Durability Evaluation of an Integrated Diesel NOx Adsorber A/T Subsystem at Light-Duty Operation

Jim (Jianwen) Li, Sriram Popuri, Jason Chen, Arvind Suresh, Aleksey Yezerets, Brad Stroia, Lisa Prentiss

Cummins.Inc.

Howard Hess
Johnson-Matthey

Ken Howden
Department of Energy

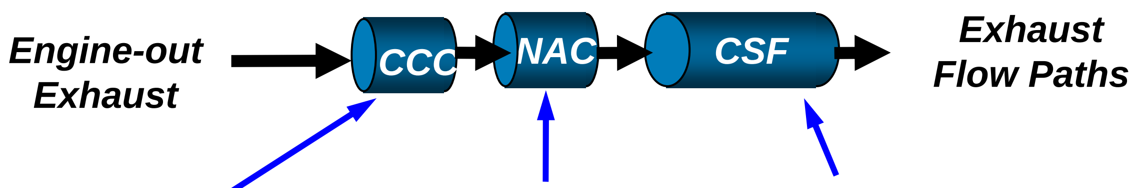
Presentation Highlight

- Objectives
- A/T System Outline
- Design of A/T Durability Test
- NOx Management/Performance
- A/T System Capability at Cold Ambient Field
- Conclusions and Future Work

Objectives

- To develop the generic aftertreatment subsystem technologies applicable for LDV and LDT diesel engines
- To acquire information regarding the durability of an aftertreatment and engine system to maintain NOx conversion efficiency against a light-duty emission useful life requirement of 120,000 miles
    - NOx conversion efficiency over FTP75 cycle > 80%
    - PM conversion efficiency > 90%
- To generate aged aftertreatment samples for post-mortem investigations to aid material improvements
- To gain durability/reliability experiences in cold ambient condition

A/T System Outline



CCC Function:
1. HC/CO Oxidation (heat)
2. NO>NO2 Oxidation
3. Reductant Reforming
4. SOF

NAC Function:
1. NOx
2. Heat for CSF
3. SOF

CSF Function:
1. PM/HC/CO
2. Noise Abatement
3. Regen "slip-getter"

Integrated NOx Adsorber A/T System

NOx Regeneration
SOx Regeneration
Soot Regeneration

By Engine Management

Design of Test: Deactivation of NOx Adsorber

Sintering

Sintering of precious Metal on catalyst support and catalyst carrier at high temperature

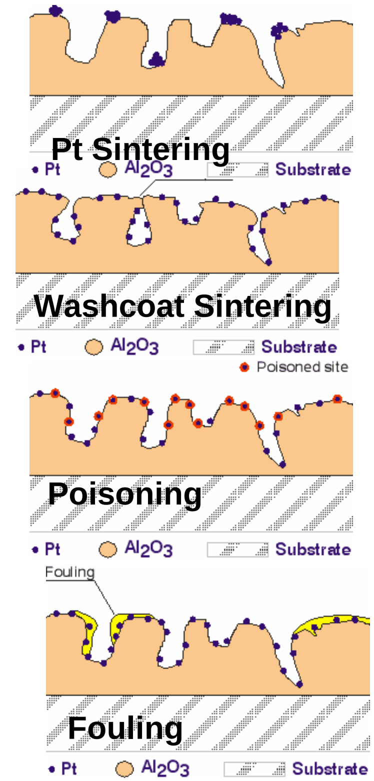
Poisoning

Sulfur, P, Zn, Ca, Mg

Fouling

Physical deposition of species from the exhaust onto the catalyst surface (HC + aromatic compounds +others)

The focus is to study the thermal & sulfur poisoning impact on NOx adsorber in LD operating conditions

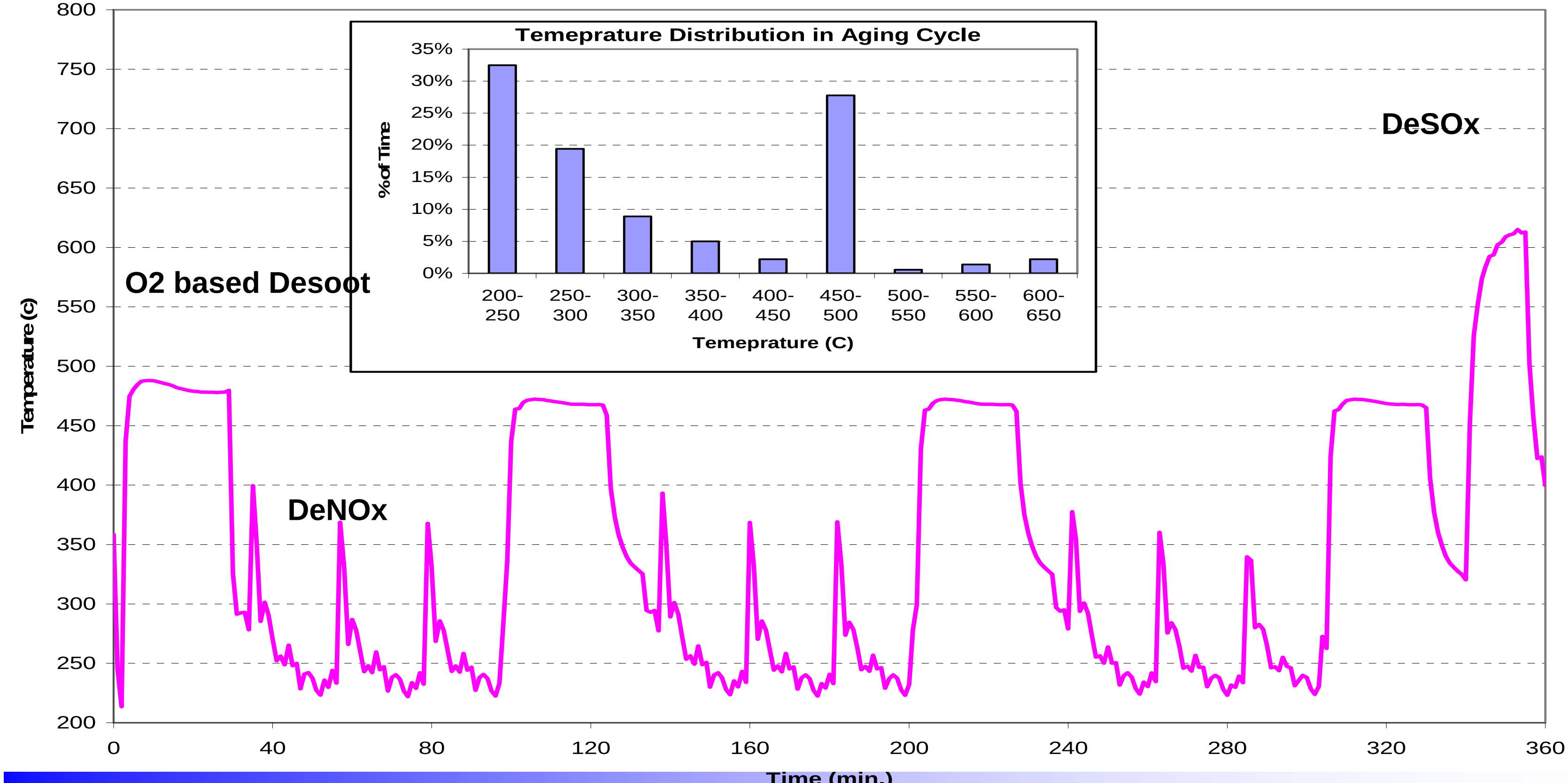


Design of Test: A/T Durability Tests

				Winter Field
Major Focus	500 hr w/o S	500 hr w/ S	1250 hr w/ S	Cold Operation Capability
	Thermal	Thermal & Sulfur	Real Time Aging	
Cycle	LD on Engine Dyno.	LD on Engine Dyno.	LD on Engine Dyno.	Vehicle Driven in City
Accelerated or non-accelerated	Accelerated	Accelerated	Non-accelerated	Non-accelerated
Fuel Sulfur	Ultra Low S Fuel (<5ppm)	Low Sulfur Fuel (<15ppm) +Current Diesel Fuel (350ppm)	Low Sulfur Fuel (<15ppm)	Low Sulfur Fuel (<15ppm)
Equivalent Mileage	~120,000	~120,000	~50,000	12,250

Design of Test: LD Aging Cycle

- **Thermal effect – Desulfation events expected in the useful life time**
- **Sulfur poisoning effect – Total sulfur exposure expected in the useful life time**
- **Soot regeneration events + Time accumulation at FTP75 type conditions**

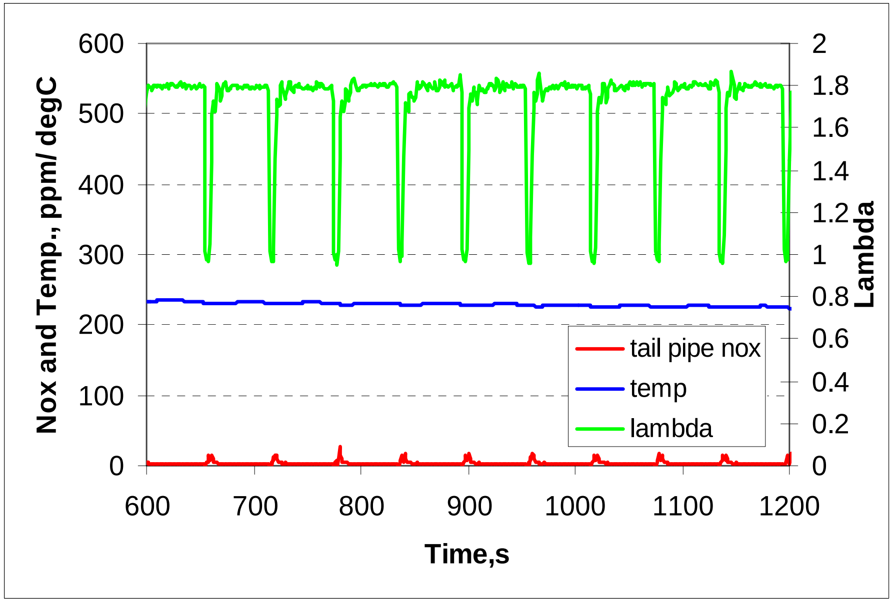


NOx Management: NOx/SOx Regeneration

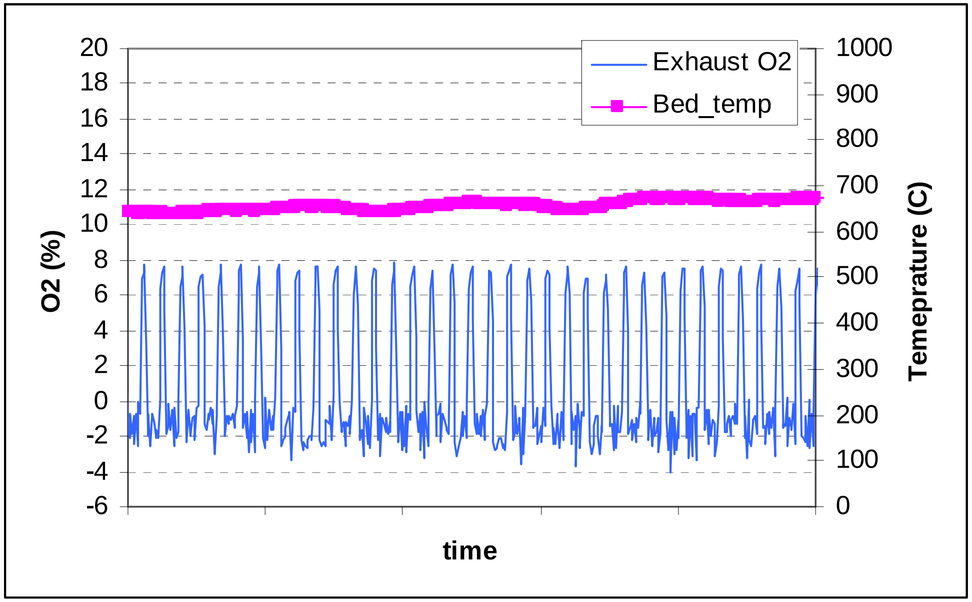
	Nox Regeneration	Sox Regeneration
Trigger	• Time Based; • Fueling Based; • Amount of NOx Trapped; • NOx Trapping Efficiency;	• Time/Mileage Based; • Fueling Based; • Amount of Sulfur Trapped; • NOx Trapping Efficiency;
Reductant	Quantity - Richness and rich time Quality – HC, CO, H2 and etc.	
Temperature Window	200 ~ 450 C	> 600 C

NOx Management: A Portion of a Typical DeNOx and DeSOx Cycle

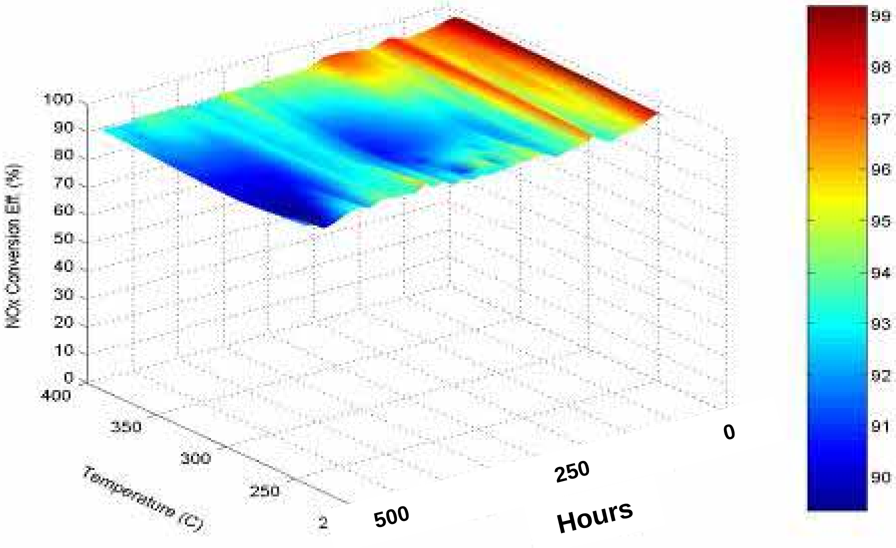
A portion of typical DeNOx Cycle



A portion of typical DeSOx Cycle

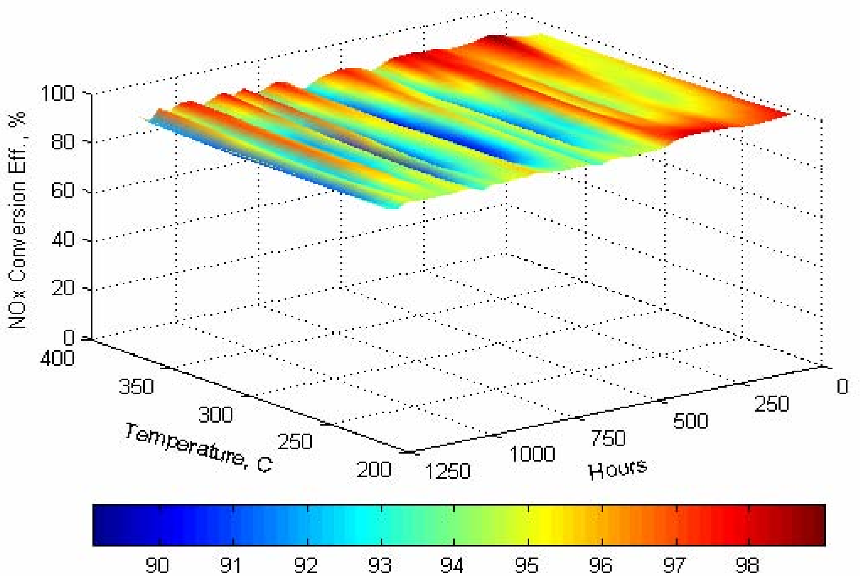


NOx Performance: NOx Conversion



500 Hour Accelerated Aging with Sulfur

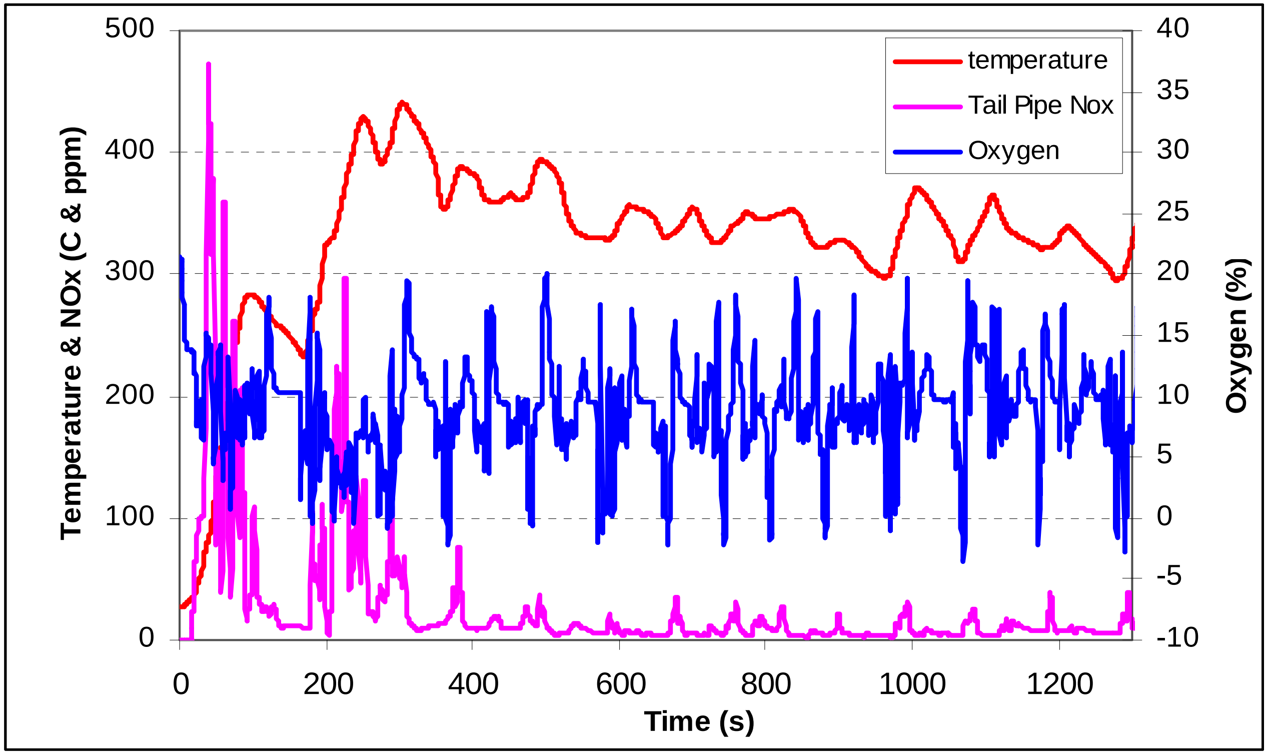
1250 Hour Real Time Aging



The aged parts are still able to achieve 90%+ NOx conversion efficiency at the temperature range of 250 ~400 C

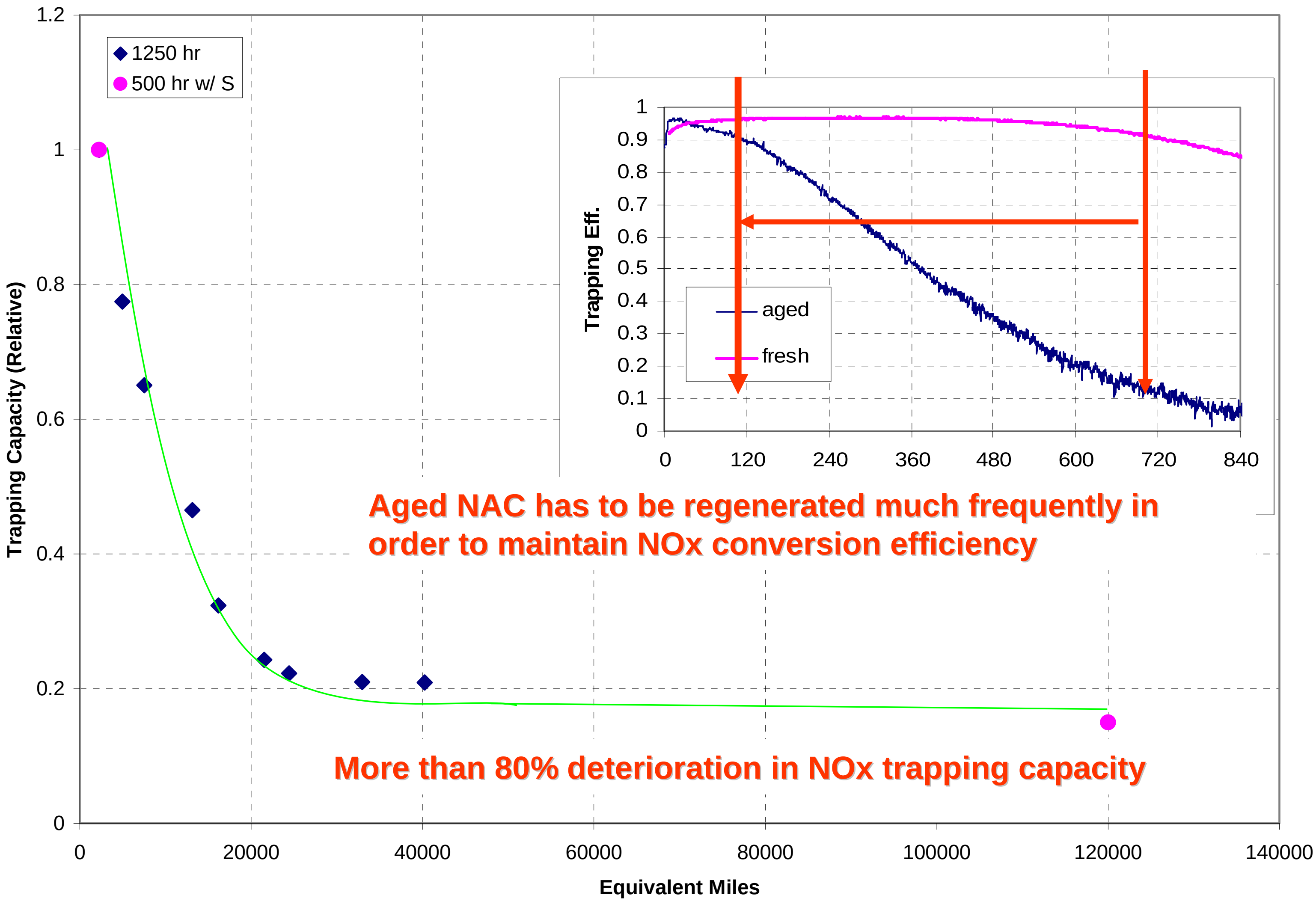
NOx Performance: Transient Cycle

NOx performance in Simulated FTP75 cycle (Aged parts, 500 hr w/s)



Aged Parts	500 hr W/O S	500 hr W/ S	1250 hr
Composite NOx conversion efficiency	> 80%	>80%	>80%

NOx Performance: Trapping Capacity



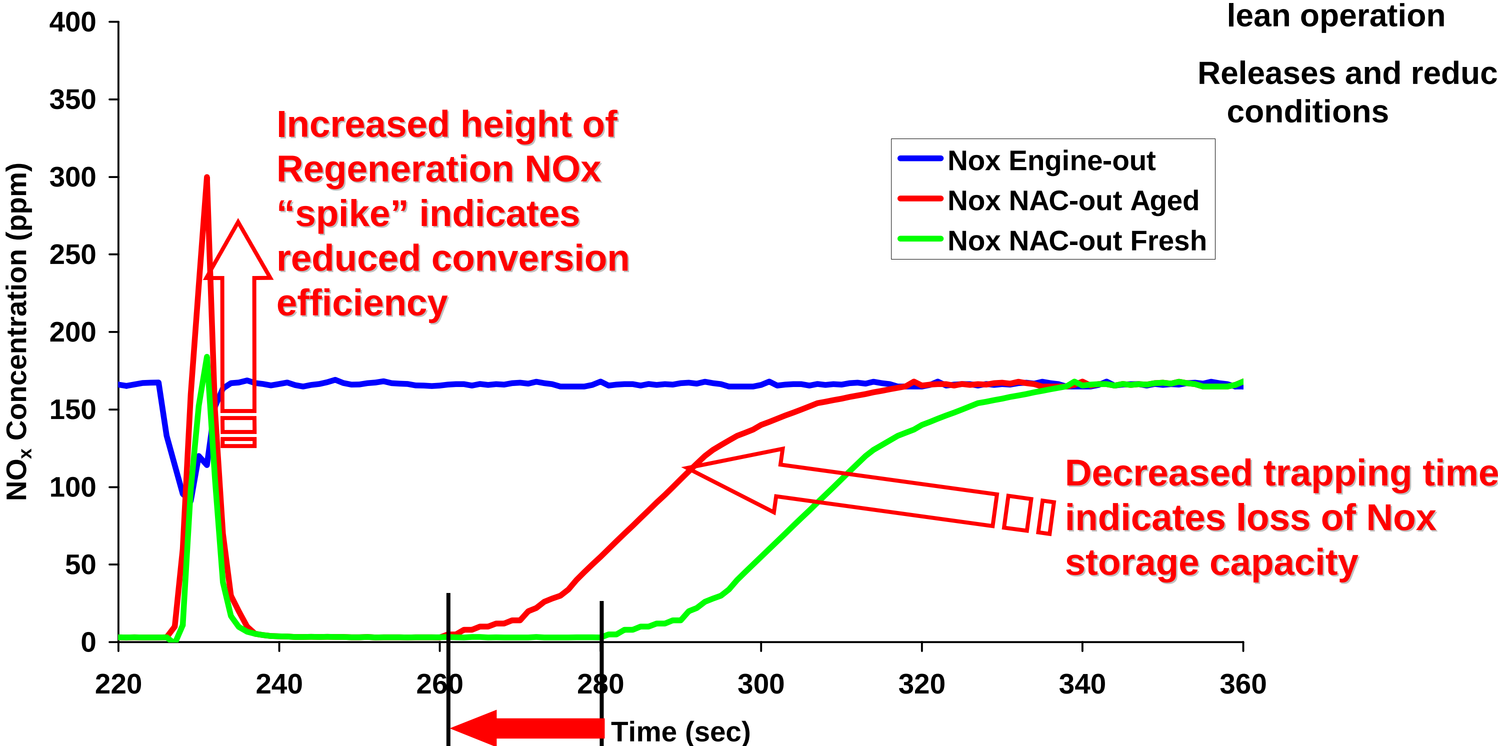
NOx Performance: Effect of Aging on NOx Adsorber Operation

NAC Function:

Adsorbs and Stores NOx during normal lean operation

Releases and reduces NOx under rich conditions

Typical Nox Adsorber Regeneration and Filling Scenario



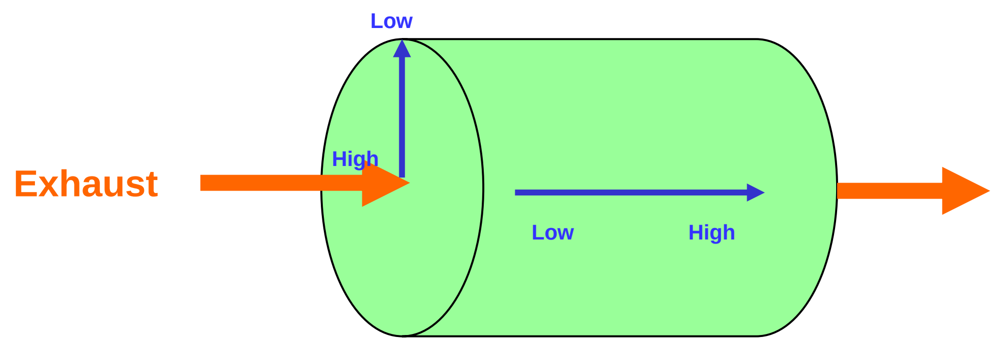
Regeneration freq. increase to compensate for degradation

NOx Performance: Thermal Management

- DeSox temperature

  -> Sulfate decomposition is temperature dependent
  ->higher the temperature, faster the rate
  ->but, too high temperatures will cause the degradation

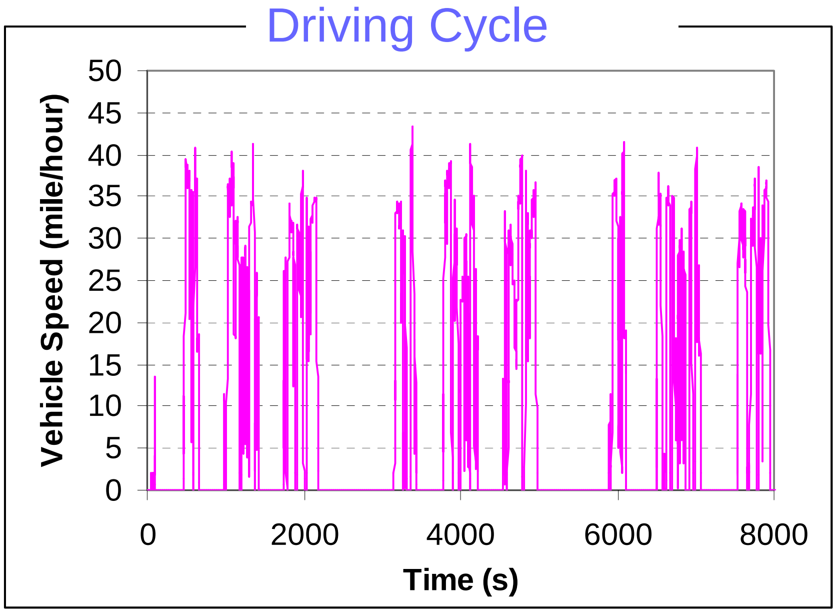
- Reduce the residual sulfur over the entire NAC
  ->more uniform temperature distribution
  ->more uniform richness

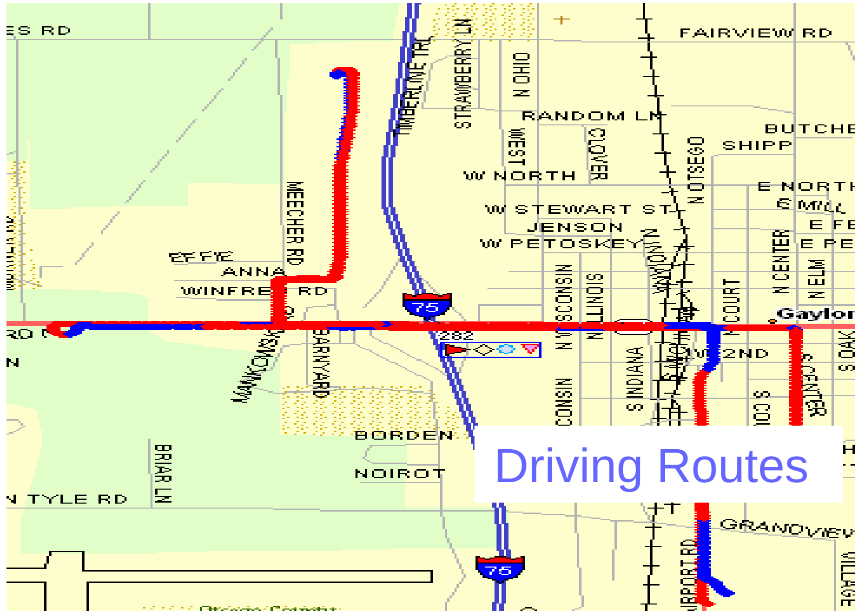


Temperature gradient

Recovery of NOx Trapping Capacity is possible through the careful thermal management

A/T System Capability at Cold Ambient Field





- Vehicle ran in Michigan from January to April experiencing cold temperatures down to -20 C
- 12,250 miles accumulated
- No face plug or any failure observed
- System performance evaluation is expected after the field test

Conclusions and Future Work

Conclusions:

- Extensive study has been conducted on durability of an integrated NOx adsorber aftertreatment subsystem
- The system is capable to reduce NOx by 90% plus at steady state and 80% plus at simulated FTP75 cycle at the end of full useful life
- A substantial loss of NOx trapping capacity was observed at the end of full useful life
- The deterioration of trapping capacity should be considered as one of most critical factors in sizing NOx adsorber
- The recovery of NOx trapping capacity is possible through the careful thermal management

Conclusions and Future Work

Future Work:

- **Post mortem analysis of aged samples to aid the improvement of catalyst formulation**
- **Further optimization on the system performance in test cell and vehicle at various environments to develop a durable/reliable/low cost A/T system for LD diesel application**
- **Continuation of real time aging test to collect the information regarding with CSF ash accumulation and the effect of fouling on CCC and NAC performances**