DPF Modeling - Industry Perspective for Light Duty Diesel Applications

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Outline

- System requirements for DPF application in LD environment
- System elements for DPF design, control and modeling
- DPF modeling objectives
- DPF modeling requirements
- DPF system model
- Desired optimal results

System Requirements for DPF Application in LD Environment

- The regeneration system must operate under all anticipated conditions.
- The regeneration system must be transparent to the driver
- The system must have acceptable product packaging on vehicles
- It must have a minimal effect on engine performance and fuel economy
- It must be reliable and durable (I.e. able to satisfy the 120,000 miles emission compliance liability and maintenance interval requirements)
- It must have an acceptable environmental impact (no unreasonable risks due to unregulated emissions)
- It must have an end-product and service life cost that is acceptable to the customer. This aspect is particularly important, as diesel engine competes with gasoline engines in the light duty market

System Elements for DPF Design, Control and Modeling

- Engine/Vehicle System - Upstream of DPF
  - Engine architecture and packaging
  - Technologies available on the engine
  - Engine out emissions level relative to tail pipe emission target
  - Engine control system

These provide the upstream boundary conditions for DPF in terms of flow rates,exhaust temperatures, required trapping efficiencies, other emission levels, and capability to enhance favorable conditions for regeneration.

- DPF
  - Substrate
    - Mechanical & thermal characteristics
    - Porosity and filtration mechanism
    - Pressure drop characteristics
    - Packaging design

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System Elements for DPF Design, Control and Modeling - continued

- Regeneration Methodology & Control for Reliability and Durability

Must operate within the operational limits of temperature, thermal and mechanical stresses of trap substrate.

- Oxidation temperature requirements
  - O2 based
    - Catalysts
    - Additives
    - Exhaust composition (HC, NO….)
  - NO2 based - Exhaust composition (NO, C ..)
- Regeneration Temperature Generation
  - Engine
    - Operating conditions
    - Supplemental measures (Post Injection/DOC….)
  - External to engine
    - Fuel oxidation - Burners etc.
    - Electrical
      - » Heaters - configuration
      - » Microwave
  - Combination of both
- Regeneration Rate Control - Compatible with Substrate
  - Gas or substrate temperature
  - Space velocity
    - System configuration (Full or partial flow..)
    - O2 availability
  - Soot loading

Velocity, temperature and loading gradients are important

- System Controls
  - controlled effective regeneration under all operating conditions
    - Transient operation

DPF Modeling Objectives

- Initial aftertreatment system component & configuration evaluation and optimization
  - Engine/vehicle
  - Aftertreatment system matching
    - catalyst, additives ….
    - Configuration
    - Interaction with other devices(e.g. downstream system affected by regeneration temperatures)
  - Control strategies
  - Packaging requirements
- Design of experiments to reduce development time & cost
- Better understanding of experimental data
- Optimized, reliable & durable system

DPF Modeling Requirements

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Level of detail to match available fundamental information and intended results

- Model Elements
  - Flow distribution into filter (Soot and temperature distribution)
  - Pressure drop calculations (substrate properties, flow rate, temperature, loading)
  - Soot collection/efficiency (Soot gradients)
  - Regeneration - based on energy application
    - Soot Oxidation - Chemical reactions and kinetics
      - O2 based
        - » Plain filter
        - » Fuel borne additives
        - » Catalysts
      - NO2 based
    - Regeneration induced chemical reactions (Regulated & unregulated species production)
  - Ash accumulation
  - Heat flow model - Convection, conduction, radiation - for burning pattern
    - Temperature and temperature gradients
  - ***Linkage to Finite Element Analysis (FEA) as post process or integral model to assess durability***
- Validation
  - Relevant experimental data

DPF System Model

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- Variables
  - Substrate
    - Dimensions (geometry, diameter, length, location/packaging)
    - Properties (density, thermal and mechanical properties, max. safe temperature)
    - Cell configuration (density, dimensions, wall thickness)
    - Pore size (porosity, permeability)
    - Packaging design
  - Engine Exhaust - Variation with duty cycle
    - Mass flow rate
    - HC, O2, NO/NO2 concentrations
    - Temperature
    - PM concentration
  - Regeneration Strategy
    - Thermal
    - Chemical & thermal
  - Fuel and lube properties - ash, sulfur
- Output
  - Pressure drop over DPF
  - Trap temperature and temperature gradient profiles
  - Ash accumulation
  - ***Durability assessment by combining temperature and gradient information to FEA and ash interaction***.
  - DPF exhaust composition
  - Energy consumption
  - Control strategies

Desired Optimal Results

- Best substrate material and size selection (Cost, weight….)
- Optimum configuration
  - Full flow, partial flow
  - location
- Minimum thermal energy requirements
- Lowest exhaust back pressure increase and fuel consumption penalty
- What if evaluation with calculated intermediate data.