Potential Effects of Mixed Mode Combustion on Diesel Particulate Filters

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Summary

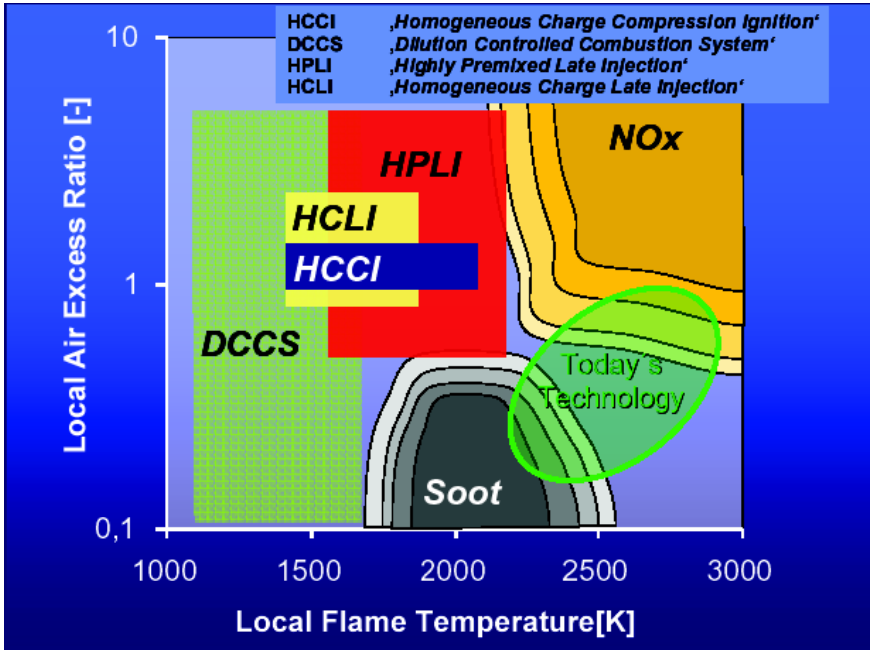
Engine technology is moving towards mixed mode control. Advanced combustion at low load, traditional diesel combustion at high load.

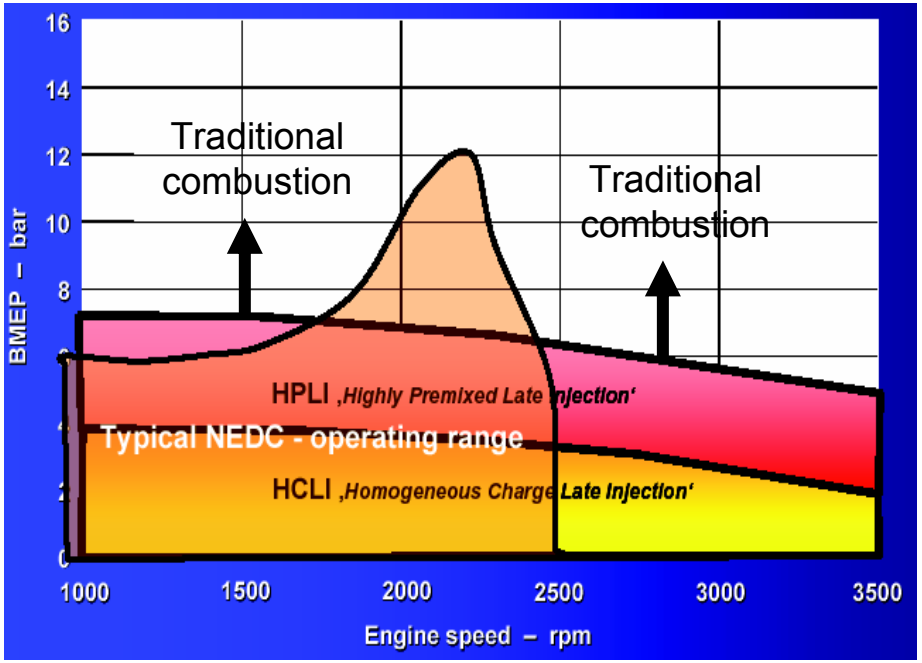
- Combustion characterized by high HC and CO, low PM, and low NOx
- With mixed mode combustion, filter regeneration can largely be passive.
  - Very little PM generated at low load – reduced burden on active regeneration
  - High load will largely be passive, like today
  - If regeneration is needed at low load, HCs and CO are available
    - Potential for more passive regeneration
- Integrated PM and NOx control enhanced with mixed mode combustion.

Engine Technologies – Mixed Mode Combustion

Alternative combustion strategies are moving forward in many varieties.

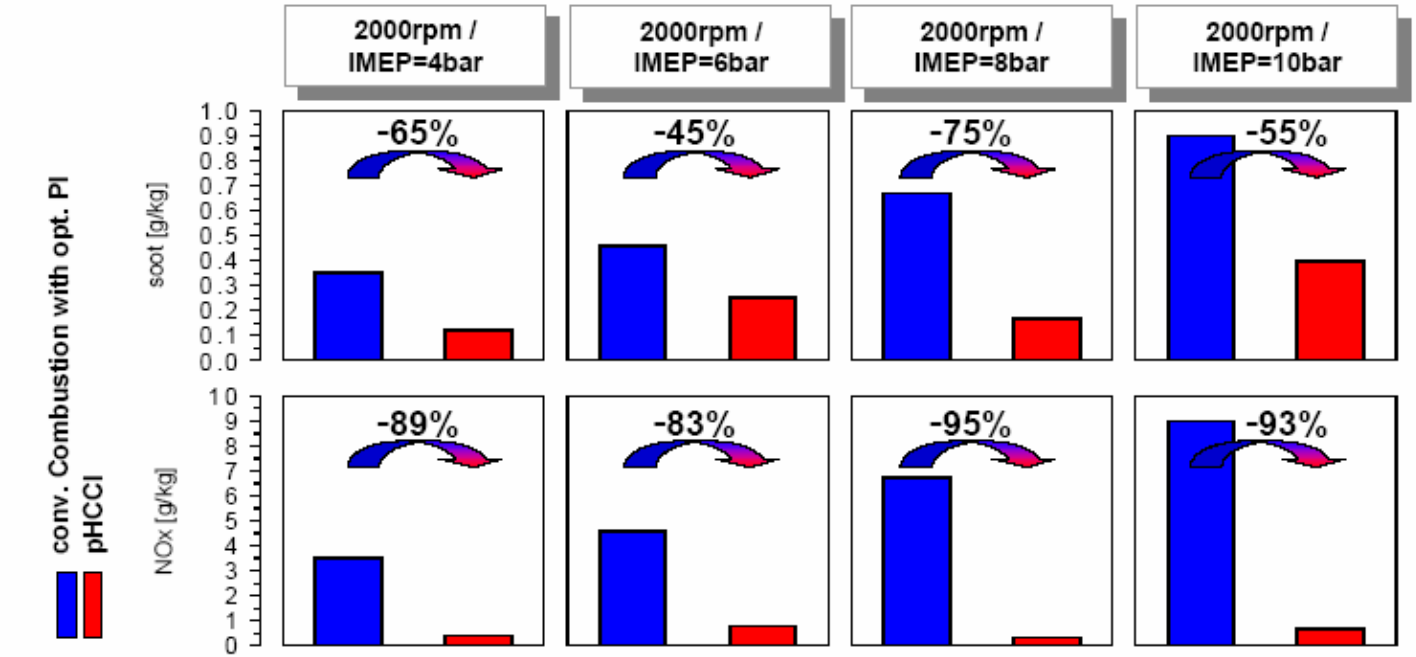
AVL DEER 9-03





- Application of pre-mixed combustion at low load minimizes low temperature PM and NOx, but delivers higher HC and CO
- Everything changes: LT HC and CO control, minimal DPF management at LT, and little or no LT NOx treatment needed
- Driven by low NOx regulation – US Tier 2, and maybe US2010 and Japan 2009 HD

Emission comparisons and fuel penalties for advanced combustion are shown as a function of load

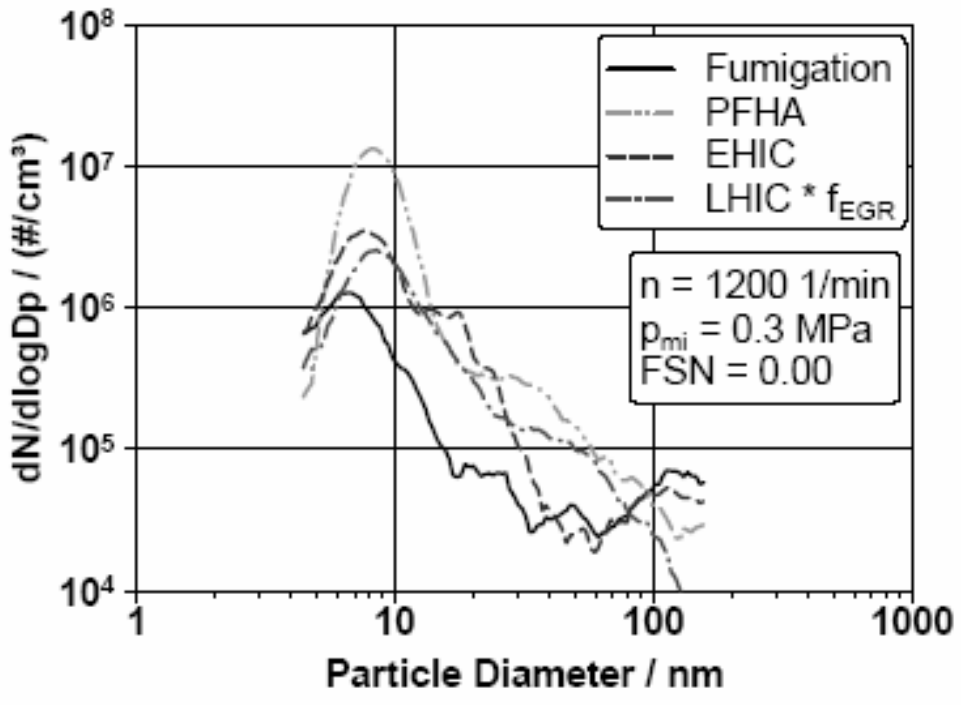


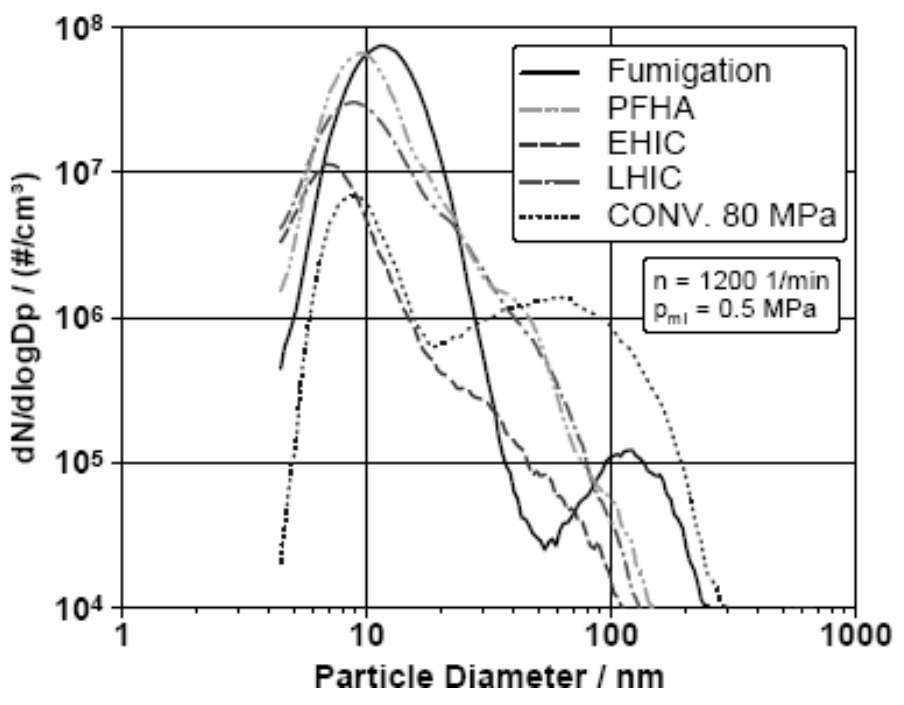
	2000rpm / IMEP=4bar		2000rpm / IMEP=6bar		2000rpm / IMEP=8bar		2000rpm / IMEP=10bar	
EGR [%]	37	54	26	41	17	47	9	33
HC [g/kg]	0.8	6.3	0.4	1.1	0.2	2.2	0.1	0.9
CO [g/kg]	7.7	117	4.4	24.3	3.8	57.7	4.2	23.4
noise [dB(A)]	87.2	88.9	88.1	92.9	89	89.4	88.4	91.5
isfc [g/kWh]	213	214	213	216	215	214	213	223

NOx/soot ratios go down with advanced combustion, but HC and CO go up. Effect on DPF regeneration at low load?

Bosch, Hyundai Symposium 10/04

Pre-mixed combustion has perhaps 90 to 99% less soot particles than conventional diesel. Nucleation mode is high.





PFHA: port fueled hot air

EHIC: early homogenization in-cylinder

LHIC: later homogenization in-cylinder

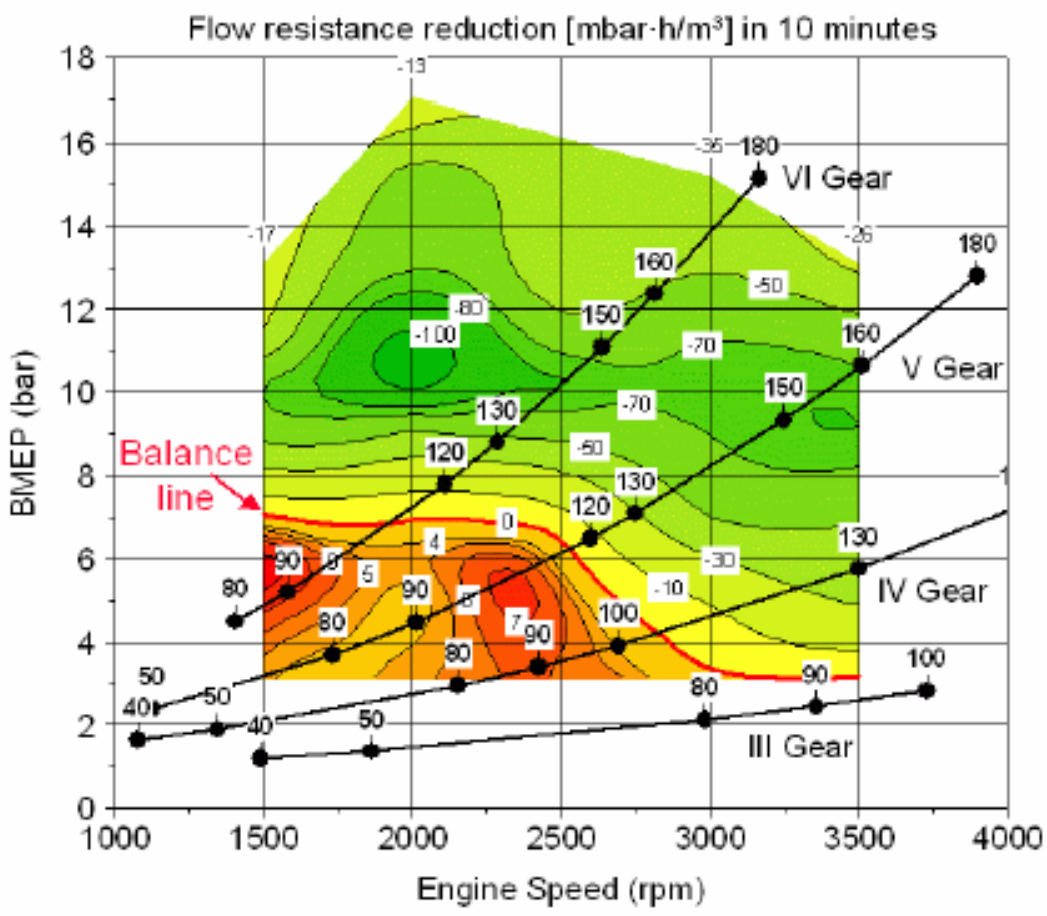
TU Braunschweig SAE 2001-01-3576

CORNING

Effect of Mixed Mode Combustion on DPF Management

Today, in the upper part of the load range, filter regeneration is largely passive

Traditional Diesel Combustion



Above the “balance line” is passive regeneration using DOC+CSF. 1.9 liter CR DI engine, D-Class vehicle, contours are 10 minute backpressure changes at 10g/liter soot. Fiat FISITA 5/04.

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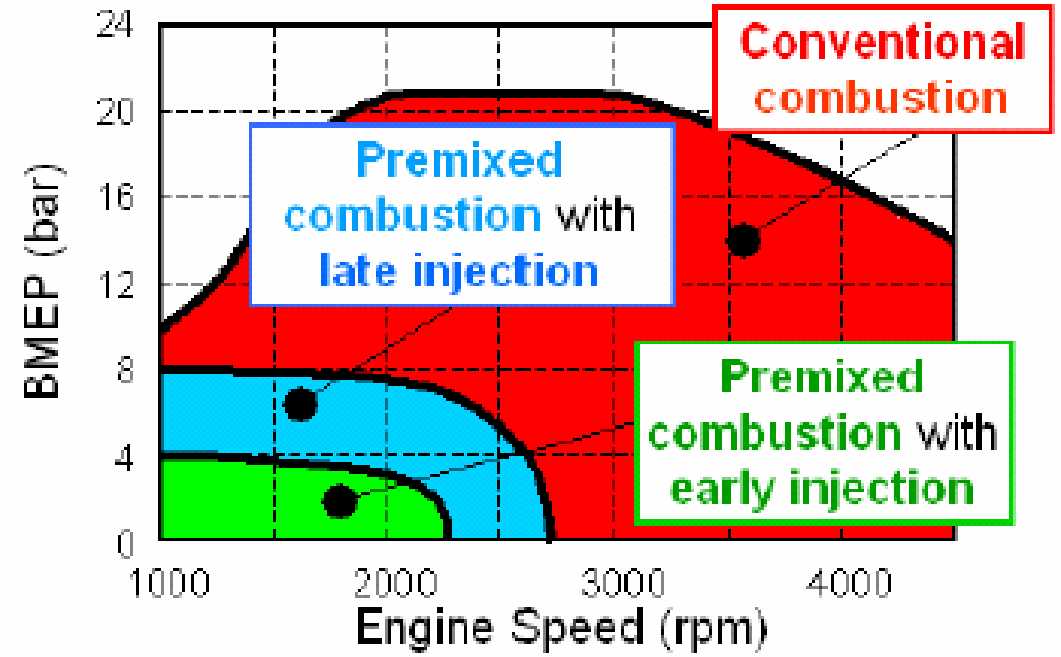
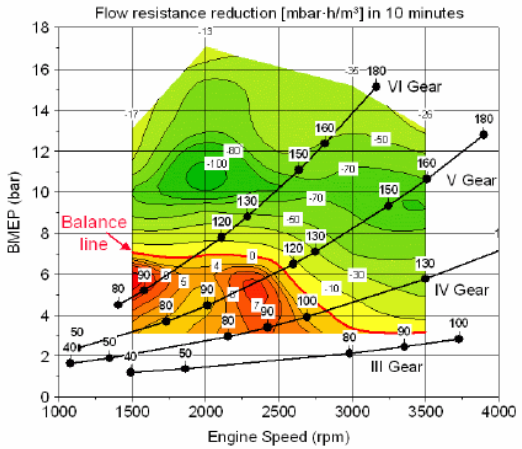
Advanced combustion strategies can occupy the regimes of active regeneration at lower load





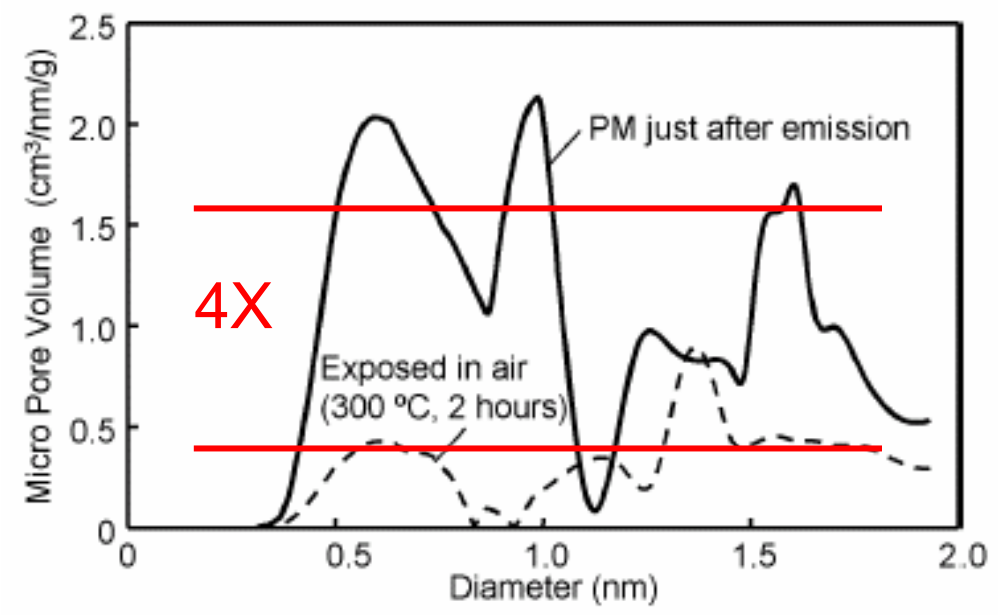
"Pre-mixed late": -60% PM vs. traditional; same NOx:C

Pre-mixed early: -30% PM; -70% NOx:C

As PM production rates go down, region of active regeneration (red on previous slide) probably gets smaller. Caveat: Is regen. impact of lower NOx and lower temperature offset by higher CO and HC?

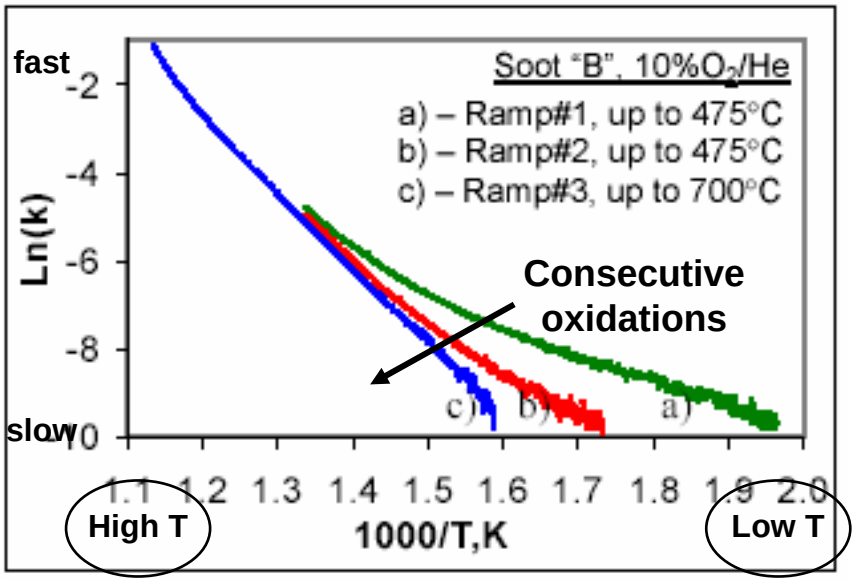
Fiat, ATA Conf, 10-04

Fresh soot is easier to oxidize. It might burn continually in the presence of enough HC and CO.



Fresh soot has more micropores than older soot

Toyota SAE 2002-01-0957



Fresh soot is more reactive than older soot

Cummins, SAE 2003-01-0833

In LNT systems, the rich pulse results in more-active soot.

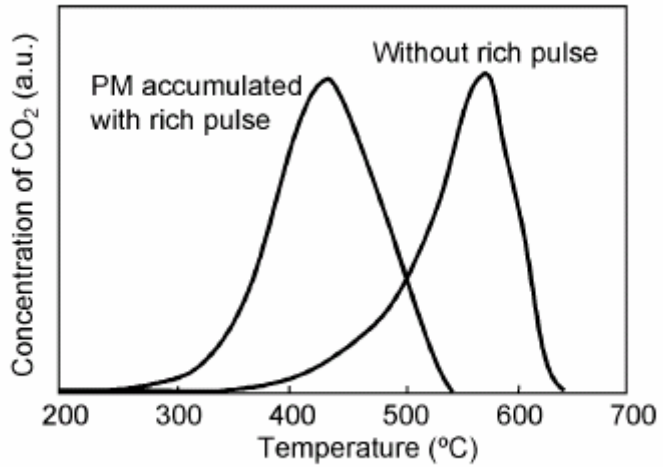


Figure 14 Oxidation characteristics of PM trapped both with and without rich pulse

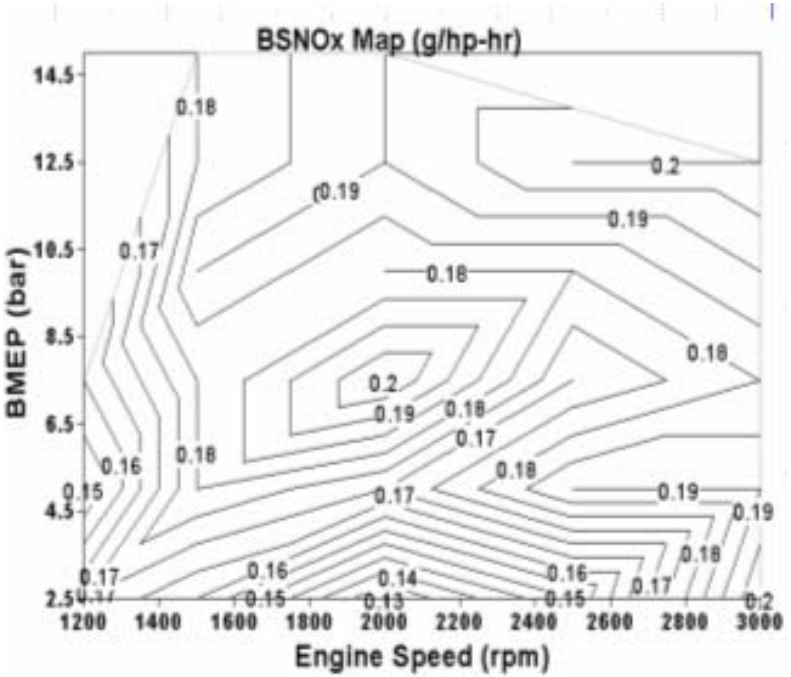
PM was accumulated using rich pulses and steady lean, and then oxidation temperatures of soot were measured. PM collected under rich pulse is more active.

the disorder of PM surface decreases in lean exhaust gas and it causes the lowering PM oxidation activity. However, air fuel ratio modulation keeps PM oxidation activity high. This phenomenon can't be explained as the effect of local temperature rise and catalytic activity improvement.

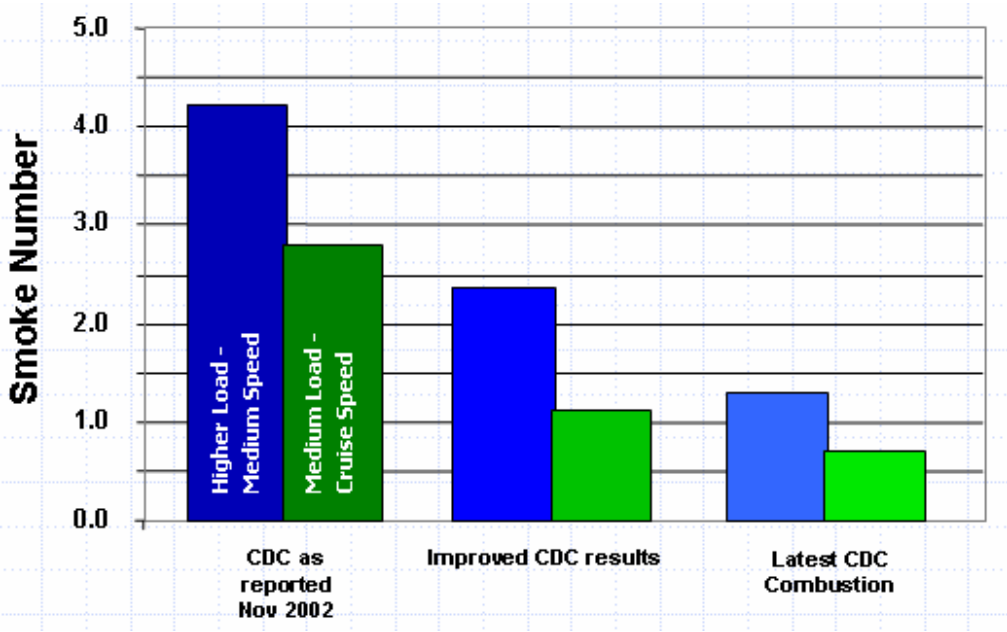
Is the higher activity due to physical changes in the soot under periodic rich conditions, or more frequent soot oxidation due to HC oxidation and local phenomenon?

Toyota SAE 2002-01-0957

In the EPA CDC engine, high HC and CO apparently are burning the fresh soot on the CSF on a continuous basis



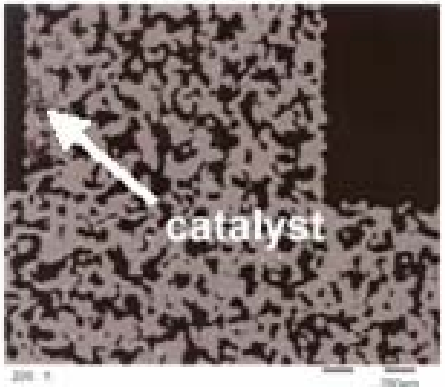
Low engine-out NOx comes from high EGR, high boost, high injection pressure.

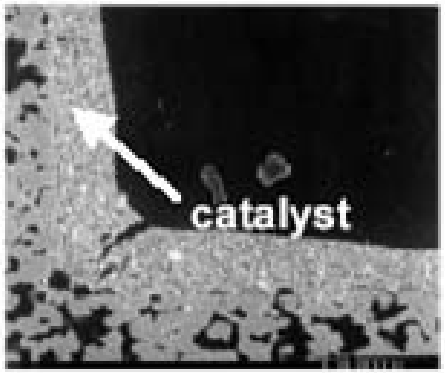


PM burden on DPF is very high. However, PM and HCs are rather high and exhaust temperatures can be low.

Despite low NOx, LT (<250C) and high PM loading, reports are that the filter stays clean. Speculation is that HCs react on catalyst to burn fresh, active soot.

New DPF catalyst coating process put DOC function on DPF, which aids regeneration by burning HCs at location of soot collection





New coating technology puts catalyst into the wall rather than on it. Δp goes up only 5 to 30% vs. 2-3X for standard coating.

Umicore SAE 2005-01-1756

System	Combusted soot amount @ 450°C [g]	Combusted soot amount @ 600°C [g]
System 1: stand-alone CDPF 9g PGM	10,2	17,0
System 2a: DOC / CDPF 15g PGM	1,7	13,5
System 2b: DOC / DPF / FBC 6g PGM	5,5	20,8

Soot oxidation compared for three configurations. At 450C new CDPF burns soot 6X faster than DOC+CSF. At 600C new CDPF and FBC achieve 100% regeneration at 6 and 4 minutes, respectively. Better performance due to HC burning on the filter.

SVR: DOC=0.65, CDPF=1.14.

Mixed mode engines might facilitate integrated DOC+DPF+NOx systems

- Current problems with integrated units are related to high NOx catalyst and soot loadings
  - High DPF back pressure due to LNT catalyst
  - Poor durability due to soot build-up and related exotherms
- Mixed mode engines relieve both problems
  - NOx catalyst loading decreases, especially in LDD applications, if LT NOx burden is removed
    - Low NOx load reduces need for NOx catalyst
  - Low soot build-up minimizes active regeneration exotherms
    - Improves LNT durability

Implications for DPF systems

- Reduced PM burden
  - More passive regeneration reduces need for high thermal mass filters
- Maximum HC and CO oxidation should occur on DPF
  - Auxiliary DOC after DPF if needed
- Facilitates NOx catalyst integration onto DPF
  - Overall system cost savings

Summary

- Mixed mode engines are evolving
  - Advanced combustion principles at low load, traditiona diesel combustion at high loads
- The PM burden on DPFs at low load (current active regeneration regime) will be reduced
  - Less need to actively regenerate filters
- If regeneration is needed, HC and CO are available to help
  - With a continuous feed of low temperature HCs and CO, and low PM loadings, it is possible that continuous burning of soot will occur on CSF
- Mixed mode engines facilitate emission control component integration