EGR System Fouling Control

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for

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Outline – EGR System Fouling Control

- Introduction
- Objective
- Technical Approach
  - *Use Aftertreatment Technology to Reduce EGR System Fouling*
- Experimentation
- Results and Discussion
- Conclusion

Introduction

- Cooled EGR is a "standard" tool to meet US2007
- Higher EGR ratio is expected for US2010 and future emissions regulations
- EGR can cause engine durability issues
  - Regular EGR System Maintenance is in Owner's Manual (MY2008 Dodge Ram with Cummins ISB), 60K miles

Effect of Diesel Particulate Matter (PM)

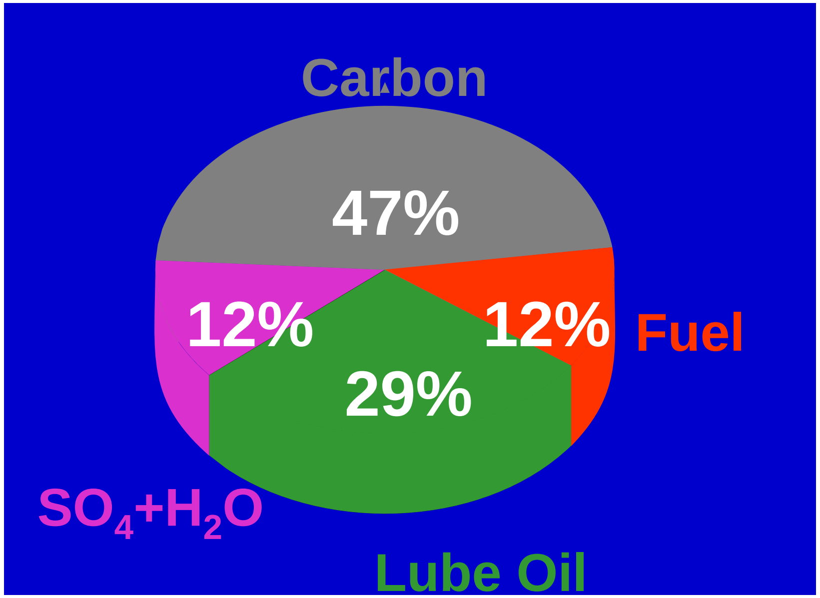
Diesel Particulate Matter

- Chemical compositions (SOF: Soluble Organic Fraction)
- Effect on regeneration performance

Effect on EGR Cooler

- High rate of erosive and abrasive wear – Mechanical durability
- Deposit and fouling of PM – Heat transfer efficiency

Fouled EGR Cooler Tube



PM Chemical Composition - one example

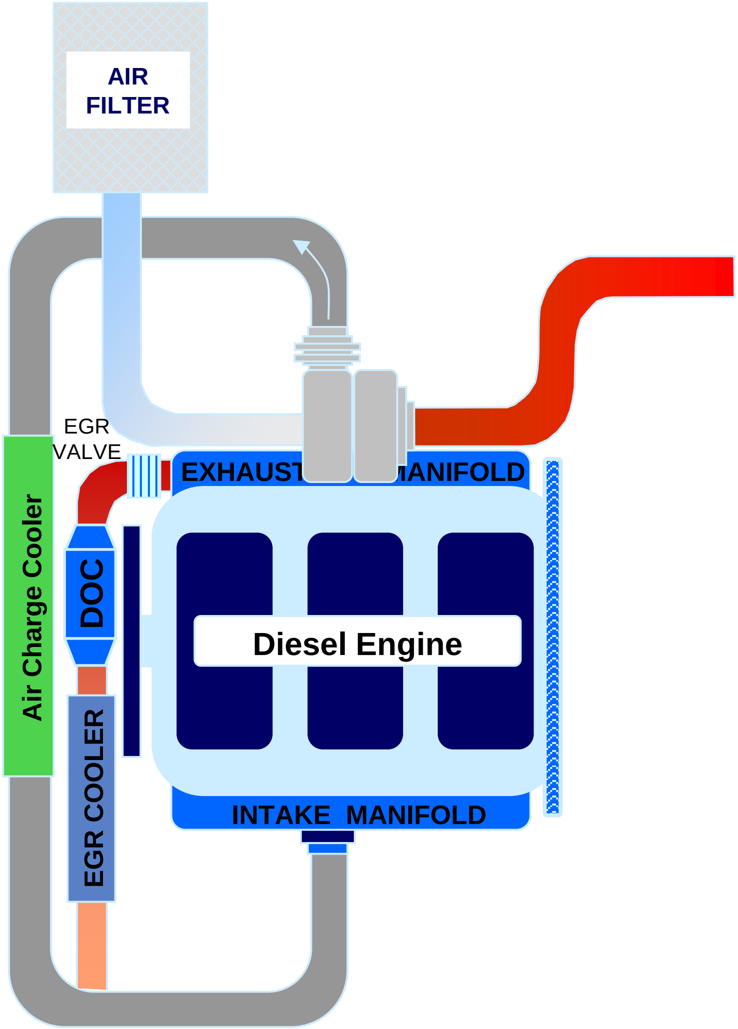
Factors Contributing to EGR Cooler Fouling

- **Two particle deposition mechanisms for EGR cooler fouling:**
  - Specific particle size deposition
  - Thermophoretic deposition
    - **Thermal gradient is the key!**

- **Four factors that increase EGR cooler fouling:**
  - High PM number (or mass) concentration
  - High gas temperature gradient across the cooler
  - Low gas outlet temperature to enhance condensation inside cooler
  - Wet particle composition (soluble organic fraction – SOF)

Objective

- Develop a Method to Effectively Reduce EGR System Fouling, with Minimum Impact on EGR Functionality



Technical Approach

- Apply Different Aftertreatment Technologies
  - A: Uncatalyzed PFT
  - B: DOC + DPF (wall-flow)
  - C: DOC + cPFT (Flow-through)
  - D: DOC + PFT (Flow-through)

- Compare Performance on EGR Fouling Reduction

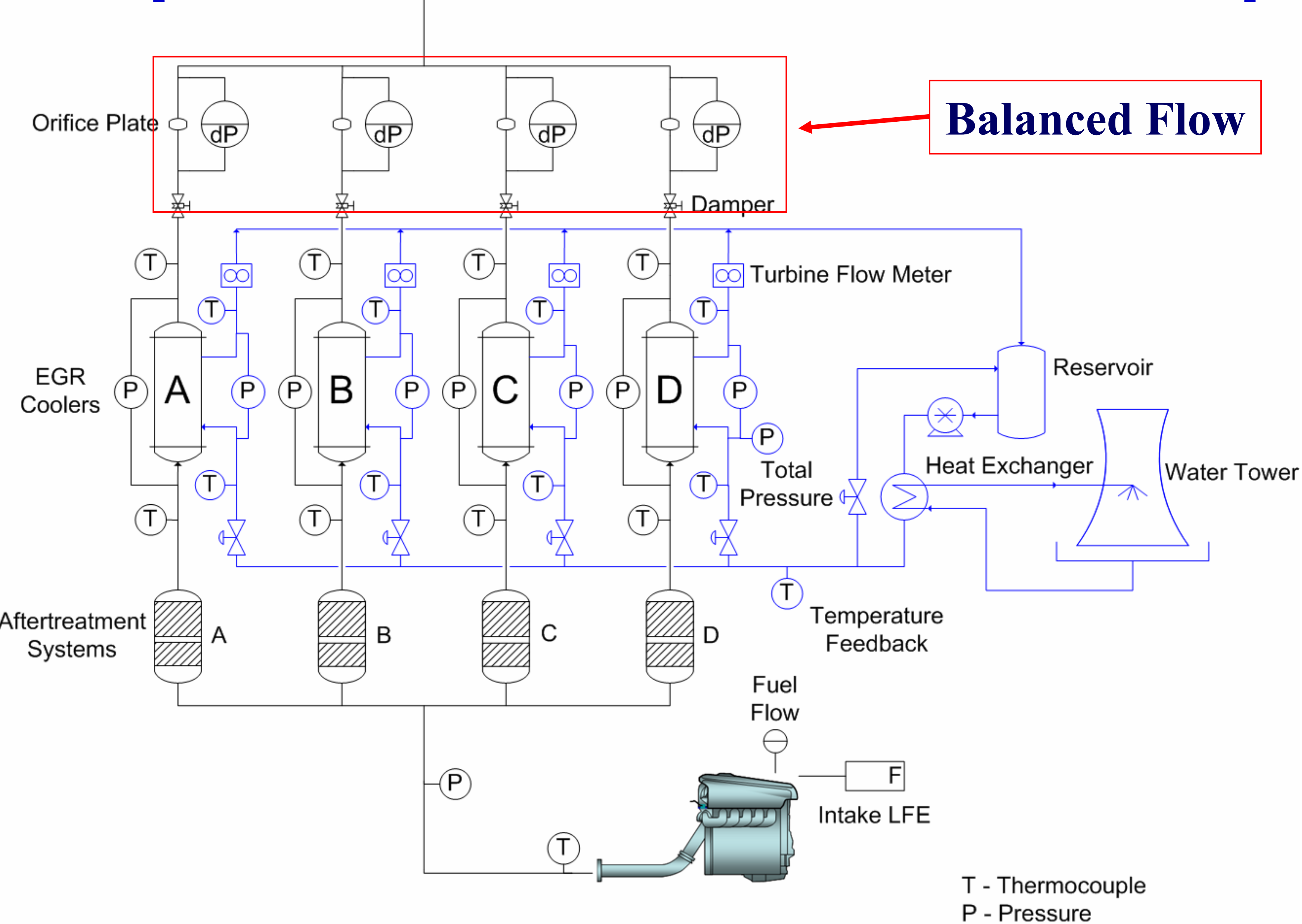
- Compare Impact on EGR System Performance
  - Pressure Drop
  - Heat Transfer Efficiency

Experimentation

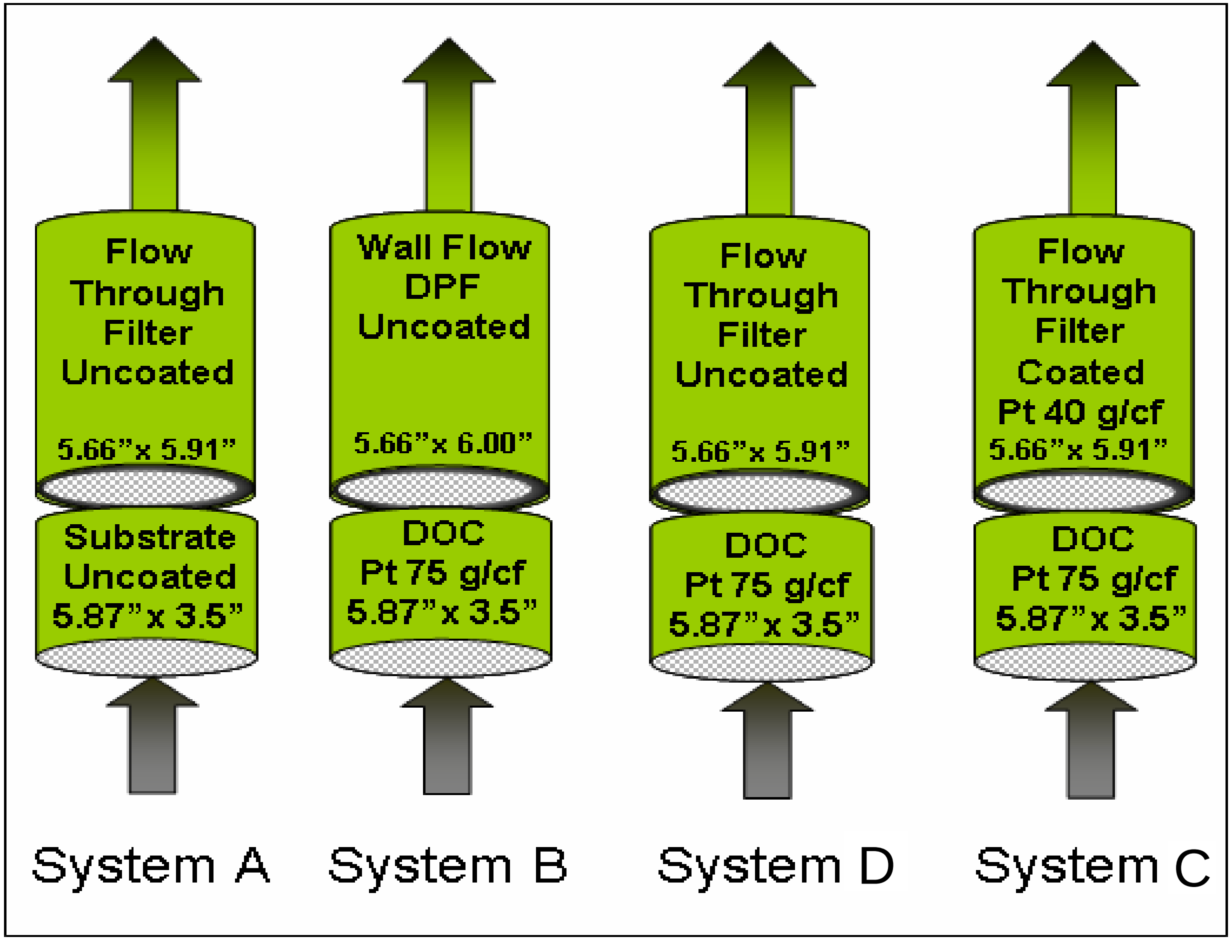
- Test Cell Setup
  - Aftertreatment Systems
  - Engine
  - EGR Coolers

- Test Procedure

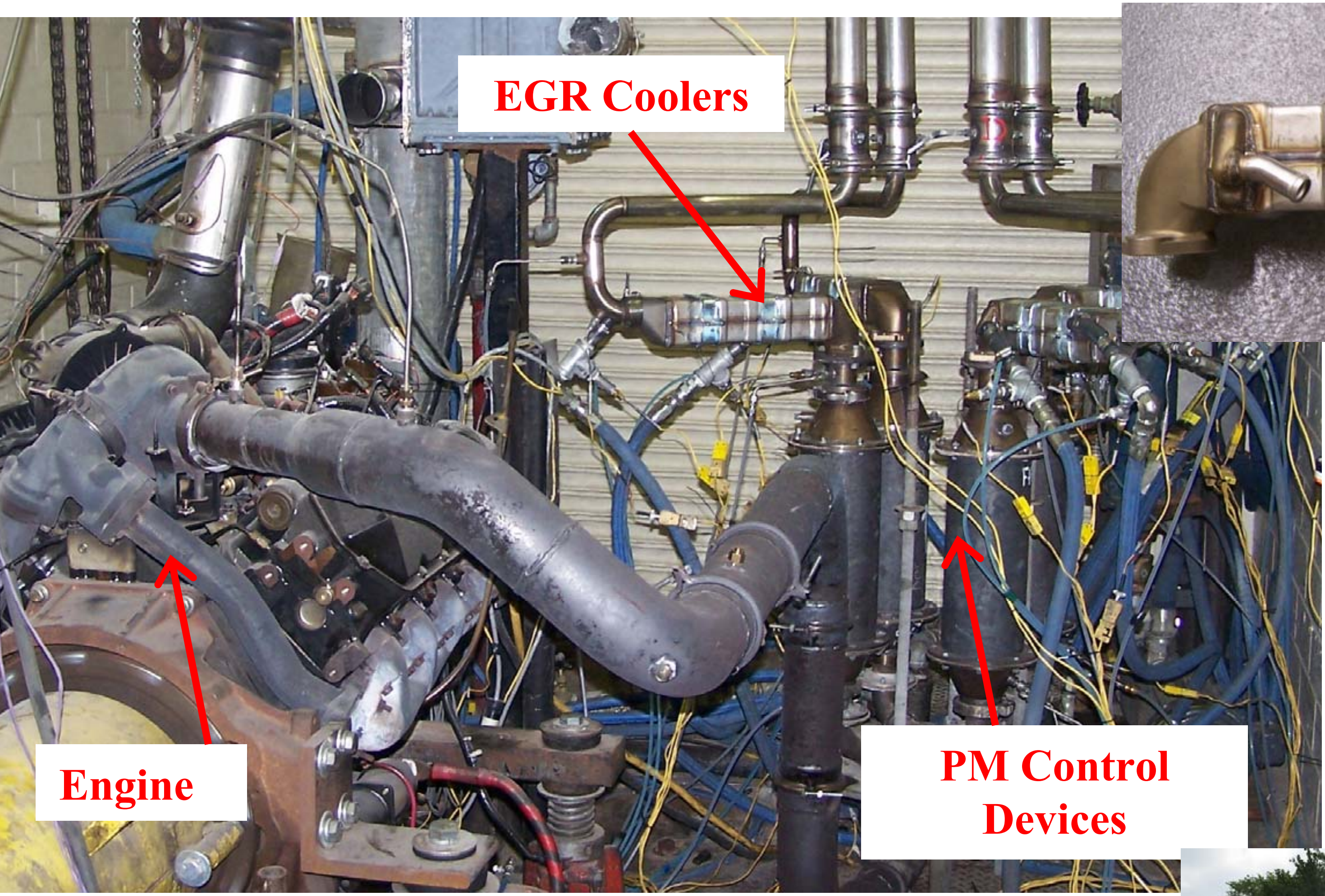
Experimentation – Test Cell Setup



Experimentation – PM Control Devices



Experimentation – Test Cell Setup



EGR coolers are from MY2008 Cummins ISB 6.7L (Dodge Ram)

Experimentation – Test Procedure

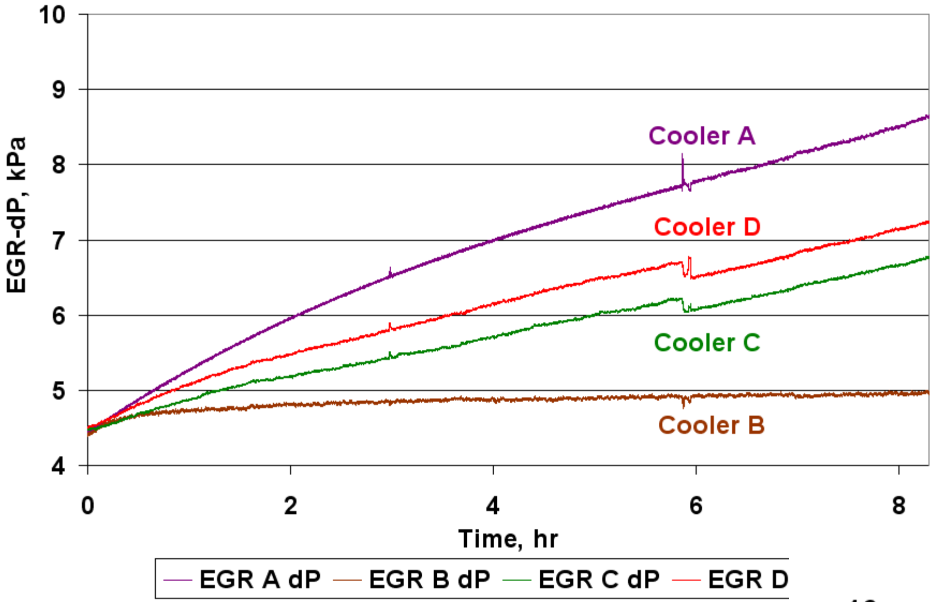
- Engine Conditions – Steady-state
  - RPM: 2000
  - Torque: 563Nm
- EGR Coolers
  - Gas Phase Flow Rate: 167 kg/hr (Balanced)
  - Coolant Flow Rate: 75L/min at 60^{o}C
- Measurements
  - EGR Cooler Inlet/Outlet Temperatures
  - EGR Cooler ΔP, Overall ΔP (EGR Cooler + PM Control Device)

Results and Discussions

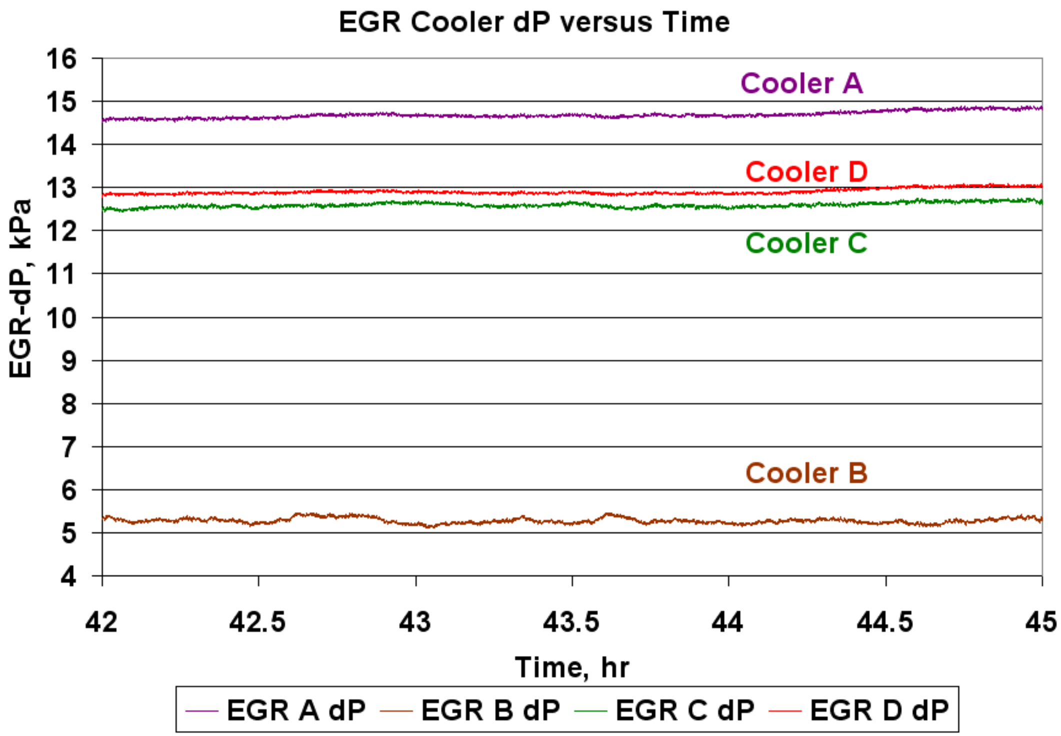
- EGR Cooler ΔP
- EGR Cooler Inlet/Outlet T
- Overall ΔP (EGR Cooler + PM Control Device)

A: Uncatalyzed PFT
B: DOC + DPF (wall-flow)
C: DOC + cPFT (Flow-through)
D: DOC + PFT (Flow-through)

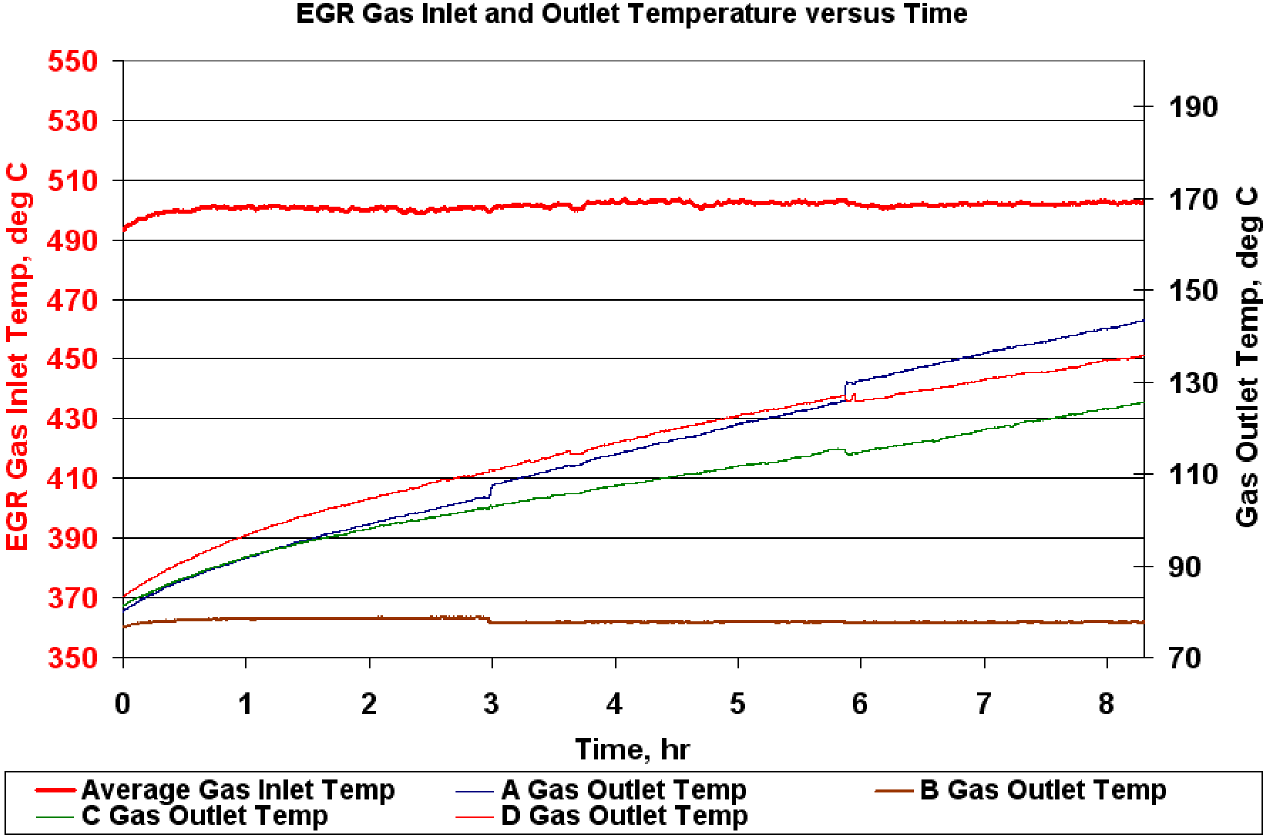
EGR Cooler Gas Pressure Drop



A: Uncatalyzed PFT
B: DOC + DPF (WF)
C: DOC + cPFT (FT)
D: DOC + PFT (FT)



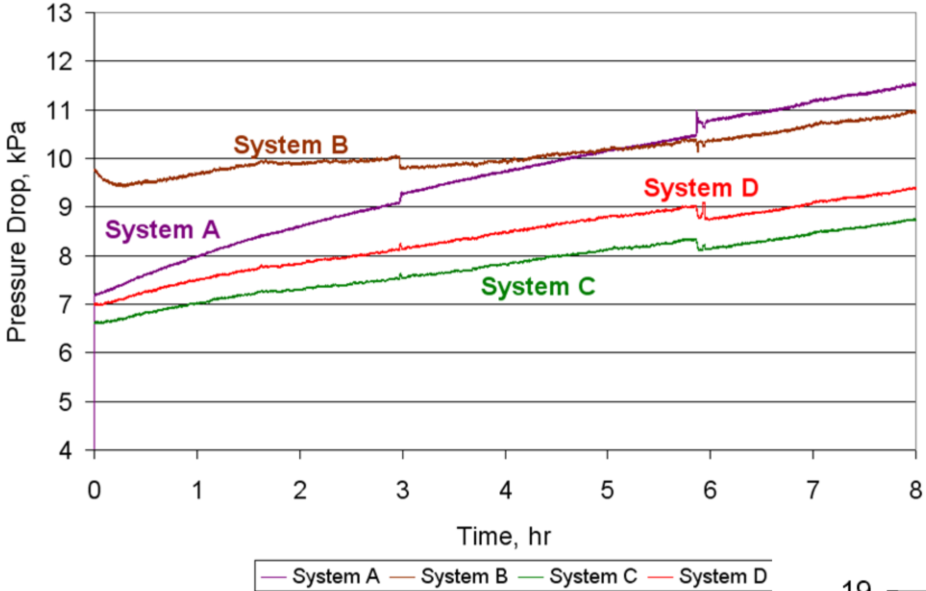
EGR Gas Temperature



A: Uncatalyzed PFT
B: DOC + DPF (WF)
C: DOC + cPFT (FT)
D: DOC + PFT (FT)

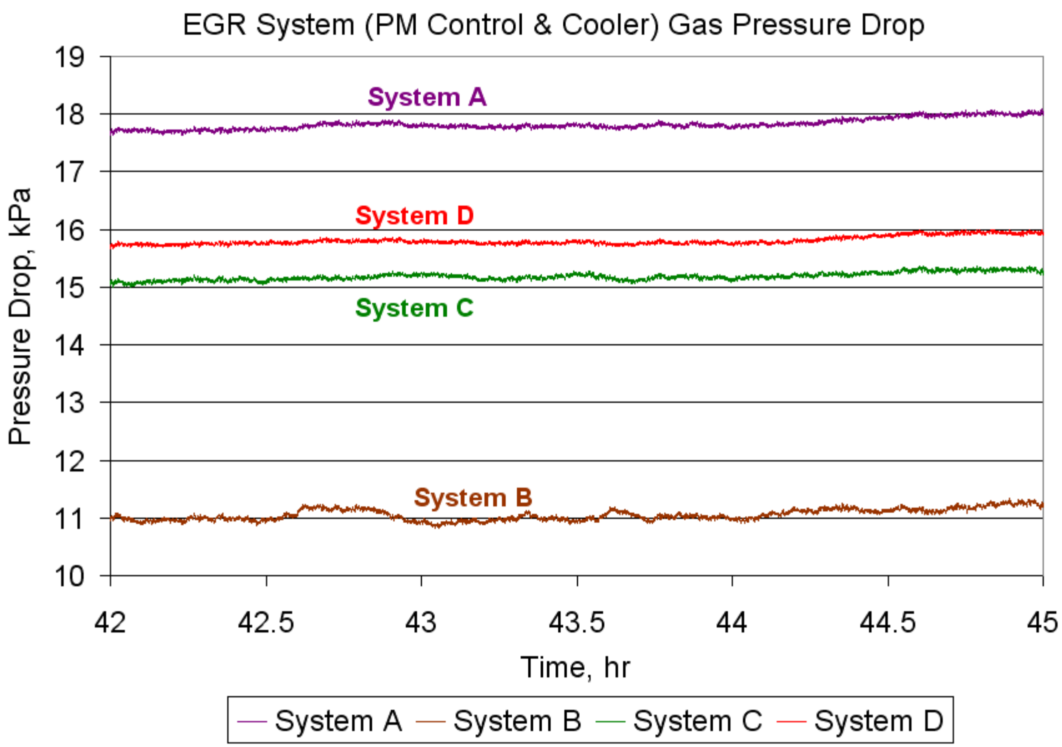
EGR Cooler	Final Outlet Temp	ΔT Rate of Change, °C/Hr
A	168°C	- 6.0
B	76°C	~ 0.0
C	172°C	- 4.5
D	175°C	- 5.3

EGR System Gas Pressure Drop



A: Uncatalyzed PFT
B: DOC + DPF (WF)
C: DOC + cPFT (FT)
D: DOC + PFT (FT)

System	% Increase
A	157
B	11
C	114
D	124



Conclusions

- Four fouling control devices evaluated
  - A: Uncatalyzed PFT
  - B: DOC + DPF (wall-flow)
  - C: DOC + cPFT (Flow-through)
  - D: DOC + PFT (Flow-through)

- The catalyzed PFT filter (C) provided no added benefit over the uncatalyzed PFT (D)

- The wall-flow DPF was the most efficient
  - Minimizing fouling
  - Lowest pressure-drop in long-run
  - Might require active regenerations

Discussion

- Cost
  - System cost vs. system maintenance
- Packaging
  - Is there space?
- Durability
  - EGR system regenerations

Future Tests

- Install the wall-flow DPF control device in a MY2007 diesel engine EGR system.
  - Determine fuel penalty / power loss effects
  - Service life system durability

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Experimentation – Engine and Diesel Fuel

Engine Type	MY2003
Displacement, cm^3	7300
Max Power, HP@rpm	235 @ 2700
Max Torque, Nm@rpm	678 @ 1600
Bore x Stoke, mm	104X162
Compression Ratio	17.5:1
Number of Cylinders	8

2003 Ford PowerStroke 7.3L

Test Fuel Properties (Commercial ULSD)

Parameters	Units	Value
Aromatics	Vol.%	21.6
Specific Gravity	kg/L	0.845
Sulfur Content	ppm	11
Cetane Number	-	43.0