Analytical Tool Development for Aftertreatment Sub-Systems Integration


Detroit Diesel Corporation
Outline

- Engine and Sub-System Integration Strategy
- Aftertreatment Model Development Strategy
- Model Applications for System Integration and Control Strategy Development
- Conclusions
System Development Methodology

Steady State
Modal Development

Simulation

Vehicle Integration

Transient Dyno Development

Control model + Engine model

Urea Injector
SCR Catalyst
CSF
Aftertreatment Model Philosophy

- **Plug & Play**
  - Simulink and Fortran Based Models
  - Common Framework
  - Can Be Combined Freely

- **Variable Resolution - Adaptable**
  - Prime Path A.T. Models are 1D
  - 0D and 3D Also Developed

- **Common Framework**
  - Sub-Models for
    - Flow
    - Chemical Kinetics
    - Thermal Modeling
    - Storage
DDC’s Tool Box Description

- **Engine**
  - Mapped Data
  - Mean Value (MV) Model
  - Cycle Simulation
  - Multi-Dimensional Models

- **Vehicle Model**
  - Simple
  - Complex

- **Aftertreatment Models**
  - DPF
  - SCR
  - LNT
  - DOC
Individual Models Have Been Extensively Validated
Outline

- Engine System Integration Strategy
- Aftertreatment Model Development Strategy
- Model Applications to System Integration and Control Strategy Development
- Conclusions
Integrated Emissions Reduction Roadmap
Light Truck / SUV Platform

- Engine Controls Strategy – Advances in CLEAN Combustion©
- Engine Controls Strategy Integrated with Aftertreatment

Graph showing NOx (g/mile) vs. Particulates (g/mile) with bins labeled:
- Bin 5
- Bin 6
- Bin 7
- Bin 8
- Bin 9
- Tier 2 Bin 10
Integrated Emissions Reduction Roadmap
Light Truck / SUV Platform

Engine Controls Strategy – Advances in CLEAN Combustion

Engine Controls Strategy Integrated with Aftertreatment

Tier 2 Bin 10

Engine Out Tier 2 Bin 10

Particulates (g/mile)

NOx (g/mile)
Integrated Emissions Reduction Roadmap
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Engine Controls Strategy – Advances in CLEAN Combustion
Engine Controls Strategy Integrated with Aftertreatment

No NH₃ Slip
Near Tier 2 Bin 9
Without Any Active NOx Aftertreatment
Tailpipe Out Tier 2 Bin 3
41% Fuel Economy Benefit
Compared to Gasoline Baseline
Bin 9
Tier 2 Bin 10

Particulates (g/mile)

NOx (g/mile)
NOx Reduction Via Combustion and Aftertreatment Development
Light Truck / SUV Platform

Contours of Iso-NOx-Reduction-Efficiency

Bin 6
Bin 5
Bin 4
Bin 3
80%
85%
90%

FTP-75 Vehicle Out NOx (g/mile)

FTP-75 Engine Out NOx (g/mile)
NOx Reduction Via Combustion and Aftertreatment Development
Light Truck / SUV Platform
NOx Reduction Via Combustion and Aftertreatment Development
Light Truck / SUV Platform
NOx Reduction Via Combustion and Aftertreatment Development
Light Truck / SUV Platform
Urea Injection Mixing and Spray Development
Urea Injection Control Issue
Hole-to-Hole Flow Rate Variation

Before Optimization

After Optimization

- 190 g/h
- 280 g/h
- 470 g/h
- 663 g/h
- 925 g/h
- 1700 g/h
3D CFD for NH3 Distribution

“Baseline” Non-Uniform Injection

“Modified” Uniform Injection
Urea Injection Control Strategy Development
Urea Control Strategies over Hot 505 Transient Cycle Using 1D SCR Model

Cycle Averaged NH3 Slip:
- Baseline: 1.0 ppm
- Control X: 2.9 ppm
- Control Y: 10.3 ppm

NOx Emissions (kg/s)
- NOx In
- NOx Out (Baseline)
- NOx Out (Control X)
- NOx out (Control Y)
Urea Injection Control Strategies on SCR Performance for a Hot 505 Cycle Using 1D SCR Model
System Integration Experimental Validation
Urea Injection Control Strategy Development

Cumulative Engine Out NOx

Cumulative Tail-pipe Out NOx
Tier 2 Bin 5 - Control Strategy X'

Cumulative Tail-pipe Out NOx
Tier 2 Bin 3 - Control Strategy Y'

Time (s)
Technical Challenges and Issues

- **Reduce AT System Complexity**
  - Require Multiple AT Model Integrations
    - Model Fidelity when They are Integrated Together
  - **Sophisticated Controls Technology Integration**
    - Soot Filter Regeneration Strategy
      - Model Fidelity to Different Types of Soot Oxidation Mechanisms
      - Kinetic Data
    - Urea Injection and Mixing Improvement
      - Small Urea Flow Rate Control
      - Uniform Urea Distribution
    - Virtual Sensors and Control (Soot Loading, NH3 Slip)
      - How Can a Complicated 1D System Model Be Simplified to a 0D for On-board Virtual Sensor?

- **Effect of Aging on Aftertreatment Performance**
  - How Modeling Can Capture Aging Effects?
    - Correlation Type or Physical Type?

- **More/Better Kinetic Data Is Required**
  - Industry, Catalyst Suppliers, National Laboratories, and Universities Can Work Together To Fill This Pre-Competitive Void
Concluding Remarks

- Modeling Framework Has Been Further Enhanced.

- Individual Models Have Been Developed and Validated.

  - Tier 2 Milestone Results Have Been Achieved

- Significant Challenges are Ahead
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