Recent Developments in Diesel Engine Emission Control Technology

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Manufacturers of Emission Controls Association
www.meca.org

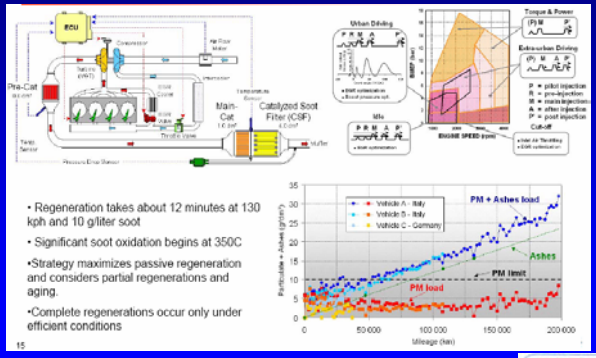
Diesel Emission Control Technology Is Making Significant Progress

- General technology approaches to hitting the regulations
  - Widespread filter usage in Japan and SCR in Europe in 2005
  - Filters provide PM control for U.S. HDE 2007
- Filter technology
  - Reliable regeneration
  - Improved properties; ash storage/management
  - Retrofit experience and options expanding
- NOx solutions
  - SCR is near commercial
  - NOx adsorbers are on HDD engine dynos
- Integrated solutions
  - SCR/DPF are on vehicles
  - LNT/DPF in commercial sales
  - Retrofit options available for combined PM/NOx reductions

Recent Developments in PM Control

- Filters can substantially reduce diesel PM across the full range of particle sizes
- Technology is in the state of optimization and cost reduction
  - Integrating active regeneration
  - Reduced back pressure and size
- Retrofit options expanding

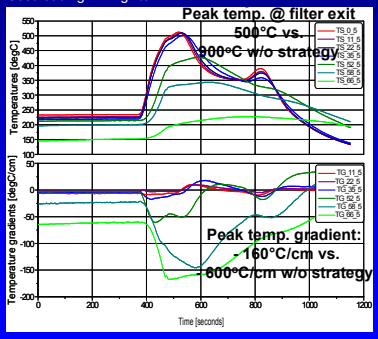
Sophisticated Engine Control Strategies Are Being Developed to Manage Filter Regeneration



Reference: Fiat – FISITA May 2004

Sophisticated Engine Control Strategies Are Being Developed to Manage Filter Regeneration/Temperatures

Soot loading = 14 g/liter



Development of a strategy to avoid uncontrolled filter regeneration during engine deceleration to an idle condition

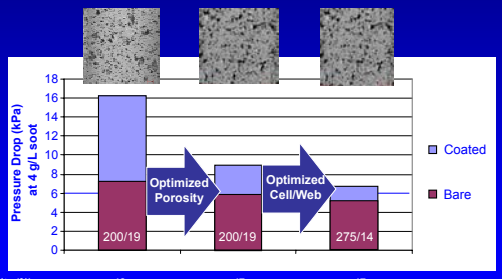
Implementation of additional regeneration control measures:

- Control of the amount of post injection
- Temperature compensation to fine tune the filter inlet temperature
- Adjustment of the mass flow
- Torque compensation

Reference: SAE 2004-01-2657

DPF Substrate Design Optimization Includes Minimizing System Backpressure

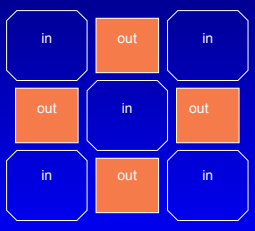
Example: Cordierite DPF Substrate Designs



Porosity (%)	**42**	**47**	**47**
Pore connectivity	**+**	**++**	**++**

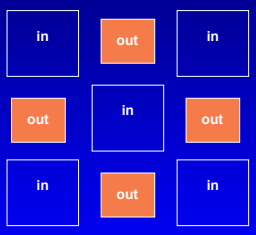
Source: 2004 SAE Commercial Vehicle Congress; Highway Diesel Panel

New Filter Cell Configurations Increase Ash Storage Capacity



Introduced on new 2.7 liter V6 from Peugeot in Europe

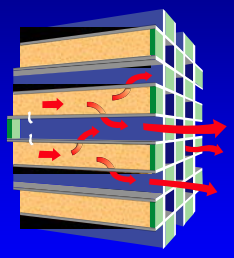
Reference: SAE 2004-01-0949



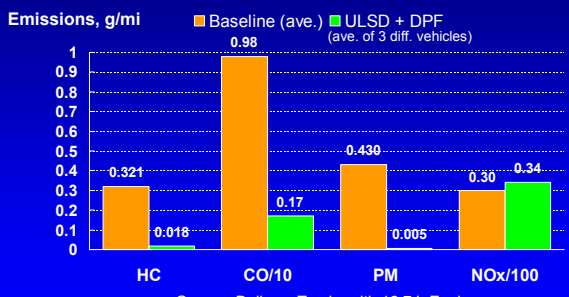
Reference: SAE 2004-01-0948

Diesel Particulate Filters (DPF) for Retrofits

- 175,000+ retrofits worldwide
- Many regions are mandating their use
- Variety of technologies for a variety of applications
- Not universally applicable, but expanded applications and technologies developing



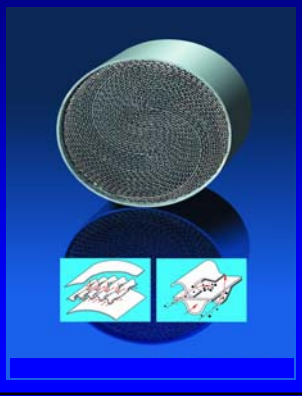
DPFs + 15 ppm S Diesel Fuel Demonstrate High Efficiencies After 400,000+ Miles of Service



Grocery Delivery Trucks with 12.7 L Engines
Emissions Measured Using City-Suburban Heavy Vehicle Route

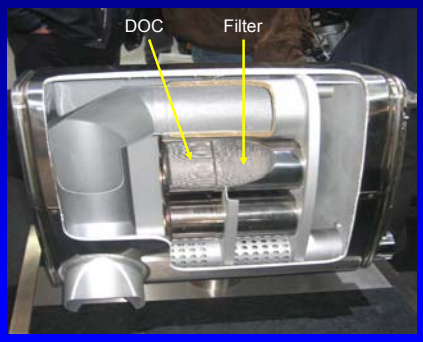
Reference: SAE 2004-01-0079

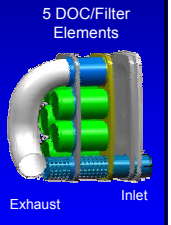
"Flow-Thru" or "Partial" Filter Technologies Emerging for Diesel Retrofits



- Potential for 50-70% PM reduction (Level 2, one technology already verified)
- Can be catalyzed or used with a DOC
- May have applicability on older engines
- Filtering achieved with sintered metal sheets or wire meshes
- Resistant to plugging

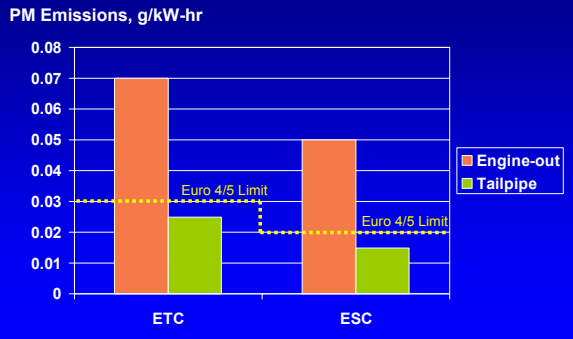
EGR, DOC+Flow-Thru Filter Selected for Heavy-Duty Euro 4 Diesel Application





Source: MAN

Euro 4 Application with Flow-Thru Filter Demonstrates 60-70% PM Reduction



Source: MAN

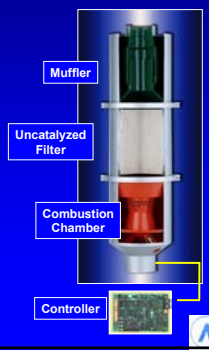
Active DPF Types Available for Low Temperature Exhaust Applications

- Passive DPFs with Electric Assist
  - Uses on-board heaters intermittently in combination with catalyst-based filters or fuel borne catalysts
- Electrically-Heated Active DPFs
  - Regenerated on-board at stand-still or off-board / exchange
- Fuel Burner / Thermal Regeneration
- Air Management with Active Air Intake Throttling to Raise Exhaust Gas Temperature
- Diesel Fuel Injection with a DOC or Catalyst-Based DPF

Examples of Active DPF Technology Options

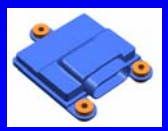
Catalyst-Based Filter with Electric Heater Assist

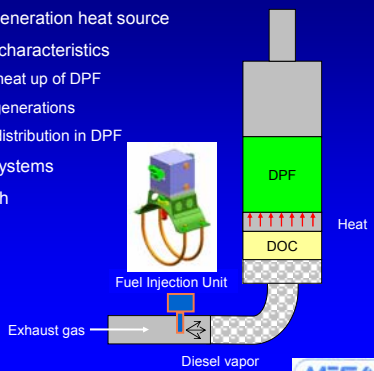
Uncatalyzed Filter with Fuel Burner



Fuel Injection Active Filter Regeneration System

- Diesel fuel provides regeneration heat source
- Preferred regeneration characteristics
  - Faster, more uniform heat up of DPF
  - Quick and efficient regenerations
  - Uniform temperature distribution in DPF
- Compatible with NOx Systems
- Dedicated controller with diagnostic functions



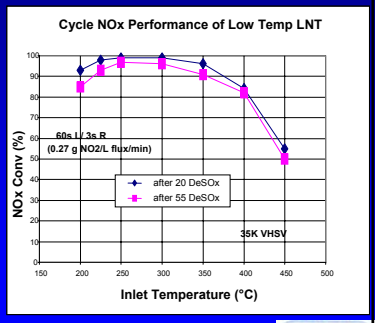


Recent Developments in NOx Reduction Technologies

- Technology development includes:
  - NOx Adsorbers
    - Continued progress on performance/durability
    - Utilizing reformate for enhanced regeneration/desulfation
  - Selective Catalytic Reduction
    - Ready for commercial introductions

Adsorber Performance Window Stable after Multiple Sulfation and Desulfation Cycles

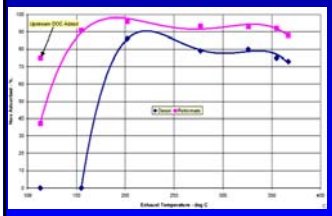
- Low Temperature system has excellent activity window at low SV
- NOx efficiency maintained through end-of-life simulation



Reference: AVECC 2004

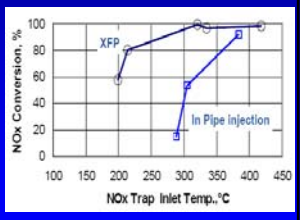
Hydrogen/CO Reformate Significantly Improves LNT Regen. & Desulfation Performance

Plasma reformer uses 250W to form 9% H_2 and 14% CO from 35 kW of fuel; w/ DOC: 20% H_2



Reference: SAE 2004-01-0582

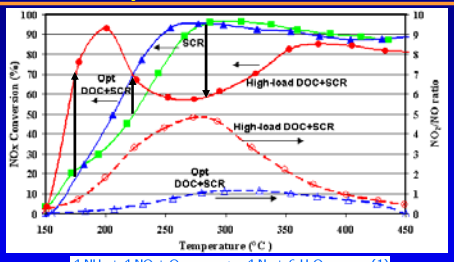
Catalytic reformer operates as low as 200 C to produce pulsed CO/H_2 reformate



Reference: DEER 2004

CO/H2 also shown to significantly lower LNT desulfation temperatures (up to 100 C)

NO_2/NO Ratio Is Important in Achieving Good Low Temperature SCR Performance



fast
slow

$4\ NH_3 + 4\ NO + O_2 \rightarrow 4\ N_2 + 6\ H_2O$ (1)

$2\ NH_3 + NO + NO_2 \rightarrow 2\ N_2 + 3\ H_2O$ (2)

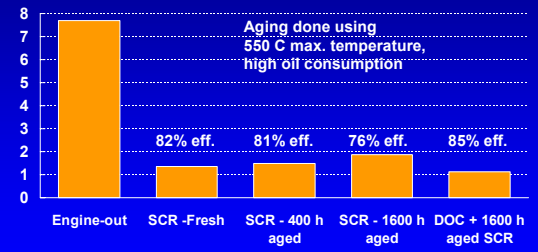
$8\ NH_3 + 6\ NO_2 \rightarrow 7\ N_2 + 12\ H_2O$ (3)

- Reaction 1 is fast, Reaction 2 is very fast, Reaction 3 is very slow
  - low temperature SCR is strongly promoted by NO_2
  - but too much NO_2 can cause problems

Reference: SAE 2004-01-1289

SCR Applications for 2005 Euro 4 Heavy-Duty Standards: High Performance & Durability

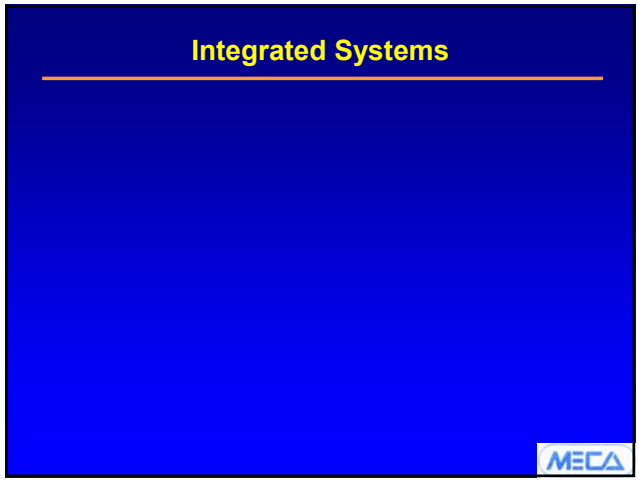
NOx Emissions, g/kW-hr



8.5 liter SCR catalyst evaluated on a 10 liter engine;
Aging estimated to be equivalent of 1.2 million km

Reference: SAE 2004-01-1791

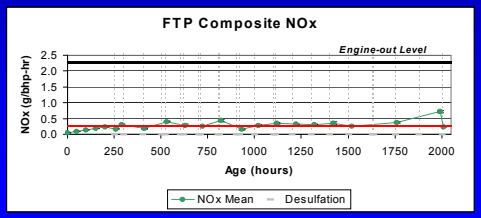
Integrated Systems



HDD DPF/LNT Demonstrates 90% NOx Efficiency after 2000 Hours of Aging

Device	Dimensions (Diameter x Length)	Volume
Upstream DOC	12" x 6"	11.1 L
DPF (x2)	12" x 14"	25.9 L (51.8 L total)
NO_x Adsorber Catalyst (x2)	12" x 12"	22.2 L (44.4 L total)
Clean-up DOC	12" x 6"	11.1 L
	Total Volume:	118 L

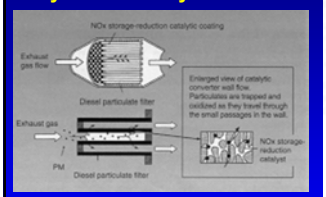
15 liter 475 hp 2004 Cummins engine. SVR DPF = 3.5; SVR LNT = 2.9

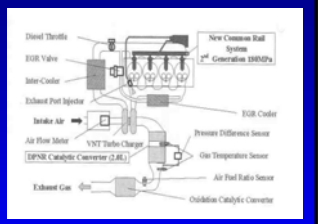


23 desulfations at 675 C and λ<0.9 for 30-60 minutes; 4.5% cycle average fuel penalty; 15 ppm sulfur fuel (Reference: DEER 2004)

Catalyst Integration for NOx Adsorbers and Filters Is Commercial

Toyota DPNR System



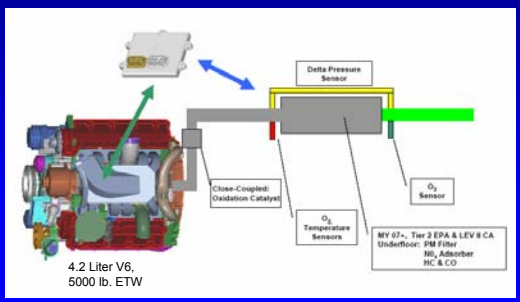


- NOx adsorber catalyst is coated directly on wall-flow filter
- "Active oxygen" aids filter regeneration
- First commercial applications:
  - Euro passenger car (2.0L): 0.12 g/km NOx (50% of Euro IV); 0.002 g/km PM
  - Japanese light-duty truck engine (4.0L)

References: SAE 2004-01-0578 and 2004-01-0579

Prototype V6 Diesel Demonstrates Full Useful Life Bin 5 NOx Performance with DPF/LNT System

- 0.074 g/mi NOx demonstrated after 68 deSOx cycles (equiv. to 150K miles)



4.2 Liter V6, 5000 lb. ETW

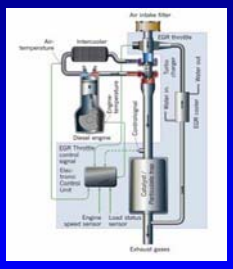
Source: Cummins 2004 DEER

Integrated Solutions for Combined PM/NOx Reductions Available for Retrofit

Lean NOx Cat. + DPF or DOC
– 25-35% NOx reduction

Emulsified Diesel Fuel + DOC or DPF
– 15-40% NOx reduction

Low Pressure EGR + DPF
– 40-60% NOx reduction



Verified Retrofit SCR Systems Expected In the Near Future

Future Diesel Technology May Approach PZEV Near Zero Emission Levels

Mercury Meta One
Diesel Hybrid Concept

Photo from www.ford.com

Meta One Exhaust Manifold with Advanced DOCs

- Diesel hybrid powertrain (2.7 liter V6 diesel engine)
- Incorporates state-of-the-art diesel emission control technologies to reach PZEV emission levels: Advanced DOCs (pre-turbo), DPF, SCR, air-gap exhaust network, NOx sensors

Reference: Ford January 3, 2005 Press Release

Conclusions

- All Major Markets Moving to Tight PM and NOx Emission Standards for Diesel Engines
- A Variety of Technologies Are Available and Emerging for PM, NOx, and Toxic HC Emission Control for Both Diesel Light-Duty and Heavy-Duty Vehicles
- Retrofit Experience Is Growing Worldwide with a Variety of Technology Options Available for Controlling PM and NOx Emissions from On- and Off-Road Diesel Engines
- Technologies Are Advancing and Recent Developments Indicate that HDDE 2007/2010 and Tier 2/LEV 2 Emission Levels Will Be Achievable
- On-Road Diesel Technologies Will Migrate into Nonroad Diesel Applications
- The Ultimate Solution to Reducing Emissions from Diesel Engines Requires a Systems Approach Utilizing Advanced Engine Designs, Advanced Integrated Emission Control Technology, and Low Sulfur Diesel Fuel

Retrofit Discussion Topics/Questions

- EPA's International Retrofit Projects
  - How can EPA & MECA work together to ensure the effectiveness of such programs?
  - How can domestic & international retrofit projects be used as models to minimize pilot program proliferation?
  - How can international interest in retrofits be turned into "real" programs?
- EPA's Retrofit Verification Program
  - Where are there opportunities to shorten the pathway for verification without compromising real emission benefits?
  - Is the new non-road transient test cycle the test cycle of choice for non-road retrofit verifications?

Retrofit Discussion Topics/Questions

- EPA/ARB Retrofit Verification Reciprocity
  - What are the guidelines on current reciprocity decisions?
  - How can technology developers take advantage of test data developed as a part of the current ARB verification program for EPA verification approval?
  - Is there value in joint discussions between EPA, ARB, and MECA on verification procedures, common data submission procedures, etc.?
- EPA's Stated Goal to Retrofit All Diesel Engines by 2015
  - How can retrofit incentives be expanded?
  - Does EPA believe that this goal can be met under a strictly voluntary effort?

MECA