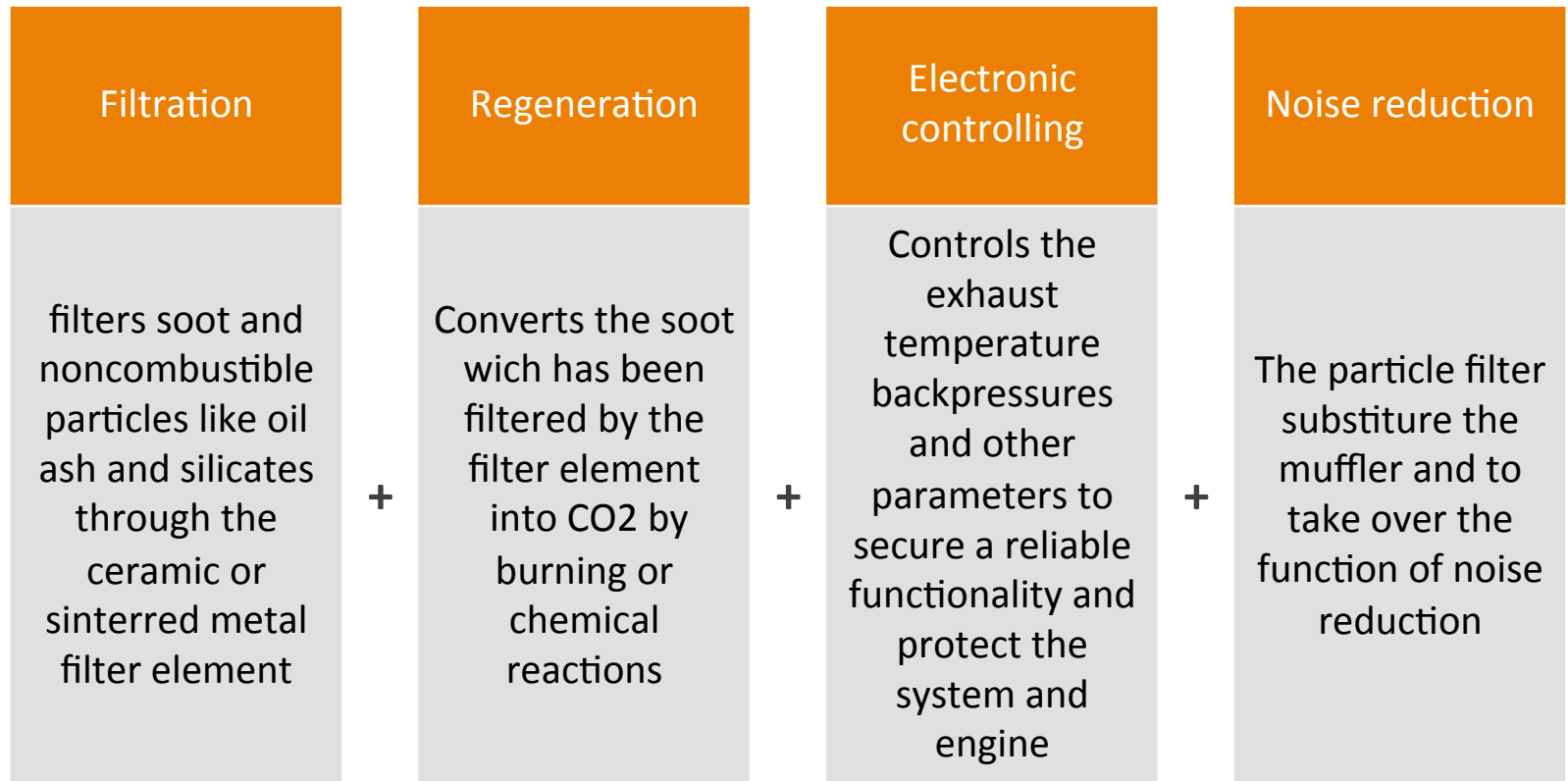
○ Technical Concept of a Diesel Particulate Filter

- Particle filters substitute the original muffler



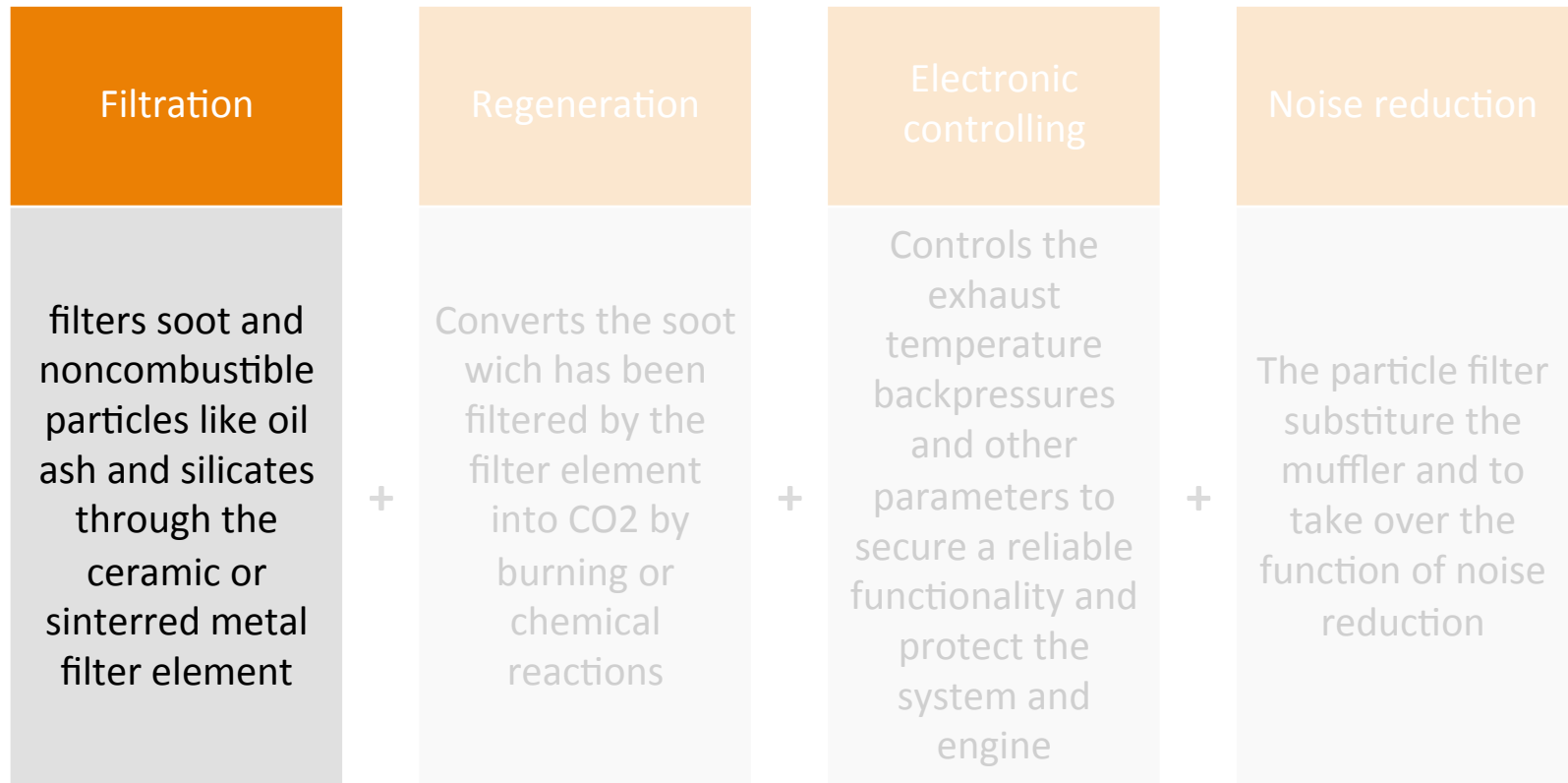
○ Technical Concept of a Diesel Particulate Filter

- Particle filters are technical systems to fulfill 4 core functions



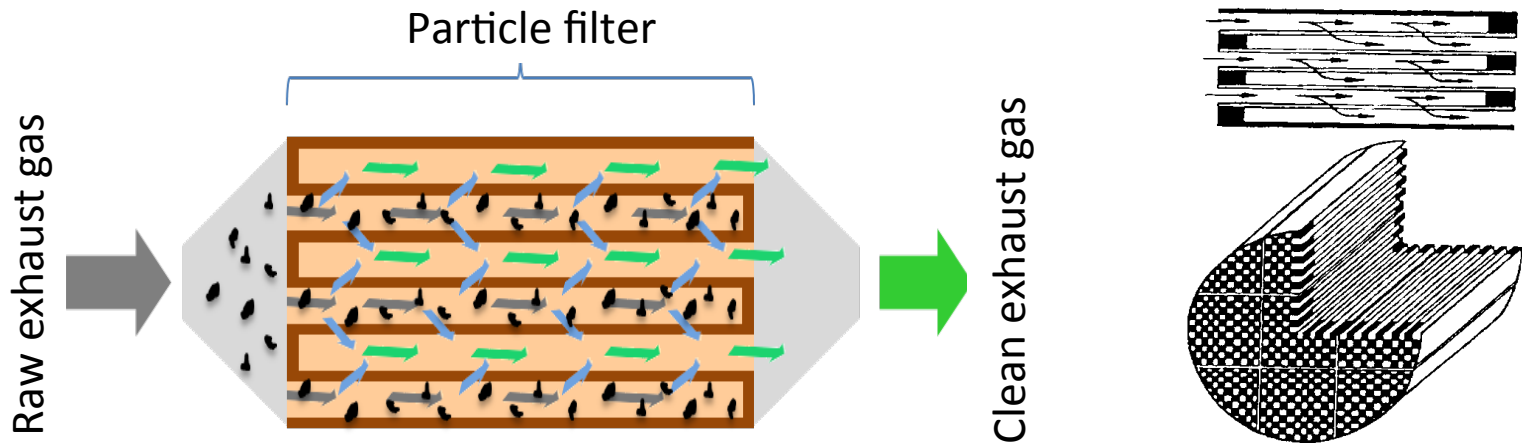
○ Technical Concept of a Diesel Particulate Filter

- Particles filters are technical systems to fulfill 4 core functions



Technical Concept of a Diesel Particulate Filter

“Closed” Filter Systems are holding > 99% of the particles back



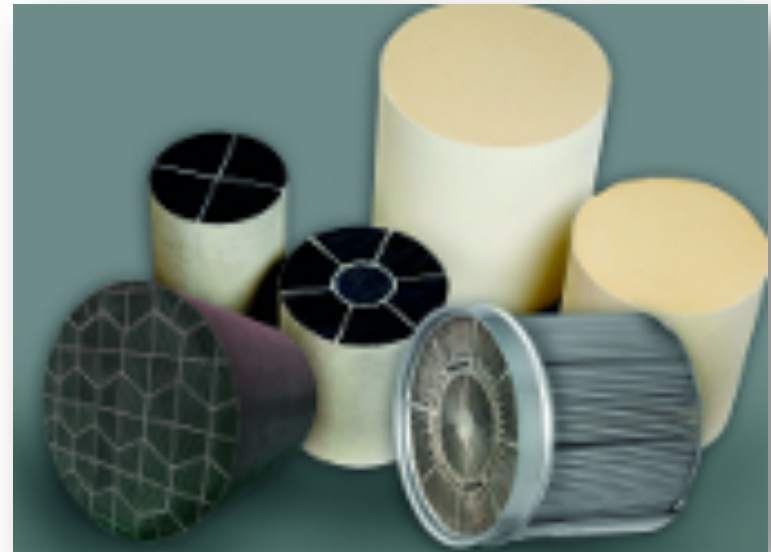
- Channels are reciprocally closed
- Exhaust gas is forced to penetrate the porous, to air permeable, walls
- Soot particles are held back and collected on the walls of the filter material

○ Technical Concept of a Diesel Particulate Filter

“Closed” Filter Systems are holding 99% of the particles back

Different Substrates for Particle Filters are used

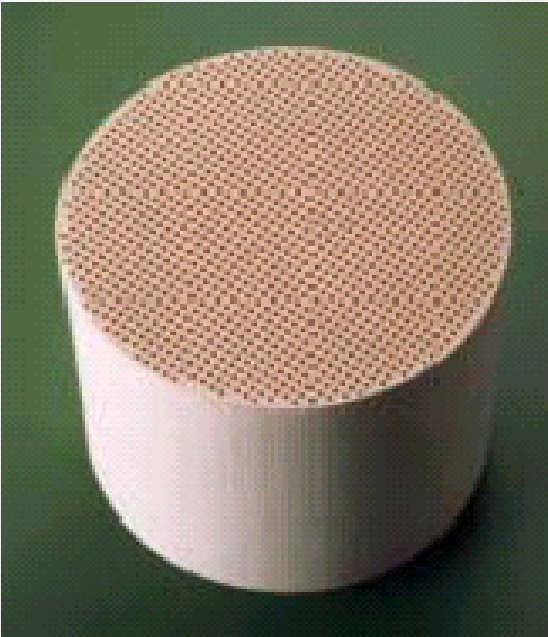
- Ceramic and sintered metal are mostly used
- Depending on application and regeneration different advantages and disadvantages
- All this substrates are closed and can filter Ultra Fine Particles (UFP)



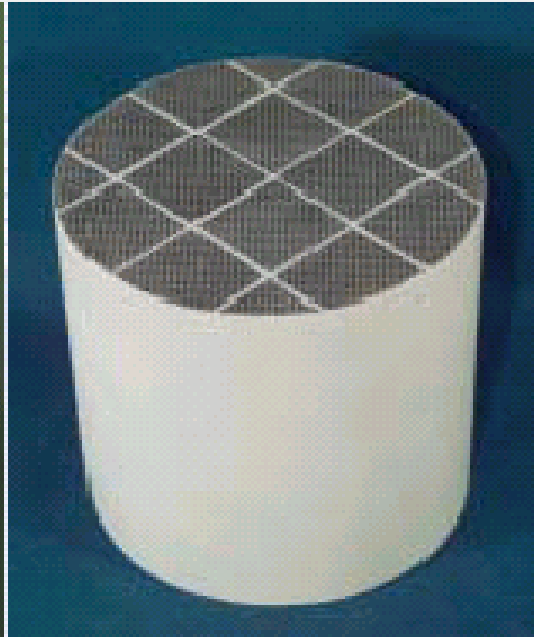
○ Technical Concept of a Diesel Particulate Filter

Extruded cordierite and silicon carbide filter monoliths

Cordierite

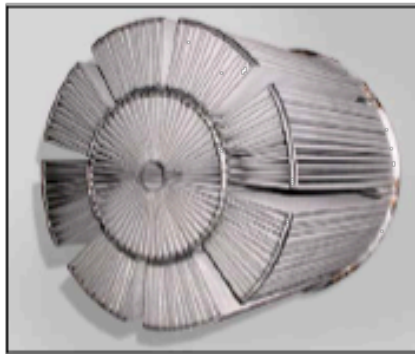


Silicon carbide



○ Technical Concept of a Diesel Particulate Filter

Extruded cordierite and silicon carbide filter monoliths



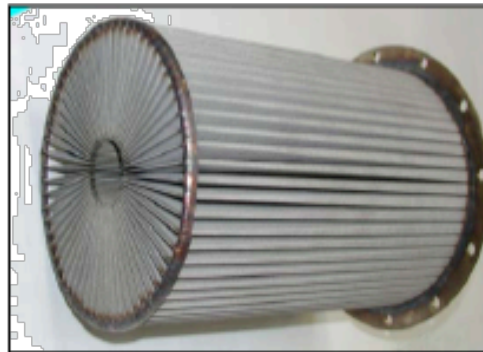
Satelliten-Filter



Filtertasche



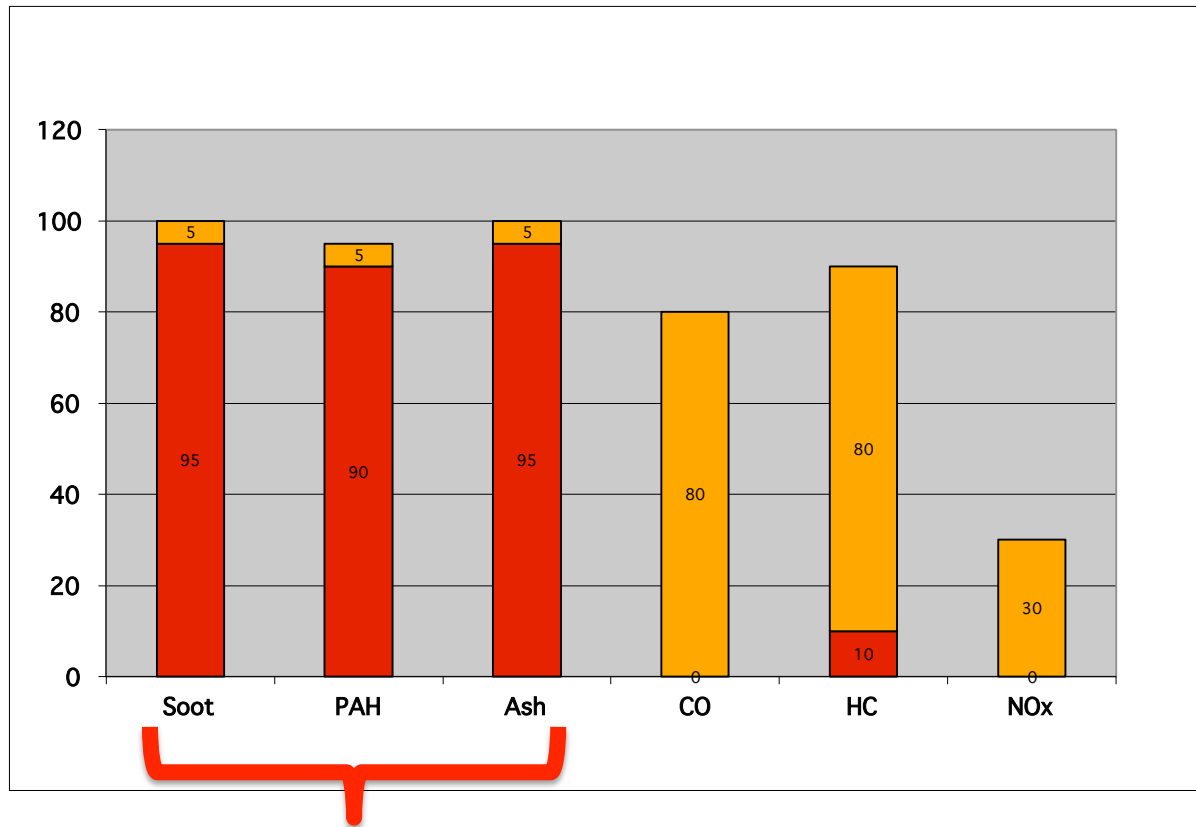
Filter-Box



HDT Tagung Partikelfiltertechnologie
HJS Fahrzeug GmbH & Co. KG
Simon Steigert, München 2004

Technical Concept of a Diesel Particulate Filter

Diesel particle filters eliminates carcinogenic substances



carcinogenic substances

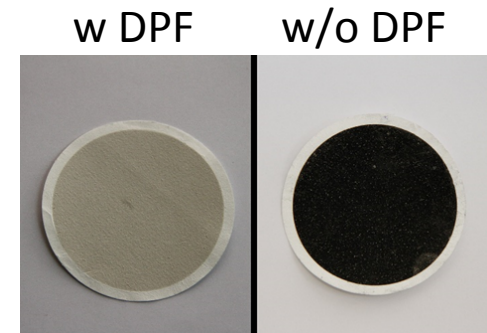
○ Technical Concept of a Diesel Particulate Filter

Different Filter Efficiencies -> Need for certified filters

Technical Concept of a Diesel Particulate Filter

Filter Efficiency tested under Iranian high sulfur conditions

- Configuration
 - BENZ OM 457 LA; 12 L; 299 hp, EURO 3
 - Iranian Diesel with 7.000 ppm Sulfur
 - DPF retrofitted with Fuel Borne Catalyst
 - Test cycle steady-state



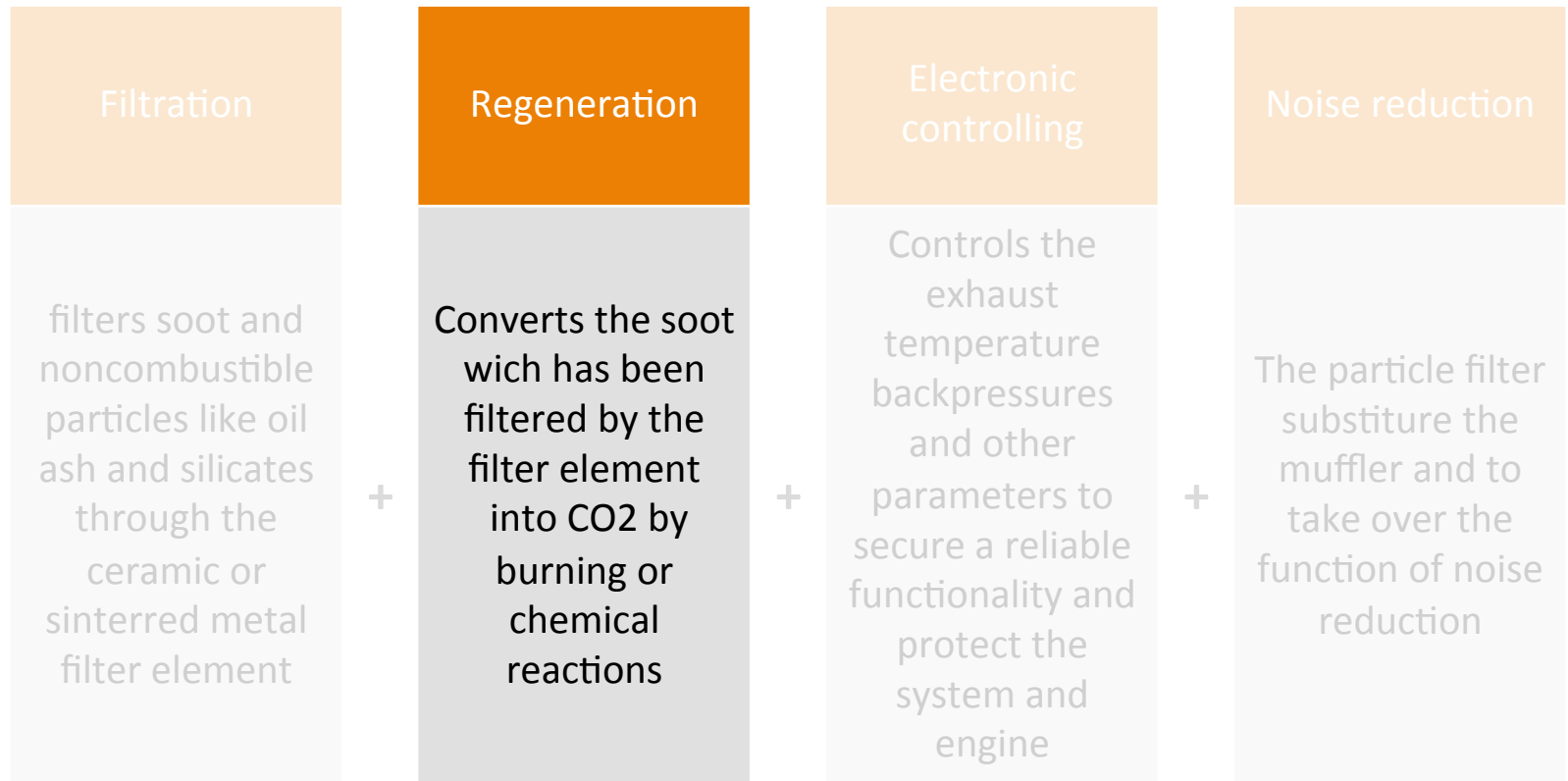
	Particle mass without filtration [gr/kwh]	Particle mass with filtration [gr/kwh]	Particle number without filtration [#/kWh]	Particle number with filtration [#/kWh]
Test Engine	0.120	0.008	3.42E+13	2.21E+11
Euro III *)	0.10	0.10		



99.35% Reduction

Technical Concept of a Diesel Particulate Filter

- Particles filters are technical systems to fulfill 4 core functions



○ Regeneration Technology

- An efficient filter stores all soot in its cells the exhaust gas exits clean, particles eliminated
- → the filter gets plugged soon (within hours)
- „Regeneration“ is controlled combustion of stored soot



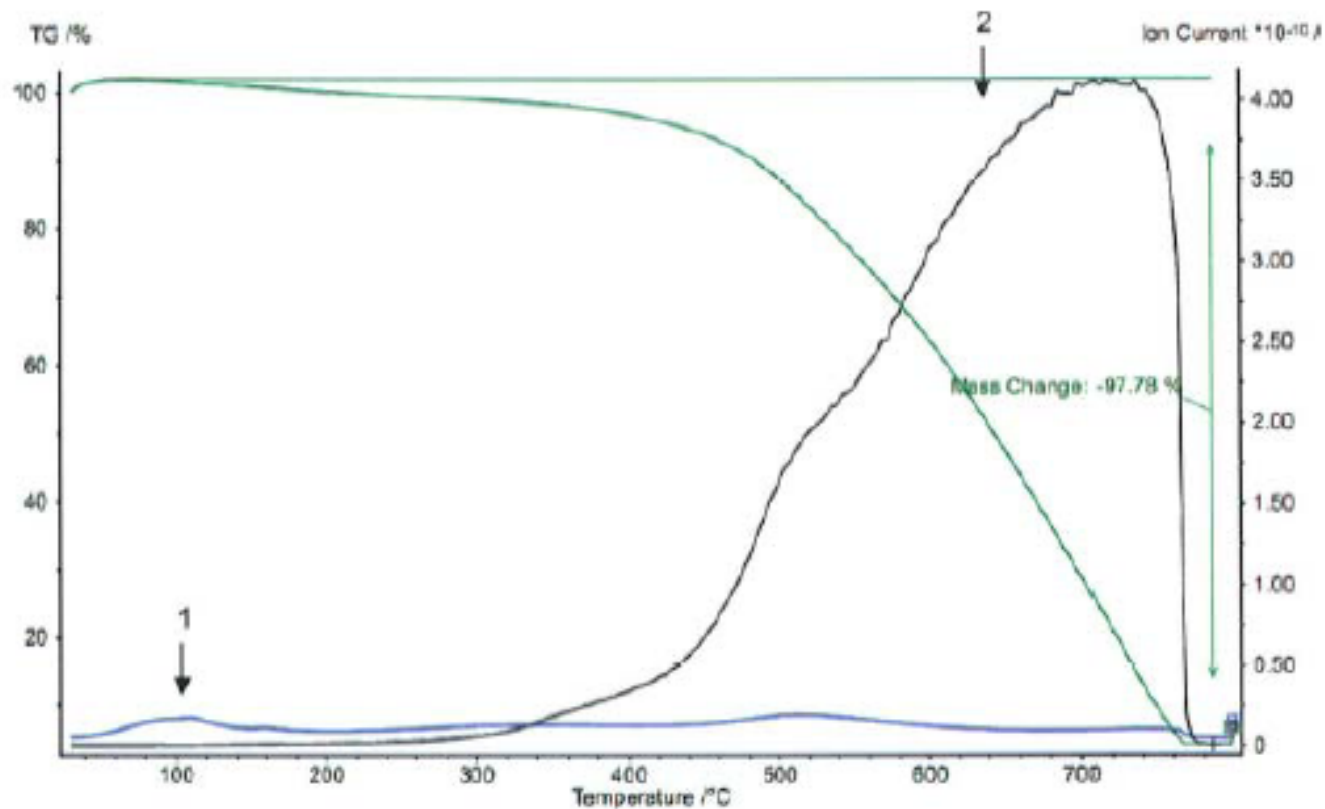
○ Regeneration Technology

Challenge:

- **Combustion temperature must be very high apr. 600° C**
- **This high temperature is practically not present in the exhaust where the filter is located!**
- **Need for Oxygen in exhaust gas > 6 %**

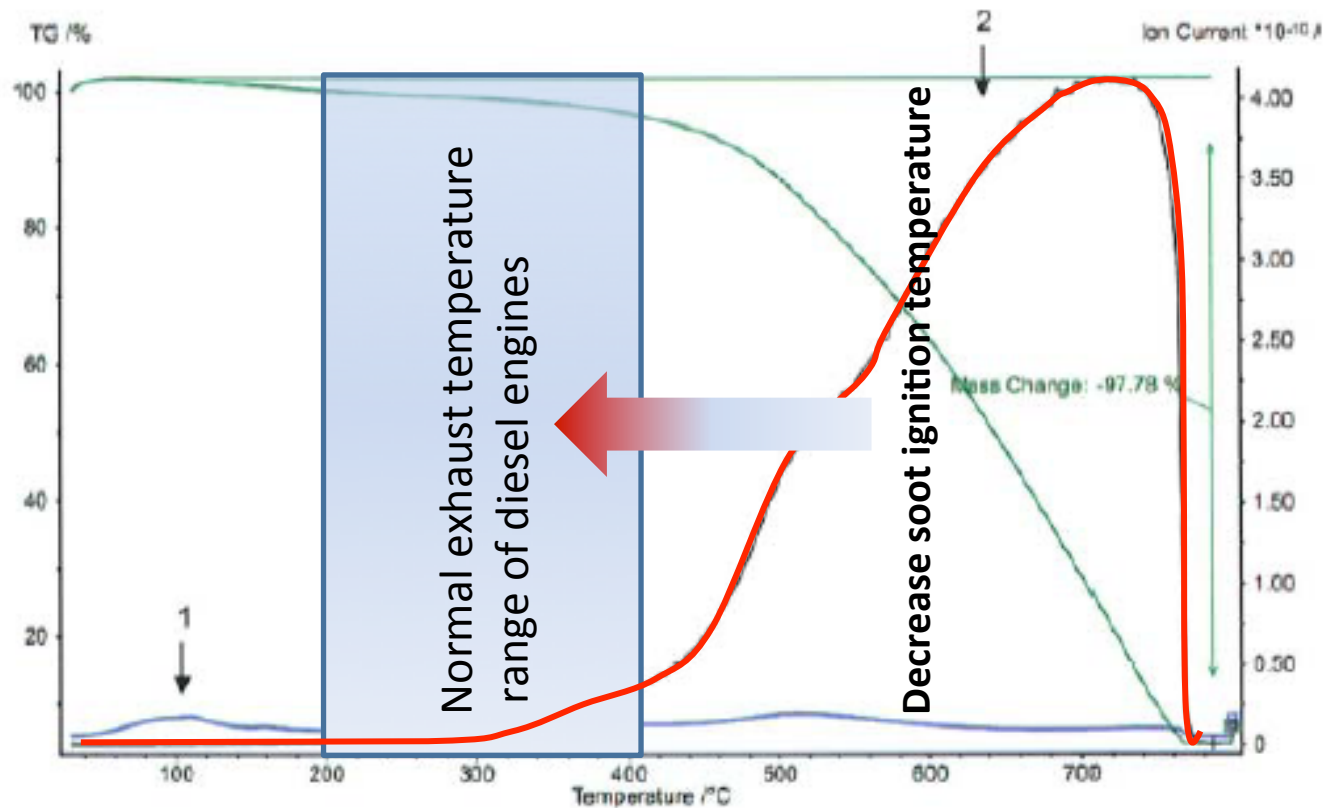
Regeneration Technology

Two options for regenerating the soot:



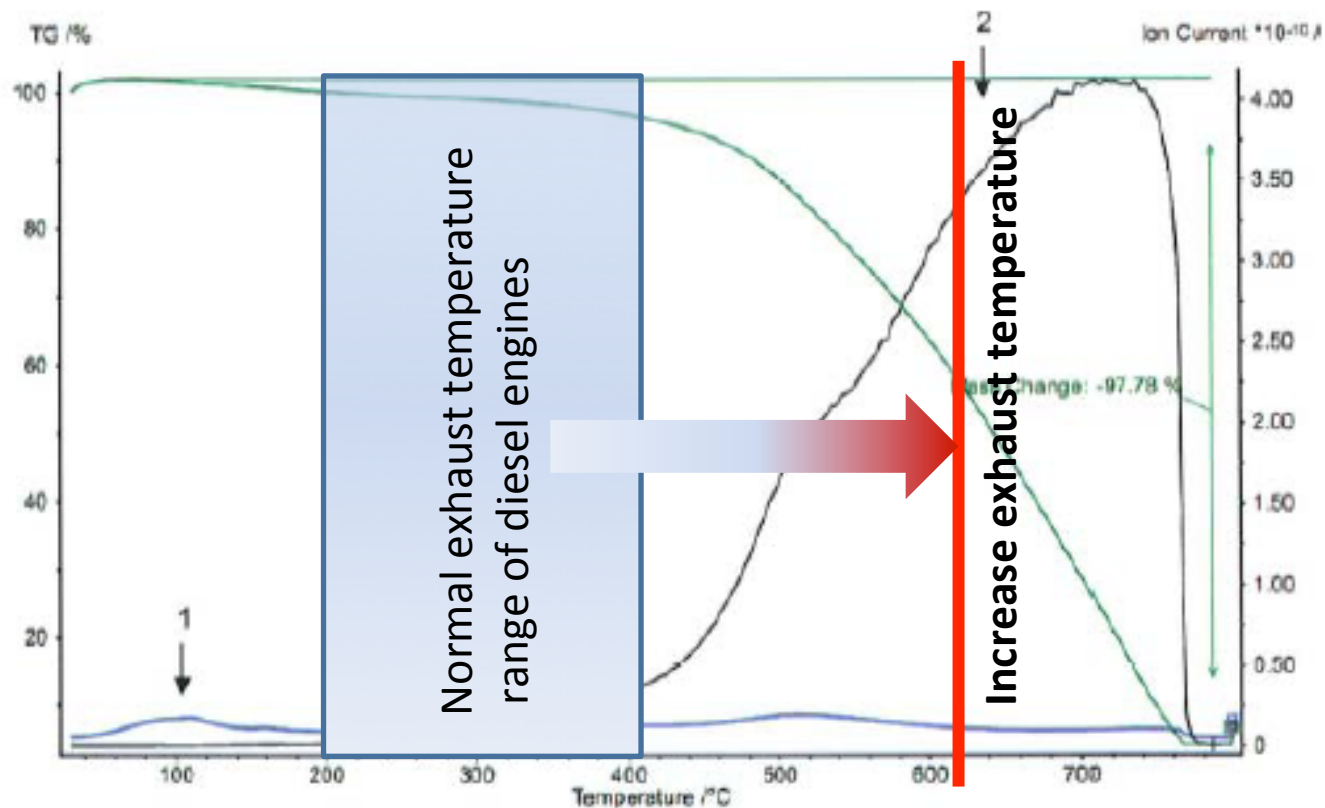
Regeneration Technology

Two options for regenerating the soot:



Regeneration Technology

Two options for regenerating the soot:



○ Regeneration Technology

- **Passive Systems** convert the soot without external energy by using chemical or catalytic effects (Use of catalytic effects to reduce temperature for soot conversion)
- **Active Systems** bring external energy in the system to increase the exhaust temperature to soot burnable level. (Increase exhaust temperature)
- **“Through away”, “Stick on”, “external regenerated”** filter can be used on the engine only until the filter is full of soot. It has treated then and put back again.

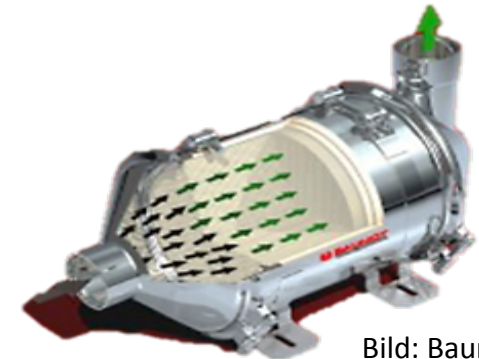
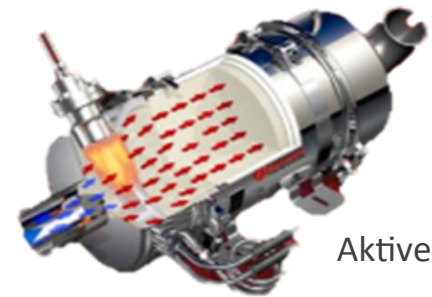


Bild: Baumot AG
Passiver Filter



Aktiver Filter



Stick on Filter

○ Diesel Particle Filter Technologies needs Certification

VERT-Requirements for Best Available Technologies (total 21)

- **Filtration efficiency > 97% for solid particles 20-500 nm**
- **No secondary toxic compounds**
- **Back pressure < 200 mbar**
- **Safe and complete regeneration**
- **No negative impact on noise**
- **No additional risks (heat radiation, visibility,...)**
- **Filter life = engine life**

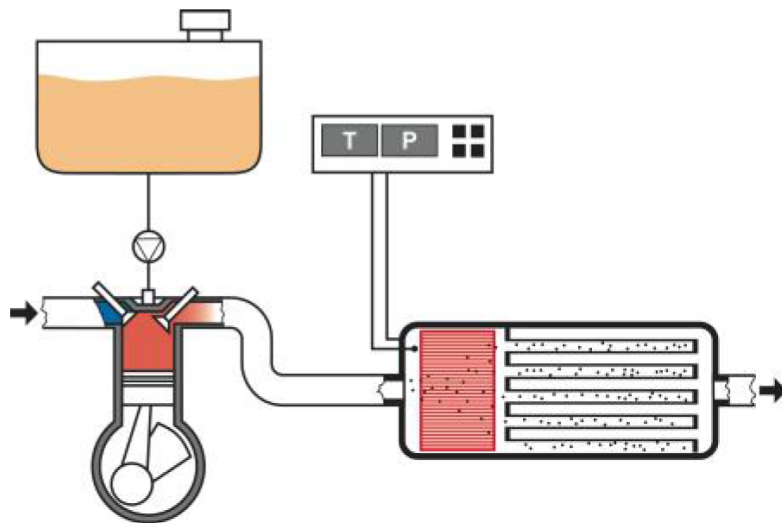


VERT testing is recognized worldwide by

BAFU, SUVA, ASTRA, BAV – Switzerland | AUVA, Wien, Tirol – Austria | BG Bau, UBA, TRGS 554 –Germany |
CARB, MSHA, NY City – USA | VROM – Netherlands | Alto Adige – Italy | Santiago de Chile | DEEP – Canada |
London LEZ – UK | Denmark LEZ | Beijing –China

○ Regeneration Technologies (Passive)

CRT Systems | passive regenerating



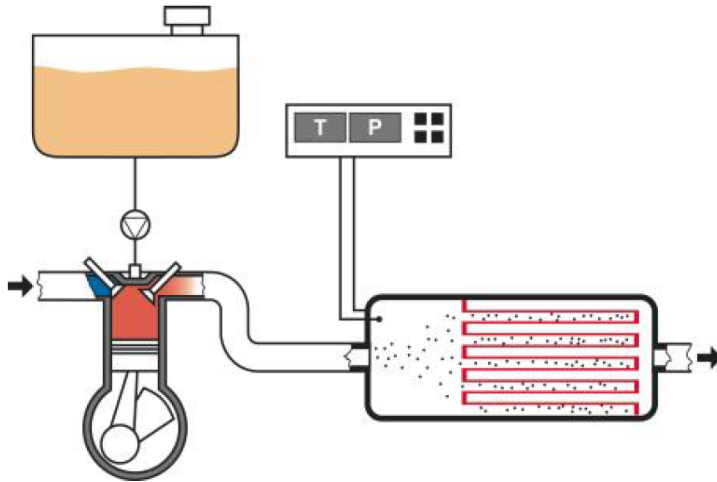
- The NO₂ driven regeneration
- It is generated in the oxidation catalyst from upstream of the filter
- According to the following reaction:

$$\text{NO} + \frac{1}{2}\text{O}_2 \leftrightarrow \text{NO}_2$$
- The soot, which is being trapped in the filter is continuously oxidized by NO₂, as follows:

$$\text{NO}_2 + \text{C} \rightarrow \text{NO} + \text{CO}$$
- Function of regeneration is depending on temperature cycles of the vehicles
- Sensitive against high sulfur (50 ppm)

○ Regeneration Technologies (Passive)

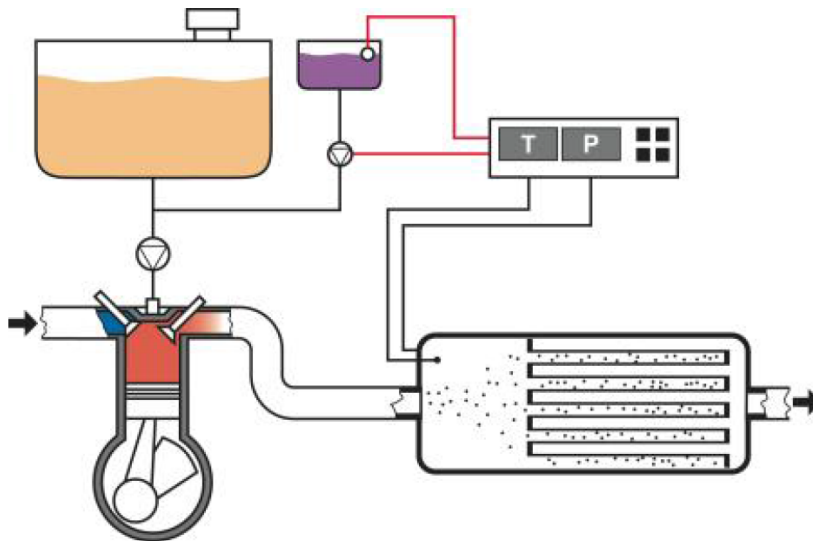
Catalytic Coated Filters | passive regenerating



- Catalytic coated ceramic filter element
- Uses NO₂ and/or O₂ for the regeneration
- Function of regeneration is depending on temperature cycles of the vehicles
- Sensitive against high sulfur (> 250 ppm)
Depending on kind of coating
- Easy to install

○ Regeneration Technologies (Passive)

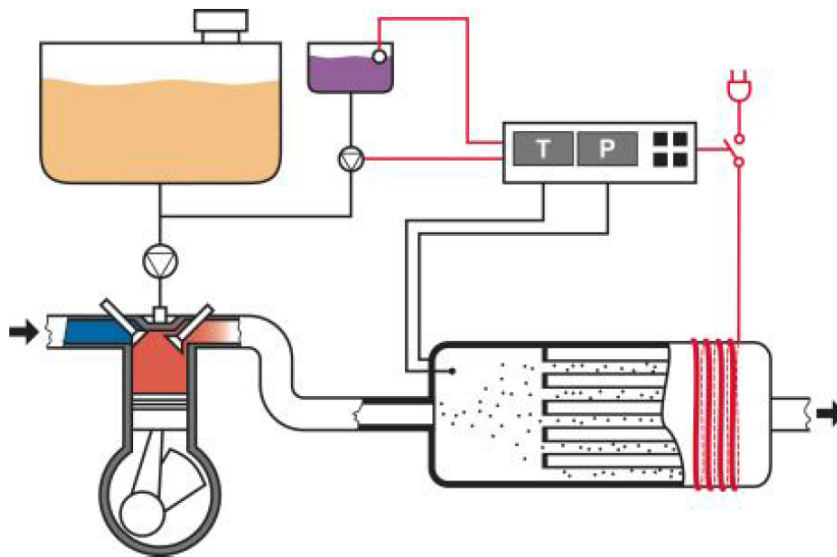
FBC = Fuel Borne Catalyst | passive regenerating



- No catalytic coating, the additive is the catalyst and comes always fresh to the filter
- Need additive on the vehicle, 1 Liter is needed for 1.500 – 2.000 Liter fuel
- Reduces significantly NO₂
- Robust against high sulfur in diesel (up to 7.000 ppm tested in Tabriz)
- Function of regeneration is depending on temperature cycles of the vehicles. Short high temperature peaks are sufficient

○ Regeneration Technologies (Active)

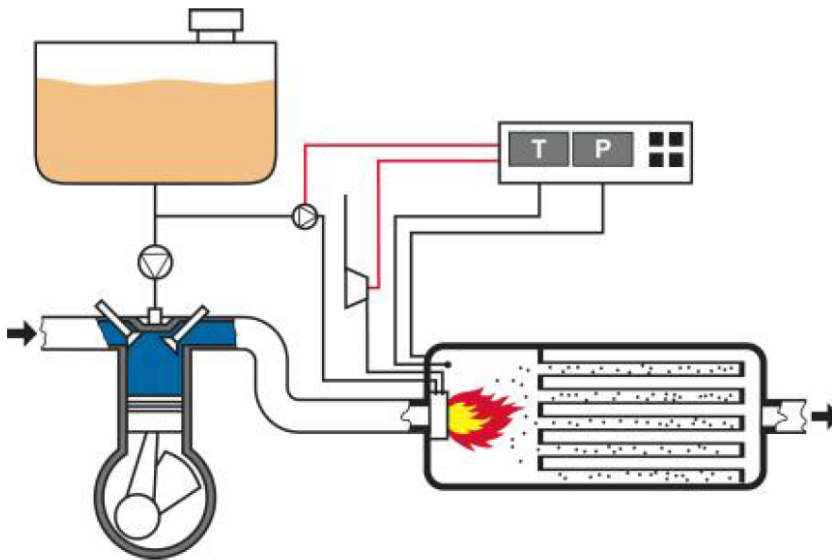
FBC = Fuel Borne Catalyst with electrical ignition (SMF-AR) | active regenerating



- No catalytic coating, the additive is the catalyst and comes always fresh to the filter
- Need additive on the vehicle, 1 Liter is needed for 1.500 – 2.000 Liter fuel
- Reduces significantly NO₂
- Robust against high sulfur in diesel (up to 7.000 ppm tested in Tabriz)
- Works with every temperature profile of the vehicle

○ Regeneration Technologies (Active)

Stand Still Burner | active regenerating



Burns the soot of with a flame

Robust against high sulfur in diesel (up to 7.000 ppm tested in Tabriz)

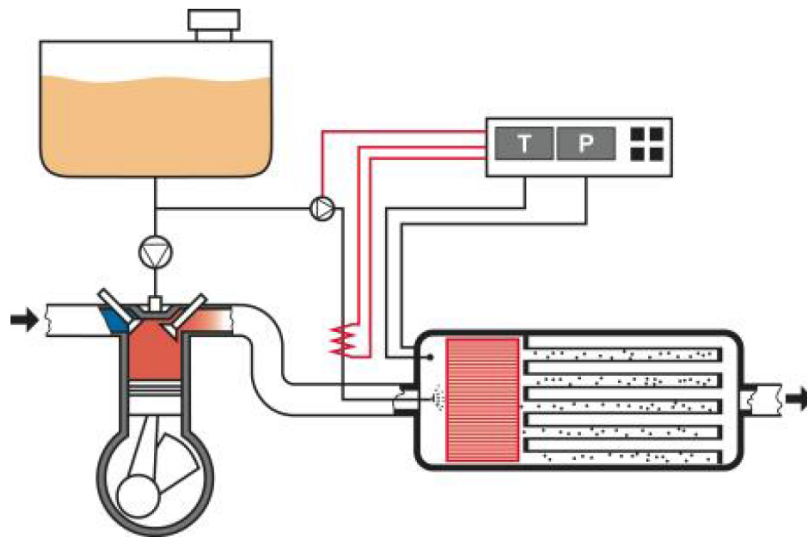
Need downtime (apr. 30 min) when the filter needs to regenerate the soot which can be aligned with driver shift change

Works with every temperature profile of the vehicle

Needs a fuel line from the vehicle to the burner

○ Regeneration Technologies (Active)

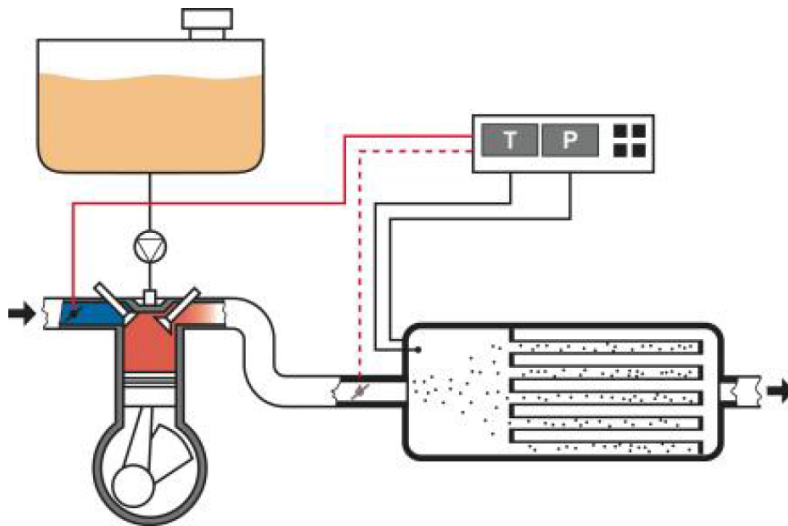
Catalytic Fuel Burner | active regenerating



- Burns the soot of over 600 °C by injection diesel on a catalytic converter
- Robust against sulfur up to 230 ppm in diesel
- Probably not robust against high sulfur diesel > 250 ppm
- No downtime, the burner works under normal operation
- Works with every temperature profile of the vehicle
- Needs a fuel line from the vehicle to the burner

○ Regeneration Technologies (Active Support Function)

Temperature Management by Throttling



- An option for passive systems is a temperature (optional)
- Exhaust temperature can be increased up to 80 °C
- Support a broader application
- Makes passive systems more independent from bus routes
- Reduces additional maintenance due to blocked passive filters

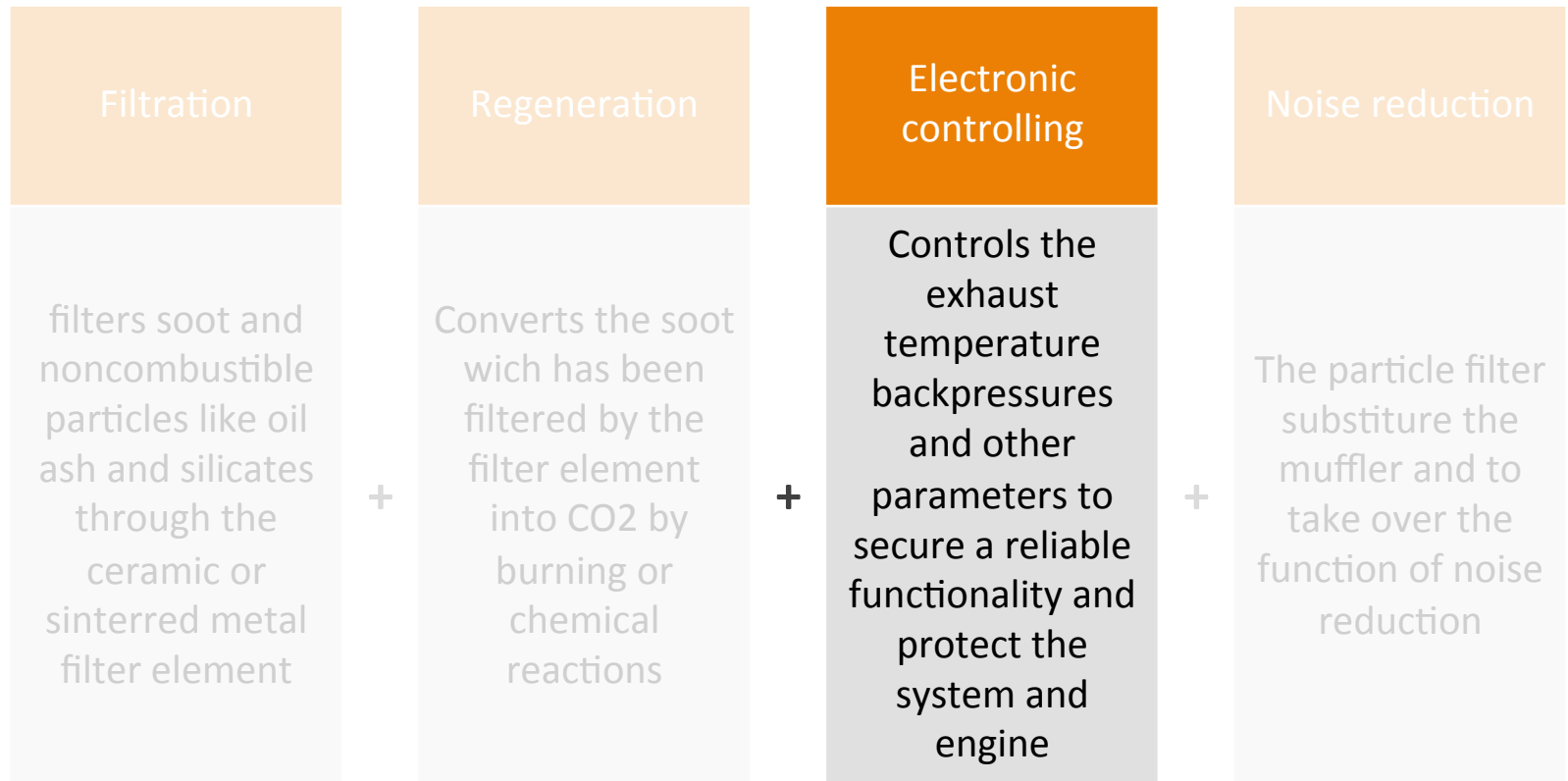
Regeneration Technologies

Technology overview

Properties	Passive Systems			Active Systems		
	CRT System NO2 Rgeneration	Catalytic Coated Filters Oxidative Regeneration	FBC = Fuel Borne Catalysts (Additive)	Stand Still Burner	Catalytic Fuel Burner	FBC plus electrical ignition SMF-AR
Sulfur resistance 50 ppm	yes	yes	yes	yes	yes	yes
Sulfur resistance 250 ppm	uncertain 1)	yes	yes	yes	yes	yes
Sulfur resistance 7.000 ppm	no	no	yes	yes	no	yes
Indipendent on temperature profiles (driving route)	no	no	no	yes	yes	yes
Increase fuel consumption	max 2%	max 2%	max 1...1,5%	max. 3%	max. 3%	max. 1...1,5 %
installation time	half to one day	half to one day	half to one day	one to two days	apr. two days	apr. two days
media for regeneration needed	no	no	additive	diesel	diesel	additive
Filter service needed	apr. once a year cleaning and if the temperature profile is not o.k.	apr. once a year cleaning and if the temperature profile is not o.k.	apr. once a year cleaning and if the temperature profile is not o.k.	apr. once a year	apr. once a year	apr. once a year
Robustness against high engine raw emissions	low	low	medium	high	medium	medium
Regularly inspection and maintenance needed	yes	yes	yes	yes	yes	yes
coordination cost due to limited routes for operation	yes	yes	yes	no	no	no

Technical Concept of a Diesel Particulate Filter

- Particles filters are technical systems to fulfill 4 core functions



○ **Electronical Controlling of the Filter Systems**

- Regeneration of soot needs Onboard Control
- All diesel particulate filters needs electronic controlling to secure the functionality and protect the engine
- Controls minimum backpressure and temperature
- Gives Feedback to the driver and service people

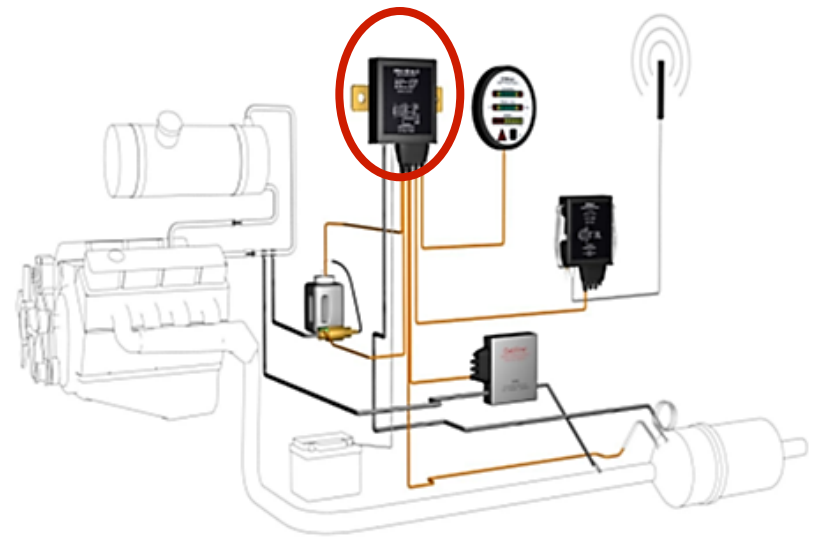
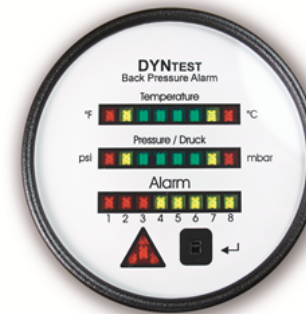
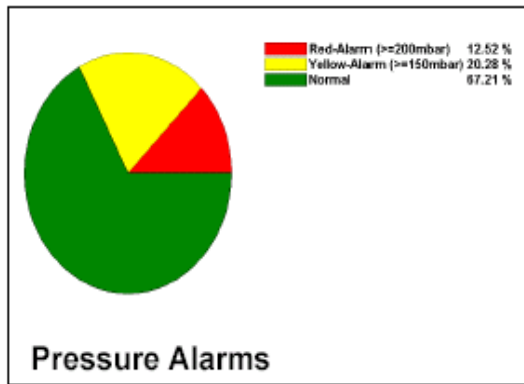


Bild: CPK Automotive GmbH & Co. KG

Electronical Controlling of the Filter Systems



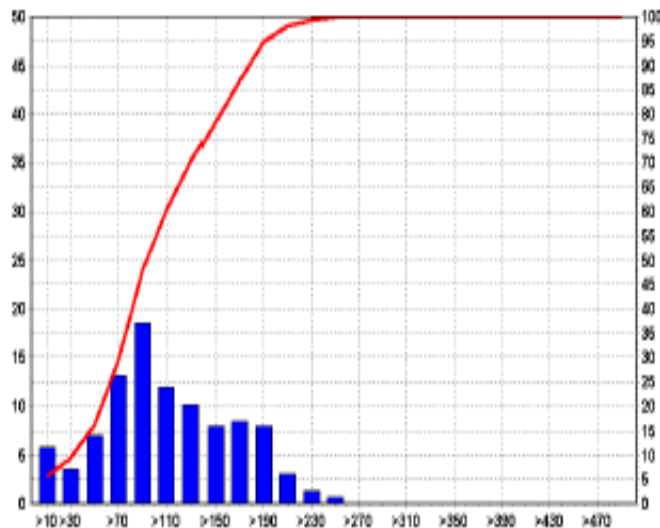
Temperature sensor

Backpressure sensor

DPF Inlet Module with sensor connections


Electronical Controlling of the Filter Systems


Statistical Analysis of the data

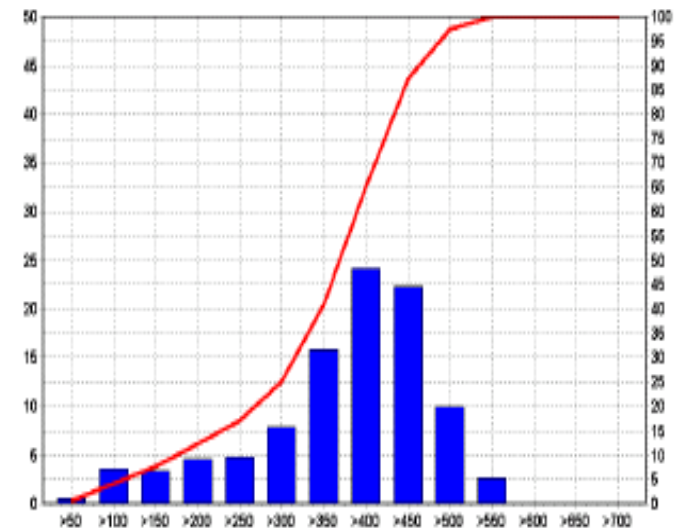


Pressure

Temperature 1

right scale: 
Sum of events
[% of total]

left scale: 
Frequency
[% of total]



Electronical Controlling of the Filter Systems

Examples for simple feedback

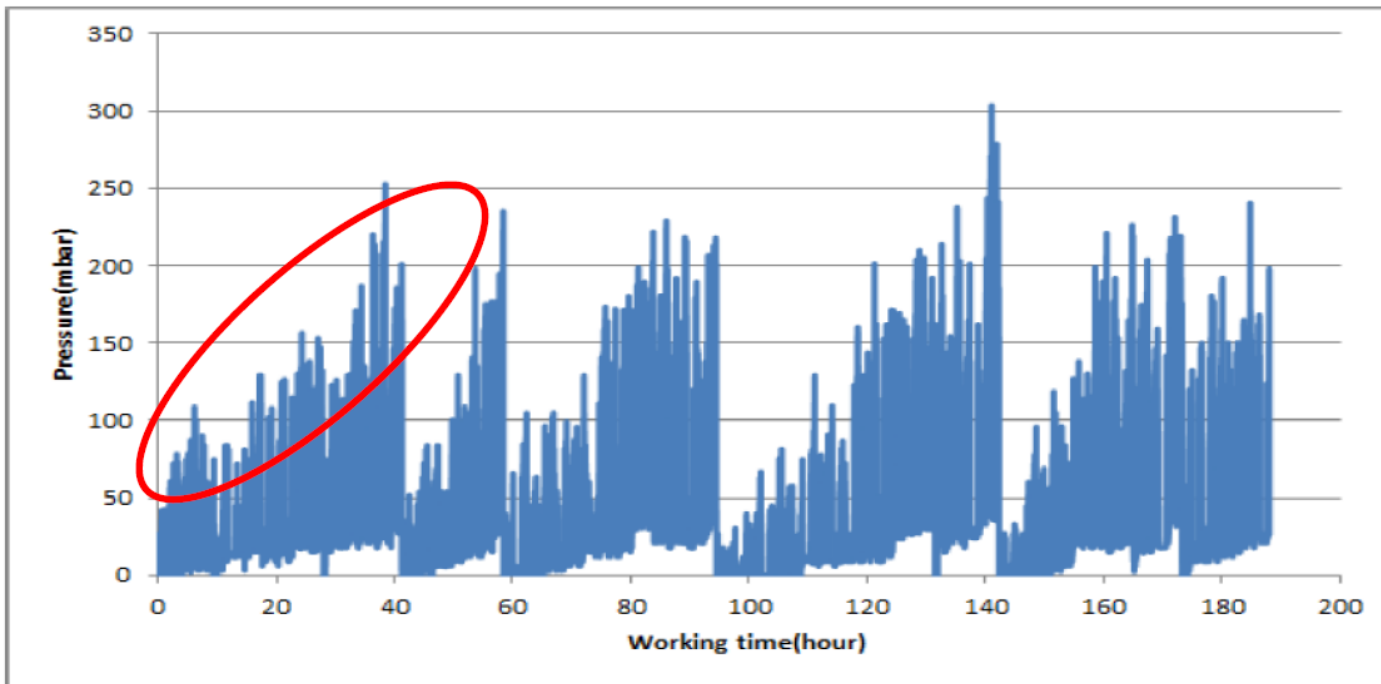
LED-Anzeige



Alarm type	LED-colour
Backpressure „pre alarm“	Orange flashing
To high back pressure	Rot flashing
Filter defect	Red flashing
Sensor defect	Red flashing
Additive level to low	Red flashing
Service needed	Red flashing

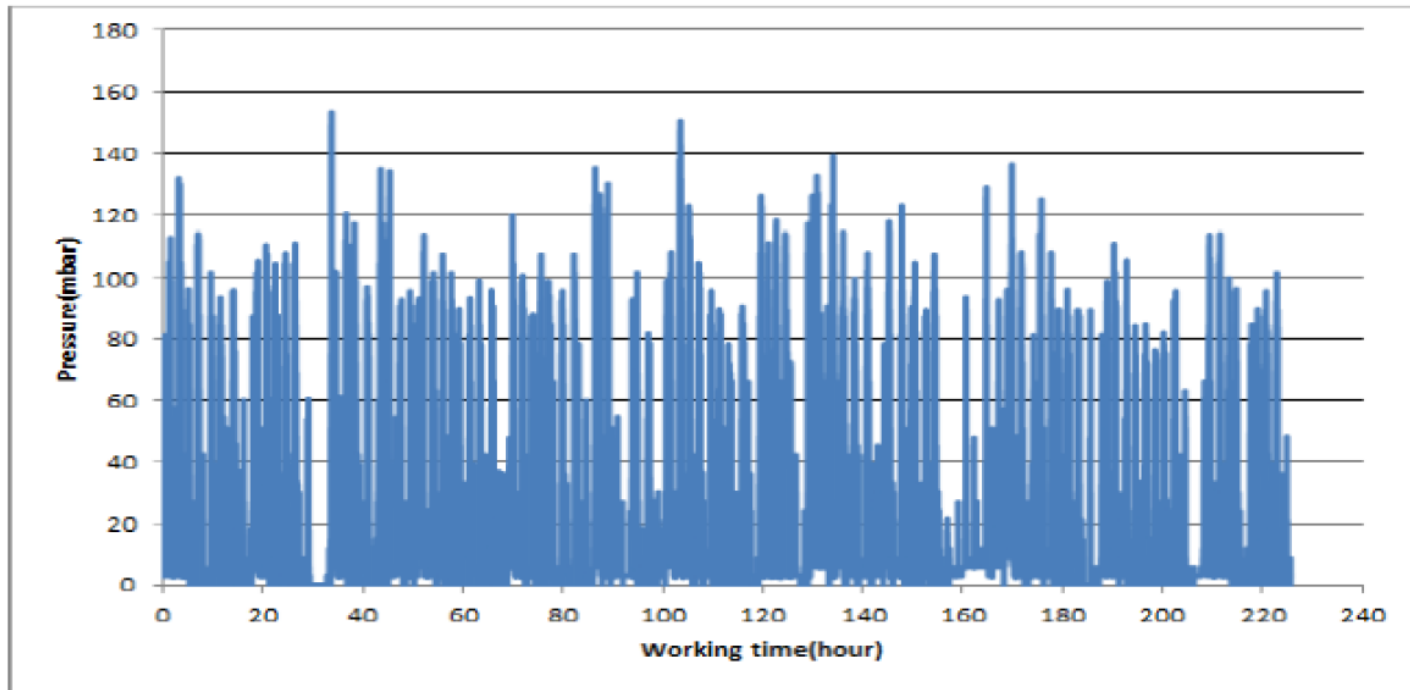
Electronical Controlling of the Filter Systems

Typical back pressure curve of an active system



Electronical Controlling of the Filter Systems

Typical back pressure curve of a passive system



○ Conclusion

Due to **health effects and economical benefits** the **focus should be solid particle** reduction out of diesel engine emissions

EURO 6 values for PN can be reached with DPF , even with retrofitted EURO 3 and EURO 4 engines

Local challenges like high sulphur content in **fuel can be managed with adapted technologies**

Diesel emissions are Carcinogenic. Solutions to eliminate harmful and Carcinogenic substances are available and already in use.
DON'T USE DIESEL ENGINES WITHOUT A FILTER

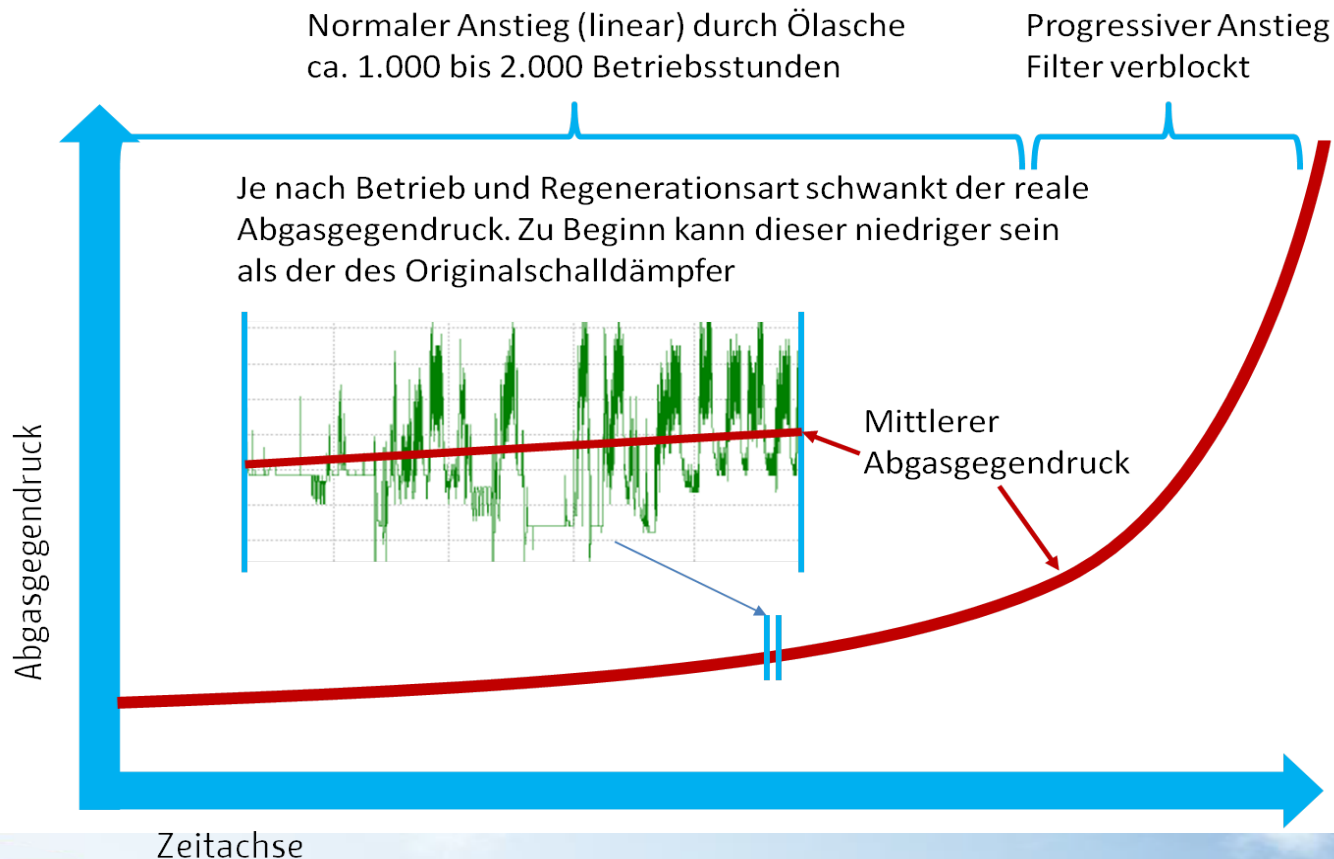


Diesel Particle Filter Technologies

Backup

Wartung und Reinigung

Auswirkung der Laufzeit auf den Abgasgegendruck



Wartung und Reinigung

Reinigung von Partikelfiltersystemen

Filterdefekte

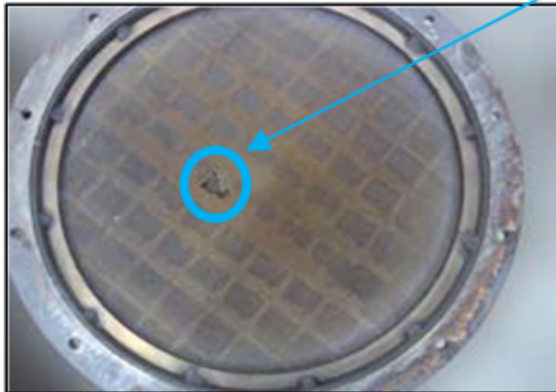


Abb. 28: Beschädigter Filter

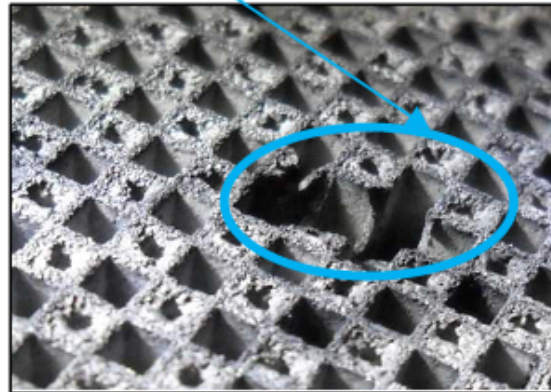


Abb. 29: Beschädigtes Substrat



Abb. 30: Gut gereinigter Filter

Wartung und Reinigung

Reinigung von Partikelfiltersystemen

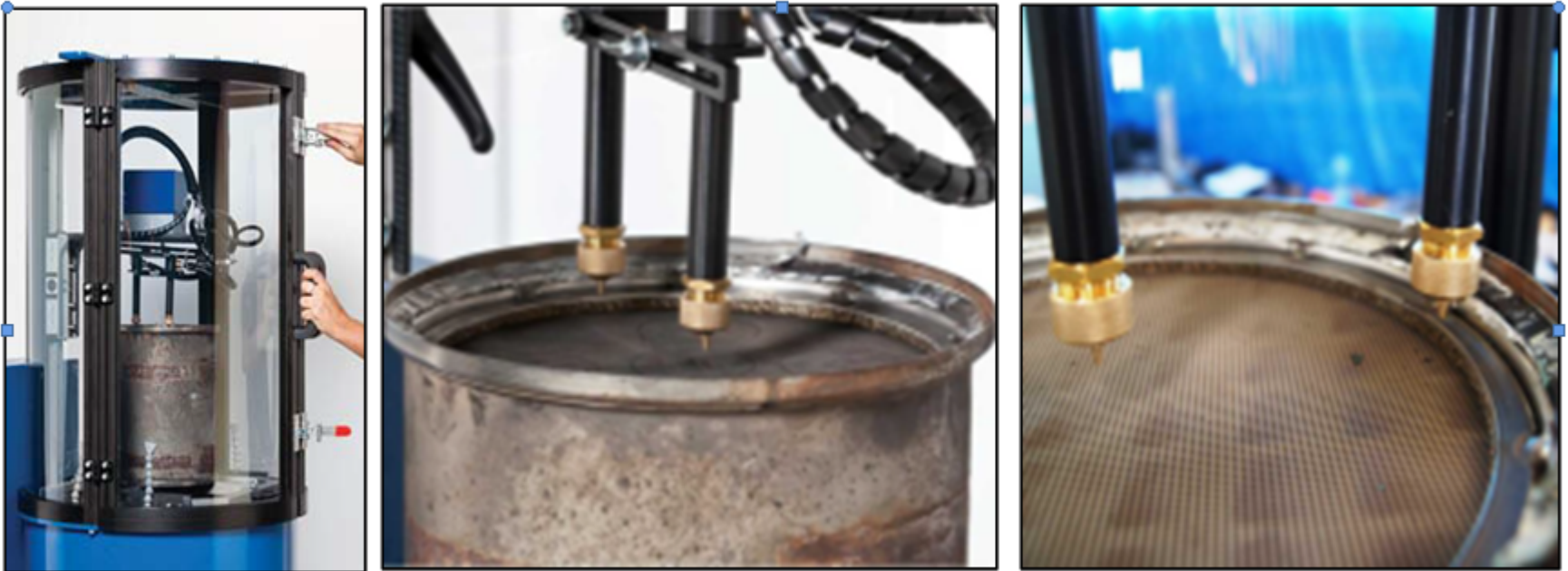


Abb. 31: Beispiel einer modernen Filterreinigungsanlage

Bilder:

PURltech GmbH & Co. KG

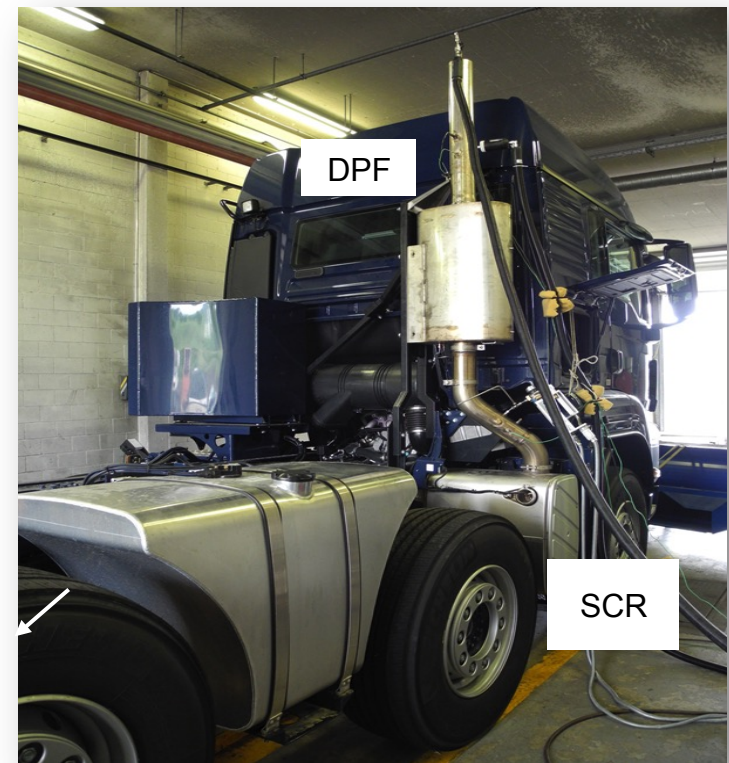
UFP Health Effects and Diesel Detoxification by Particle Filters – VERT Iran Workshop 2016 | Speaker: Volker Hensel

Global Experience with Heavy Duty Diesel Particulate Filters

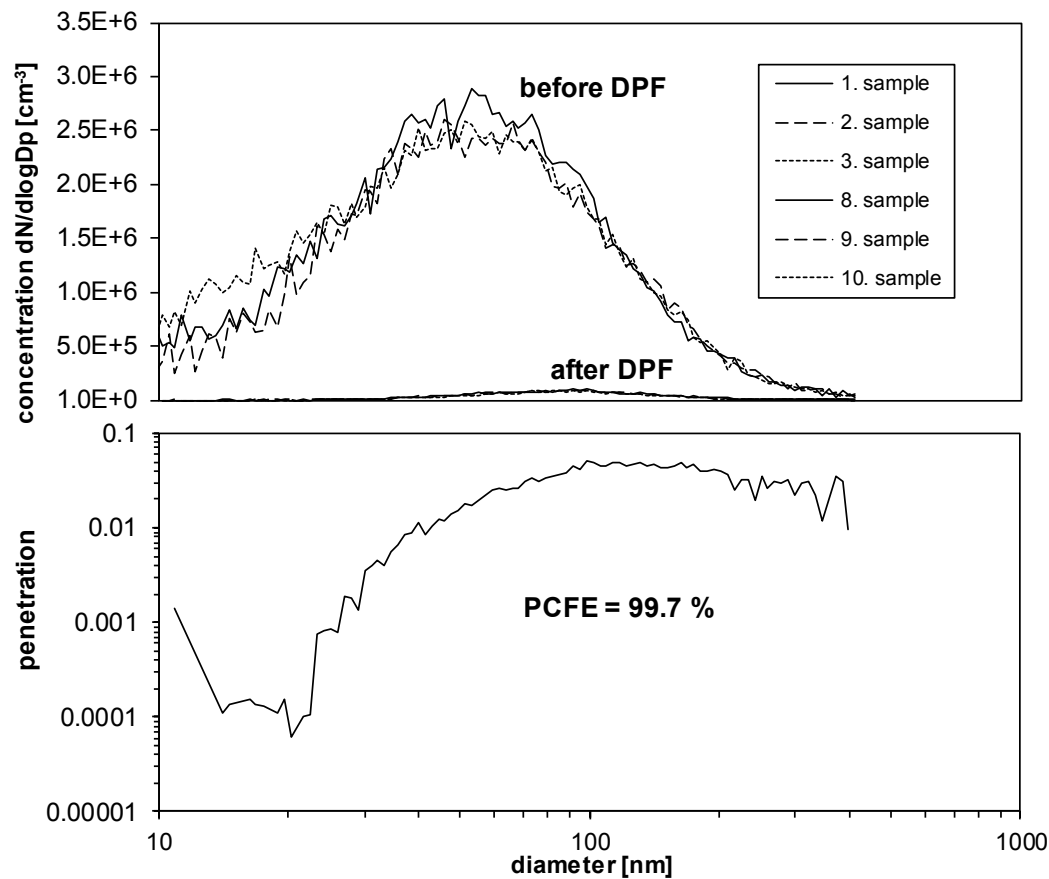
- **USA:** Construction machines in Boston “big dig”, DPF for diesel engines in all metal mines, California retrofit program for in-use heavy duty onroad vehicles, since 2007 all new heavy duty with DPF New York, New Jersey; many activities in cities under local law, large funds for school busses and transit busses > 60.000 DPF
- **UK:** London Low Emission Zone 3 phases –total > 100,000 retrofits, DPF for construction machines in London cross rail
- **Italy:** DPF for LDV and DPF for construction machines in public construction in Südtirol, Low Emission Zones in Lombardia and Emilia Romana, „Decreto“ for retrofit of HDV retrofits in the Milan and Turino area > 15.000 retrofits
- **Netherlands:** Low Emission Zones in all major cities, starting with onroad HDV, nonroad vehicles following
- **Denmark:** retrofit in Copenhagen, LEZ in all major cities > 4.000 retrofits
- **Japan and Korea:** retrofit activity started with bus and truck in Seoul and Tokyo, 2008 intensified, some are partial DPF > 150.000 retrofits
- Today 84 mil. vehicles with DPF in-use.

○ Introduction | Particle Reduction Efficiency - SCR versus DPF

- Vehicle
 - MAN TGS
 - 397 kW
 - 220 km
- Exhaust system
 - OEM SCR
 - DPF retrofitted
- Test parameters
 - SCR dosing activated
 - ULSD
 - Chassis dyno
 - Measurements before and after DPF



Effects on Particle Reduction Efficiency - SCR versus DPF



Source: SAE Paper 2014 -1-1569

J. Czerwinski, Y. Zimmerli/AFHB, A. Mayer/TTM, N. Heeb/
EMPA, H. Berger/ASTRA, G. D'Urbano/BAFU

○ Introduction | Mobility

