Diesel Aftertreatment Accelerated Aging Cycle

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DPF Durability

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Presentation Outline

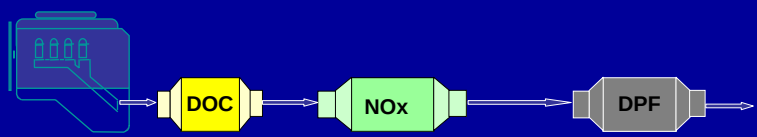
- **Introduction**
- **DPF Durability Issues**
- **Objective**
- **DPF Aging – Technical Approach**
  - Thermal Aging
  - Ash Accumulation
  - On-Vehicle Test
- **Evaluation of Aged DPF**
- **Summary**

Introduction (1/3)

- DPF Needs to Survive Vehicle Lifetime
  - *LD: 120k miles required, no DPF maintenance allowed (US).*
  - HD: 435k miles required, minimum service interval of 150k miles (over 300k miles expected for post 2007 technology) (US)
- Field DPF durability experience exists
  - HD: Mostly from European and North American retrofit applications.
  - LD: OEM vehicles equipped with DPFs approaching lifetime in Europe (large volume)
- Very limited DPF bench aging procedures in public domain
- Certification of DPF equipped LD vehicles in US – *Standard Road Cycle (SRC)* is required

Introduction (2/3)

Primary aftertreatment configuration to meet US emissions regulations – LD



Main Advantages

- Cold-start NO_x control is easier
- Depending on how the filter is regenerated NO_x control catalyst may not see elevated temperatures.

Disadvantages

- NO_x Control catalyst eliminates most passive DPF regeneration at lower temperature (NO_2).
- Must have upstream DOC for NO_2 optimization

Introduction (3/3) - DPF R&D and Application Roadmap

- **Performance**
- Filtration Efficiency
- Pressure drop performance
- Loading and regeneration
- Catalyst efficiency

Component

- **Durability**
- Thermal Aging
- Thermal survivability
  - Normal thermal cycle
  - Thermal shock
- Ash accumulation
- On-vehicle durability

Assembly

- **Validation**
- Thermal & mechanical
  - "hot vibration"
  - "Liquid spray"

System

- **Application**
- Control strategy
- Calibration
- OBD

DPF Durability Issues (1/2)

- Physical Integrity
  - Thermal Crack (Uncontrolled Regeneration)
  - Mechanical Crack
    - Vibration
    - Defective Canning

- Plugging
  - Soot
    - Incomplete Regeneration
  - Ash
    - Primarily from Lubricant Oil

- Catalyst Efficiency
  - Thermal Degradation
  - Poisoning

DPF Durability Issues – Solutions (2/2)

- Ash Plugging
  - Low ash oil
  - Reduced engine oil consumption
- DPF Poisoning
  - Sulfur – not a major concern (active system using ULSD)
  - Phosphorus and other (regeneration strategy design, e.g., 650C)
- Thermal Crack
  - Improved flow distribution
  - Sophisticated DPF regeneration control
    - Intake throttle + EGR + VNT
    - Feedback control (O_2 level)
  - More conservative design
    - Lower soot loading (increase fuel penalty)

After 10 DPF cycles

After 30 DPF cycles

Objective

- How to develop a DPF aging cycle to reflect application reality?
  - Performance
  - Durability
- Focus on DPF accelerated
  - Thermal Aging
  - Ash Accumulation
- On-vehicle Durability

Technical Approach – Thermal Aging (1/4)

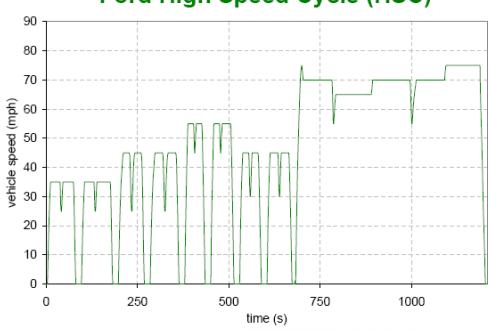
- **Thermal Aging** – Estimate the duration of LD DPF exposure to high temperature in real-world application
  - Number of regular regeneration events
  - Number of uncontrolled regeneration events
  - Soot loading levels
  - Duration of each regeneration

Technical Approach – Thermal Aging (2/4)

Durability Test Definition (Engine Dyno Aging)

- Full-size Urea SCR – CDPF system was aged for 120k mi on engine dyno with a total of 643 CDPF regenerations.

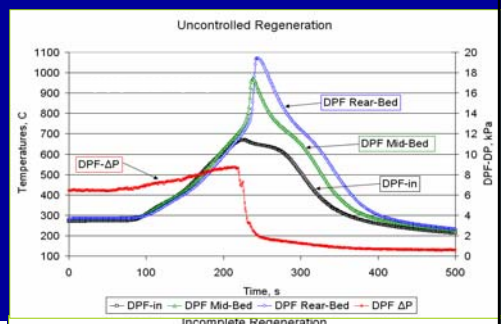
Ford High Speed Cycle (HSC)

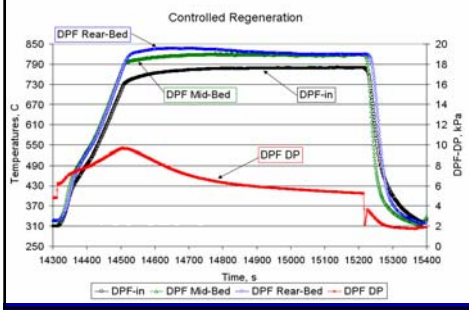


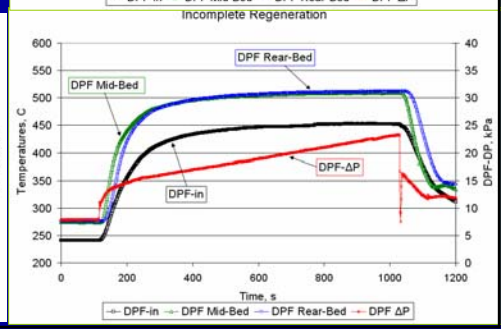
- Typical time at high temperature in SCR ~ 6 min per regen
- 643 regens x 6 min/regen x h/60min = 64 h

Technical Approach – Thermal Aging (3/4)

- DPF Regeneration
  - Controlled
  - Uncontrolled
  - Incomplete







Technical Approach – Thermal Aging (4/4)

Controlled Regenerations

DPF Inlet Temp = 650°C
200-600 Cycles

Accelerated

DPF Inlet Temp = 850°C?
? Cycles

$$Rate = A * \exp\left[\frac{-E}{kT}\right] \qquad \ln\left[\frac{t_r}{t_a}\right] = \frac{E}{k}\left[\frac{1}{T_r} - \frac{1}{T_a}\right]$$

Uncontrolled Regenerations

DPF Inlet Temp = >950°C
5% of Cycles?

Equivalent

DPF Inlet Temp = >950°C
10-30 Cycles

Arrhenius Rate Law may not apply!!!

Incomplete Regenerations

DPF Inlet Temp = 450°C
5% Cycles?

Equivalent

DPF Inlet Temp = 450°C
10-30 Cycles

Very limited thermal degradation, but high soot loading affects next regeneration

Technical Approach – Ash Accumulation (1/5)

- **Ash Accumulation** – Estimate lifetime ash buildup in LD DPF
  - Engine oil consumption
  - Ash contents in oil
  - Percentage of ash accumulated in DPF

Technical Approach – Ash Accumulation (2/5)

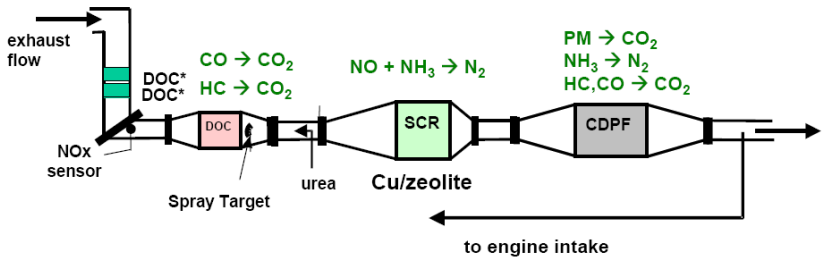
- How to accelerate ash accumulation? – Increase oil consumption
  - Inject oil to intake manifold
  - Inject oil to exhaust manifold
  - Blend oil with diesel fuel
  - Use high-ash oil
- Considerations on accelerated ash accumulation
  - How realistic (compared to real-world ash in DPF)
  - Mass balance for ash components
  - Effect due to upstream devices (DOC, NAC/SCR?)

Technical Approach – Ash Accumulation (3/5)

On-engine aging and ash accumulation (entire exhaust system) - Example

120k mi Engine Aged Diesel System

90% FTP-75 NOx conversion, 0.07 g/mi TP NOx



Ford, DEER 2007

* Note: Downpipe DOCs replaced at 50k mi.

Technical Approach – Ash Accumulation (4/5)

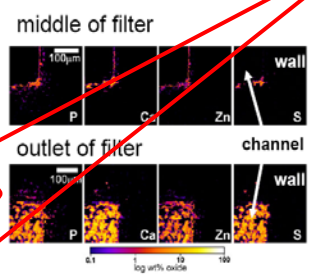
DPF Ash Accumulation

LD DPF pickup truck, targeted for 120k miles

- Ash removal was performed at 44k, 79k and 112k miles.
- Ash primarily made of $CaSO_4$, $Ca_{19}Zn_2(PO_4)_{14}$, and $CaZn_2(PO_4)_2$

Total Ash Removed = 919 g

Engine Hours	Equiv. mi	Ash (g)
940	44k	112
1688	79k	419
2375	112k	388



- Ash mainly in channel, not in wall

Ford, DEER 2007

919g ash for 112k miles
CJ-4 oil: <1% ash

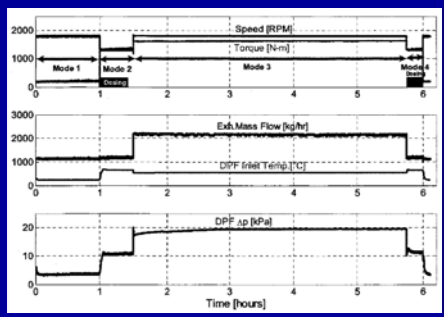
>91.9kg oil for 112k miles
Oil density: ~0.82 kg/L

>112 L oil for 112K miles
Oil change / 5000 miles

24 oil changes for 120k miles
>5.0 L oil consumed for each oil change interval !!!
(About 5.3 quarts)

Technical Approach – Ash Accumulation (5/5)

- Four-mode accelerated ash loading cycle – using high-ash oil, real oil consumption rate (Corning, *SAE Paper 2007-01-0920)*



- Oil injection into intake manifold (ORNL, 2006 CLEERS Conference)
- Fuel doped with 5% oil (ORNL, DPF, 2007 DEER Conference)

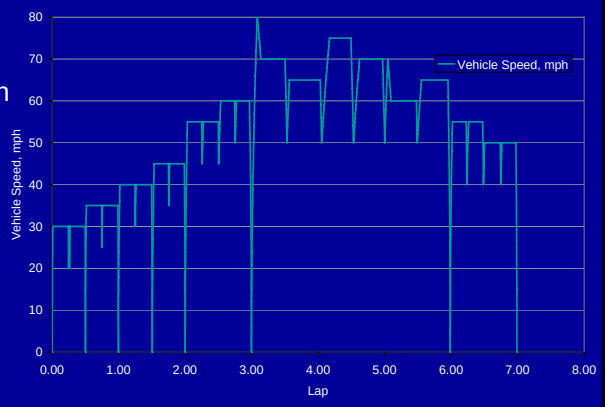
Technical Approach – On-Vehicle Durability (1/3)

- **On-Vehicle Durability**
  - Standard Road Cycle (SRC)
  - Accelerated DPF soot loading and regeneration

Technical Approach (2/3) – On Vehicle Durability

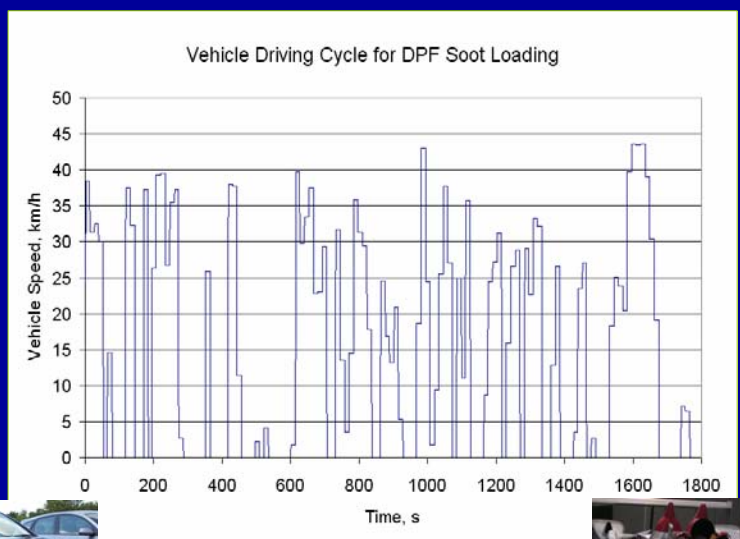
SRC

- Fuel Neutral
- 7-Laps, 3.7 miles each
- Average speed=46.3 mph
- Max cruise = 75 mph
- Light to hard accelerations
- No WOT-accelerations



Standard Road Cycle

Technical Approach (3/3) – On Vehicle Durability

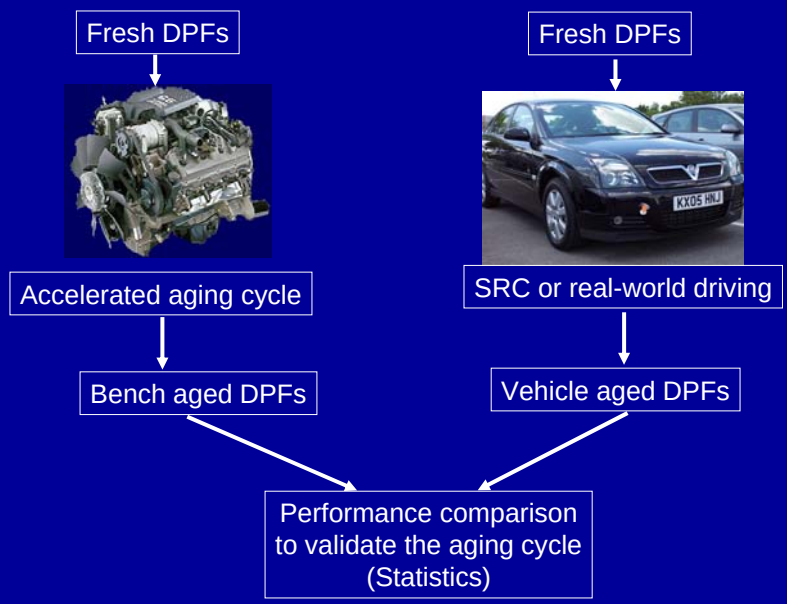


SAE 2007-01-0918

Evaluation of Aged DPFs

- On-Vehicle Performance Evaluation
  - Using standard driving cycles (e.g., FTP)
- On-Engine Performance Evaluation
  - Pressure-drop characteristics
  - Soot loading and regeneration performance
  - Catalyst performance (BPT)
    - Important for certain engine operating conditions (passive).
    - Do we even care about it if active regeneration is forced anyway?
- Comparison of on-engine aged vs. real-world aged DPFs

Summary



Q & A