Controlled Experiments on the Effects of Lubricant/Additive (Low-Ash, Ashless) Characteristics on DPF Degradation

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DEARBORN 2008 DIESEL ENGINE-EFFICIENCY & EMISSIONS RESEARCH CONFERENCE

Motivation – Ash Affects Aftertreatment Performance

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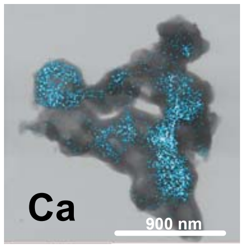
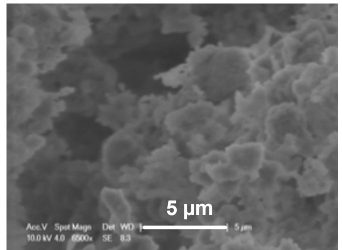
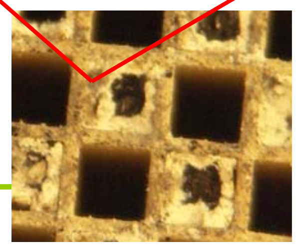
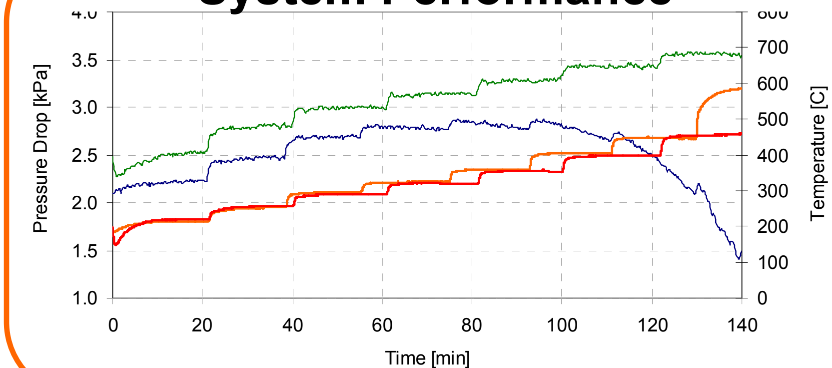
Ash Properties







System Performance



Lubricant Additives

- Zn, Ca, Mg, S, P compounds

Engine

Aftertreatment

Current State of Research

- **DPF Un-accelerated Ash Loading Studies (Fleet Testing)**
  - Cummins, BP, JM – 9 Trucks w/ 160k miles each (SAE 2006-01-3257)
- **Accelerated Ash Loading Studies**
  - Corning – 40-50 g/L ash, 1,700 – 2,600 dyno hours (DEER 2006)
  - Oak Ridge – 5% lube in fuel (DEER 2007)
  - Mani et al. – oil mist in intake (SAE 2006-01-3416, SAE 2007-01-1925)
  - Chevron – 5% lube in fuel (SAE 2003-01-1870)
  - Lubrizol – 0.2% lube in fuel (SAE 2003-01-1963)
- **Few accelerated loading studies compare results with field aged units**
- **Even less data on effects of accelerated oil consumption mechanisms on PM and exhaust characteristics affecting DPF performance**

Systematic approach to understand impact of individual acceleration methods on PM and ash characteristics to develop realistic aging protocol under carefully controlled conditions.

Experimental Apparatus – DPF Performance Testing

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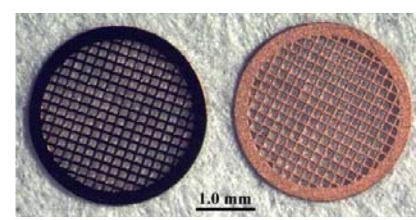
Cummins ISB used for DPF performance evaluating before and after ash loading tests on accelerated test rig.

- **Cummins ISB 300**
  - Variable geometry turbocharger
  - Cooled EGR
  - Common rail fuel injection
  - Fully electronically controlled

- **Gaseous Emissions**
  - CAI 300 HFID – Hydrocarbons
  - CAI 400 HCLD – NO/NOx
  - CAI 602P NDIR – CO/CO2/O_2
  - API 100 E – SO_2

- **Particulate Emissions**
  - Sampling and comparison to burner

Cummins ISB 300 with DPF



Accelerated Ash Loading System

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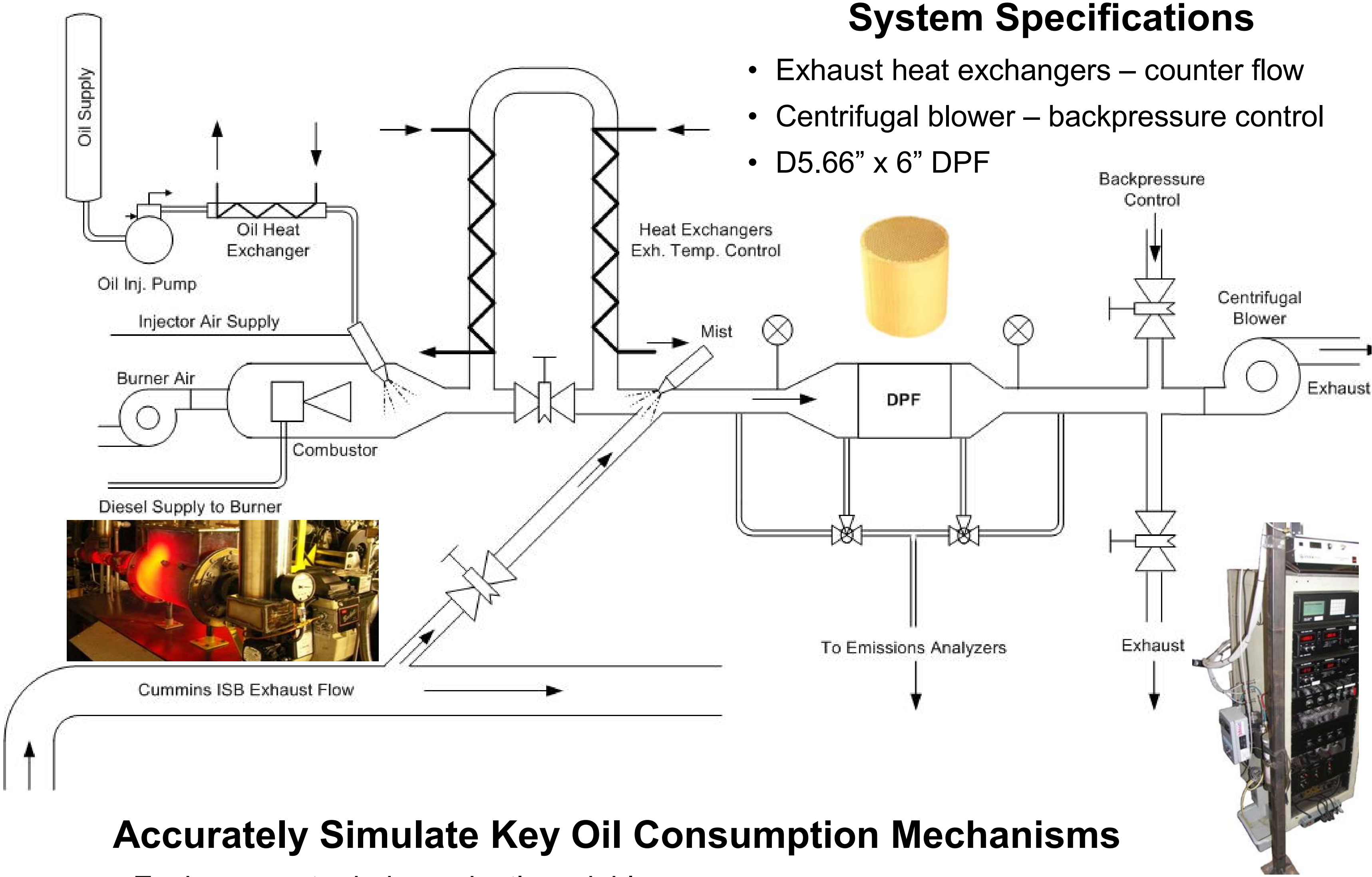
System Specifications

- Exhaust heat exchangers – counter flow
- Centrifugal blower – backpressure control
- D5.66" x 6" DPF



Accurately Simulate Key Oil Consumption Mechanisms

- Each parameter independently variable
- Precise control of quantity and characteristics of ash generated

Key Test Parameters

DPF Specifications

- Cordierite – D5.66” x 6” 200 cpsi, catalyzed
  - **CDPF-V:** ***Baseline testing***
  - **CDPF-Pt:** ***Baseline and lubricant formulations***

Lubricant Composition

- Commercial CJ-4 15w40 diesel engine oil
- Commercial base stock (ashless)

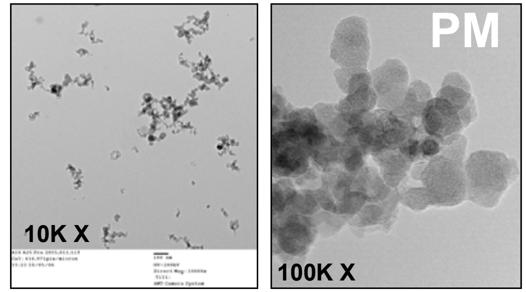
	ASTM D5185							
	B	**Ca**	**Fe**	**Mg**	**P**	**Zn**	**S**	**Mo**
Lubricant	[ppm]	[ppm]	[ppm]	[ppm]	[ppm]	[ppm]	[ppm]	[ppm]
CJ-4	586	1388	2	355	985	1226	4606	77
Base Oil	1	<1	<1	<1	8	<1	60	<1

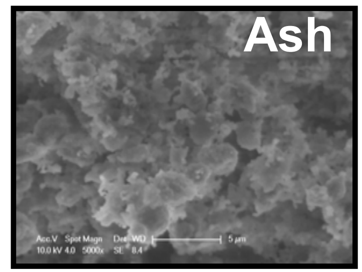
System Operating Conditions

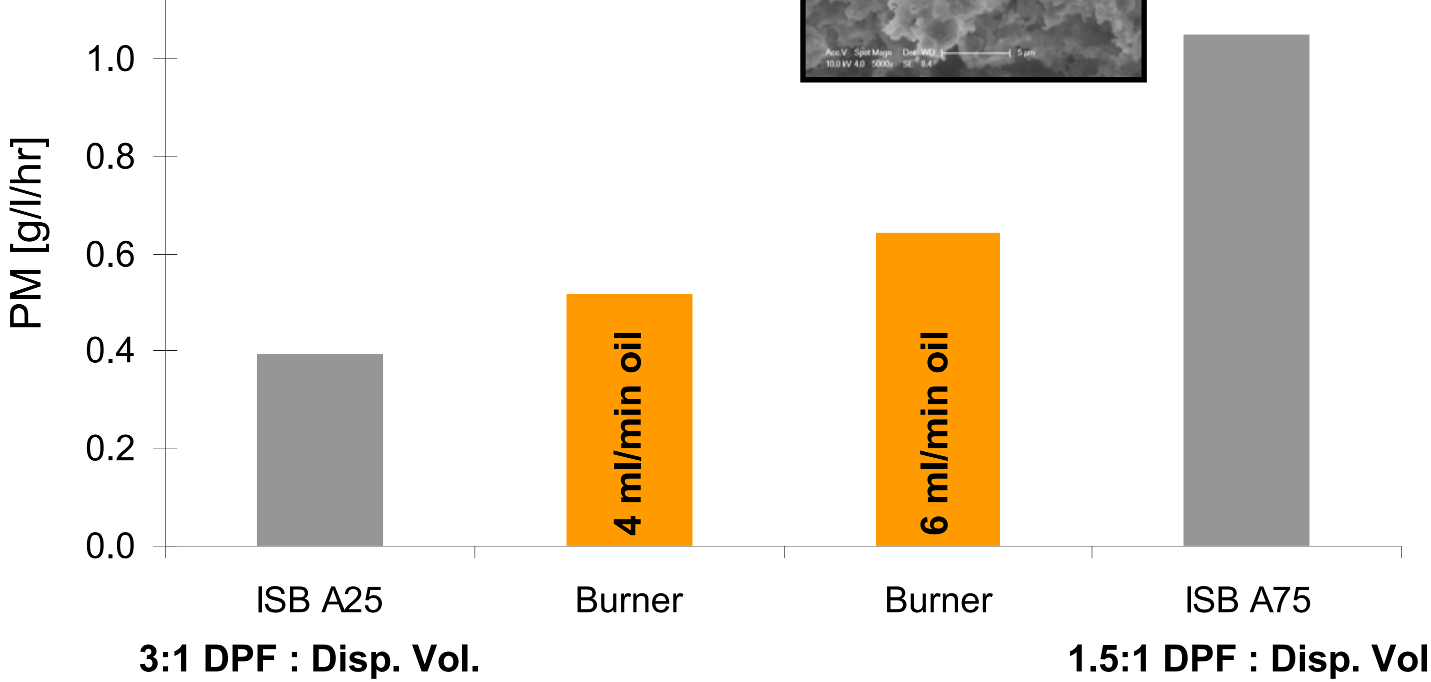
1. DPF performance evaluation (clean and aged) on Cummins ISB
2. Ash loading with accelerated loading system only to 30 – 40 g/l ash
3. Post – mortem analysis (chemical and physical) and comparison with field units

Burner PM Emission Rate Close to Engine Out PM

- **Specific PM Emissions**
  - Comparable to Cummins ISB
- **PM and Ash Characteristics** ***(SAE 2008-01-1549)***
  - Similar size range to ISB
  - Ash shows similar morphology







CDPF-Pt CJ-4 Ash Loading: Test Cycles

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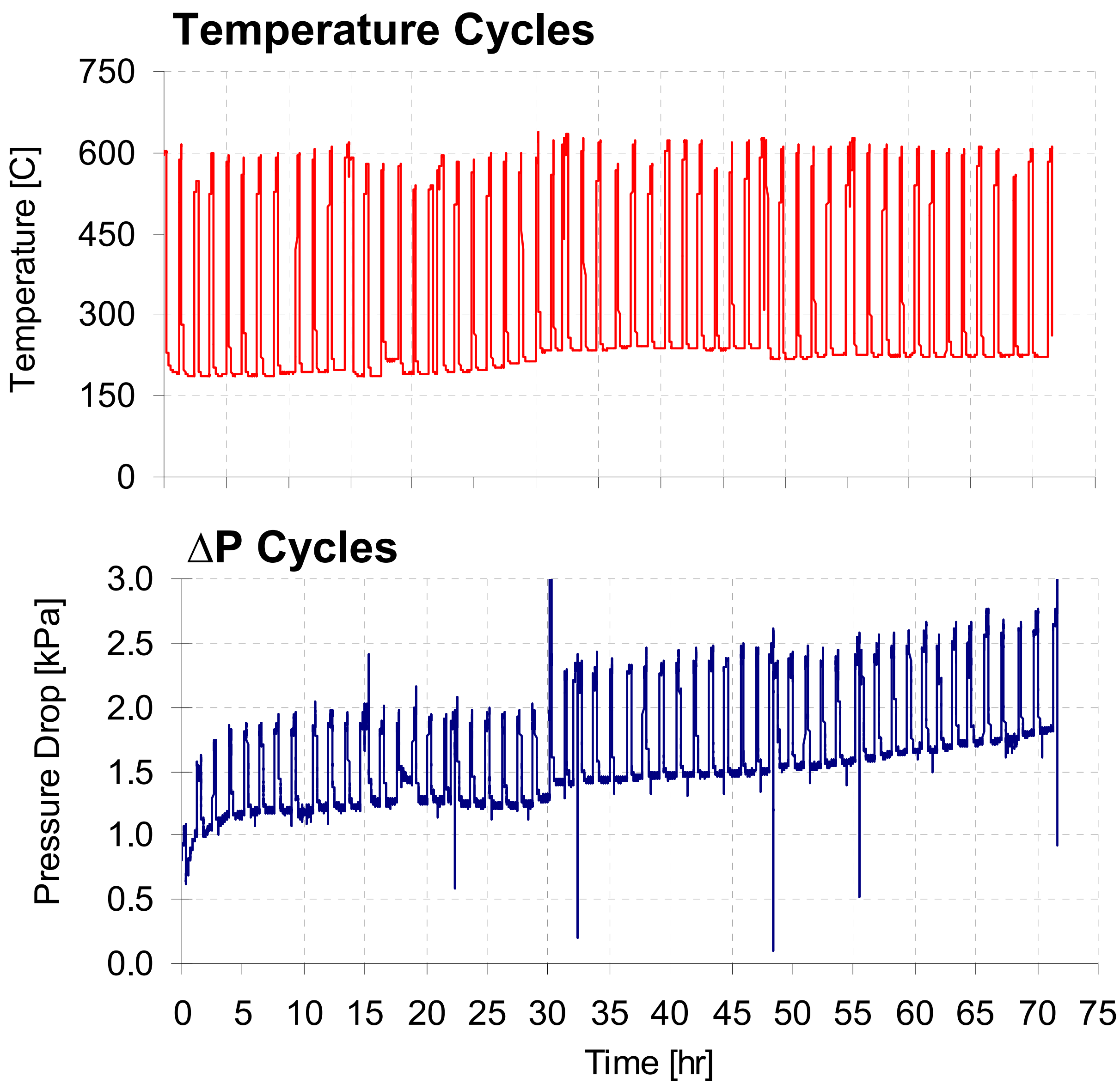
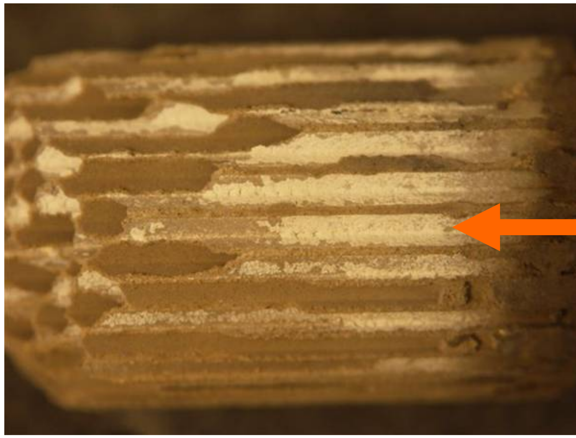


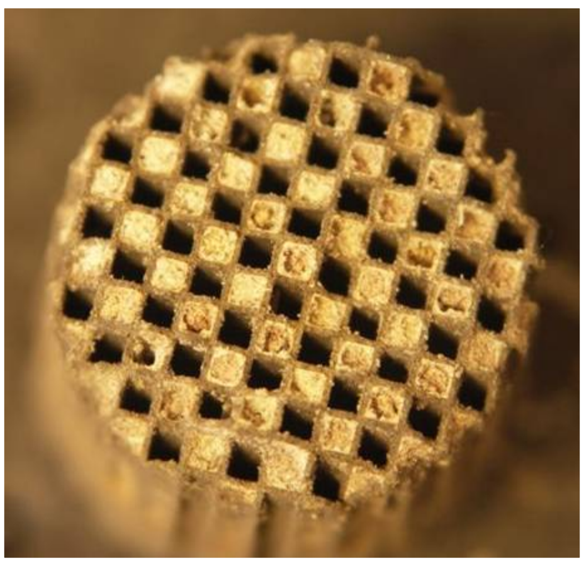
Test Parameters

- 55 cycles
- 1 hour loading @ 250 °C inlet
- 15 min. regen @ 600–620 °C inlet
- Constant exhaust flow rate
- Exhaust temp. varied via heat exchangers

CDPF-V CJ-4 Core - Accelerated Loading 33 g/L Ash

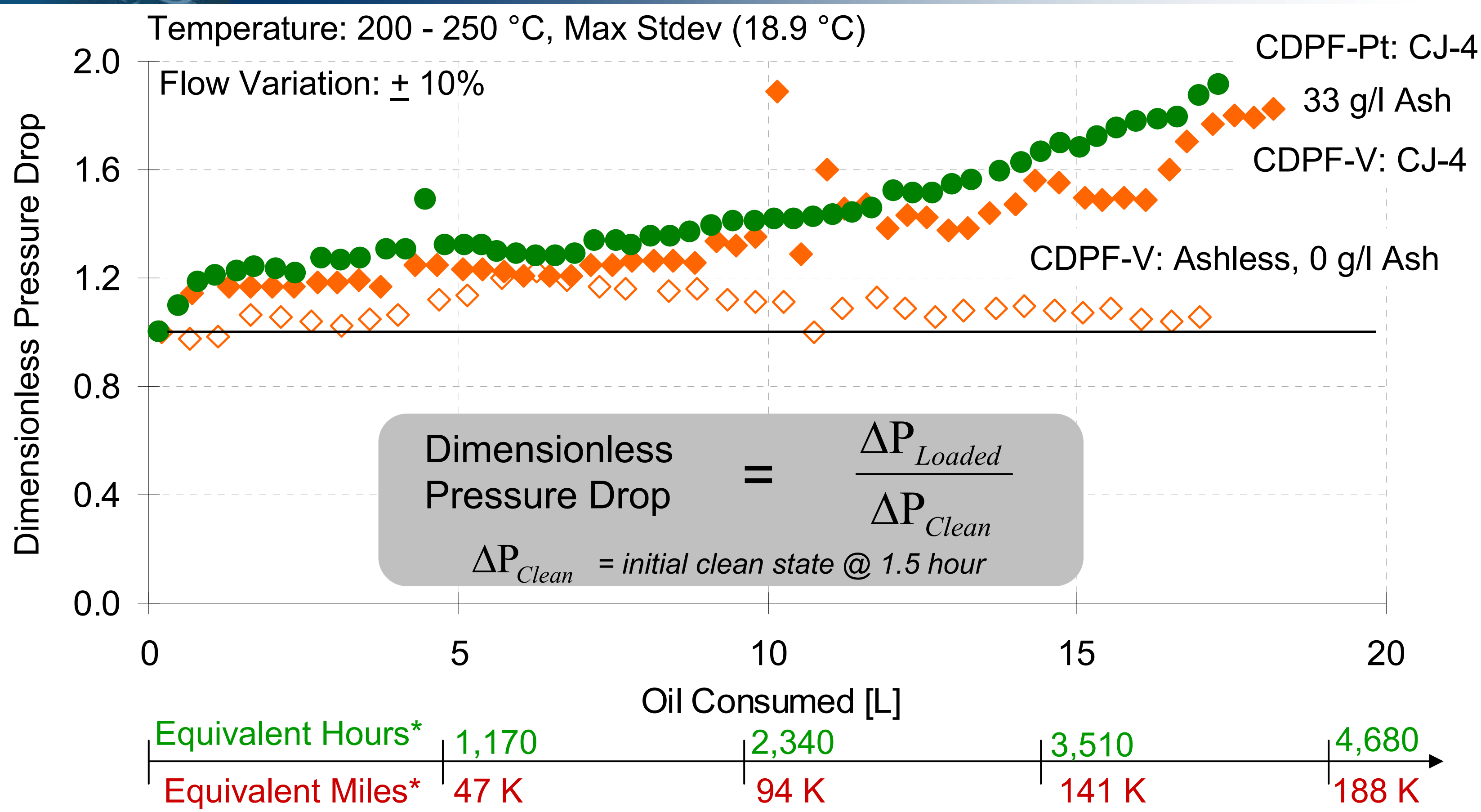


DPF Inlet



- **CJ-4 Ash Load: ~ 33 g/l in 70 hr**
- **Inlet Core Section**
  - Ash layer thickness increases with increasing distance from filter face
- **Ash Plugs at Back of Filter**
  - Plugs 1.5” to 1.8” long

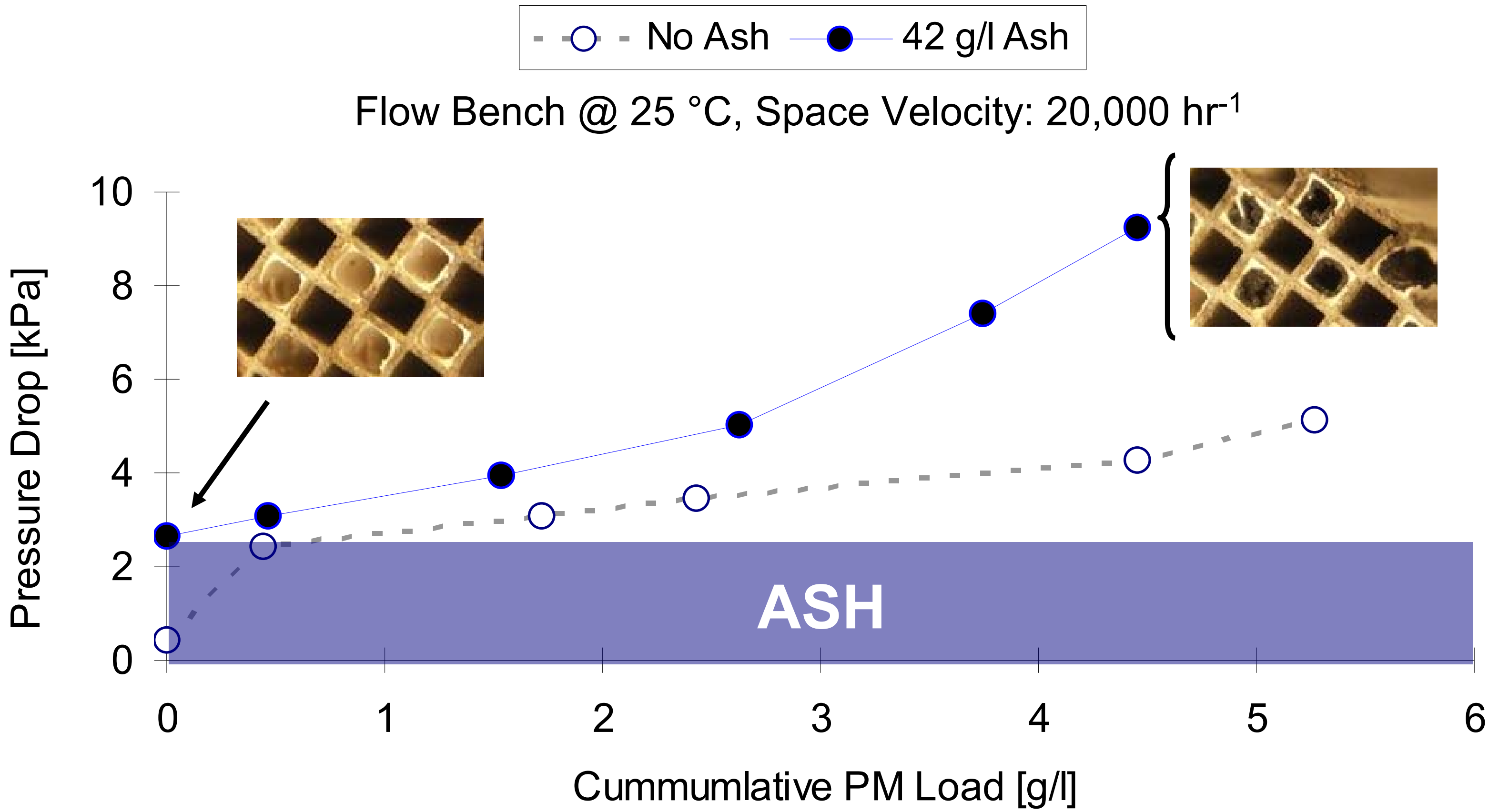
Pressure Drop Comparison: CJ-4 and Ashless Oils



- **Pressure drop increase with ash load (little change w/ base oil)**
  - Ash at 33 g/L increased ΔP by factor of **1.8 – 1.9** over clean case

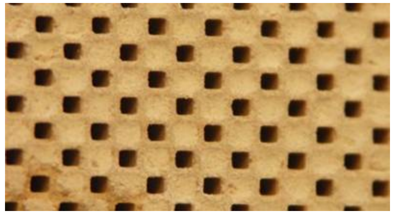
* Assumes: 15 g/hr avg. oil consumption, avg. speed of 40 mph, and full size DPF of 12 L volume

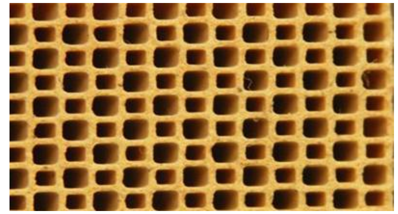
Ash and Soot Effects on Pressure Drop: CDPF-Pt

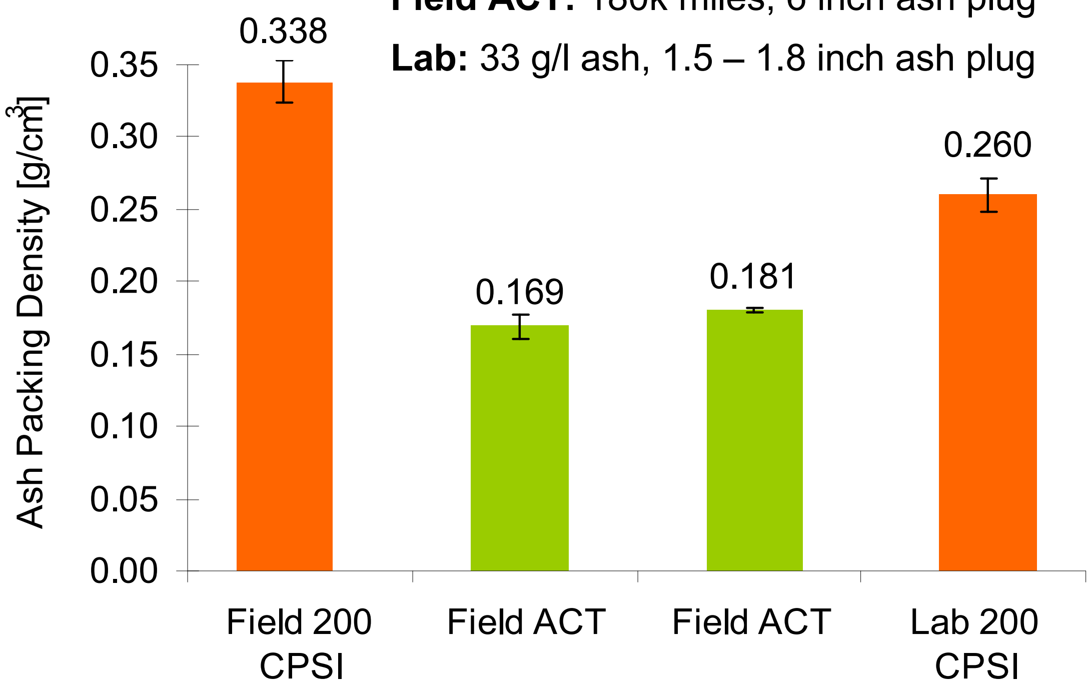


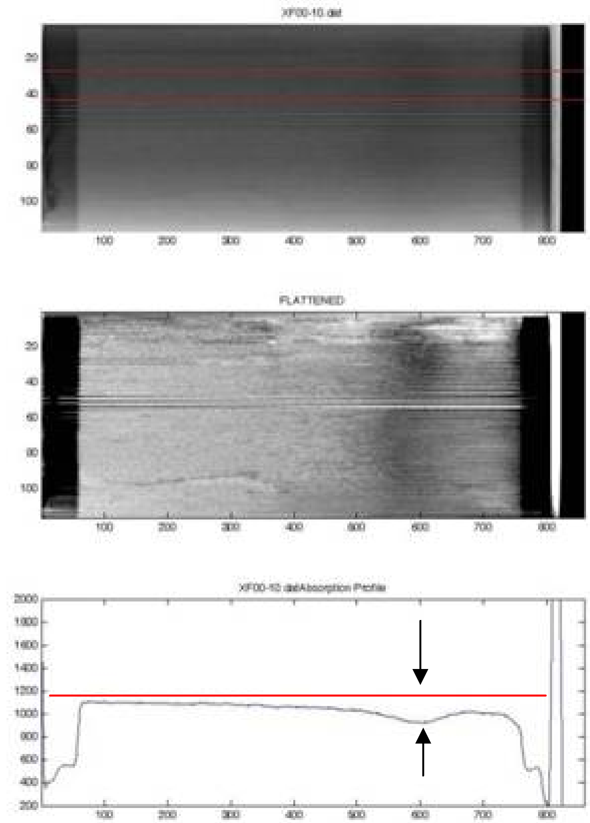
- **Soot accumulation in DPF containing ash results in:**
  1. Pressure drop less sensitive to low PM loads (<2 g/l) in DPF with ash – loss of deep bed filtration
  2. For moderate and high soot loads (>3 g/l) pressure drop increases more rapidly with additional PM loading for DPF with ash vs. clean DPF

Lab Aged DPF Ash Density Comparable to Field Ash









Analysis Courtesy: ORNL, X-Metrix Inc.

Ash Plug Packing Density Comparison

- DPF loaded on accelerated loading system comparable packing density to field ash

Ash Elemental Composition Similar: Lab and Field

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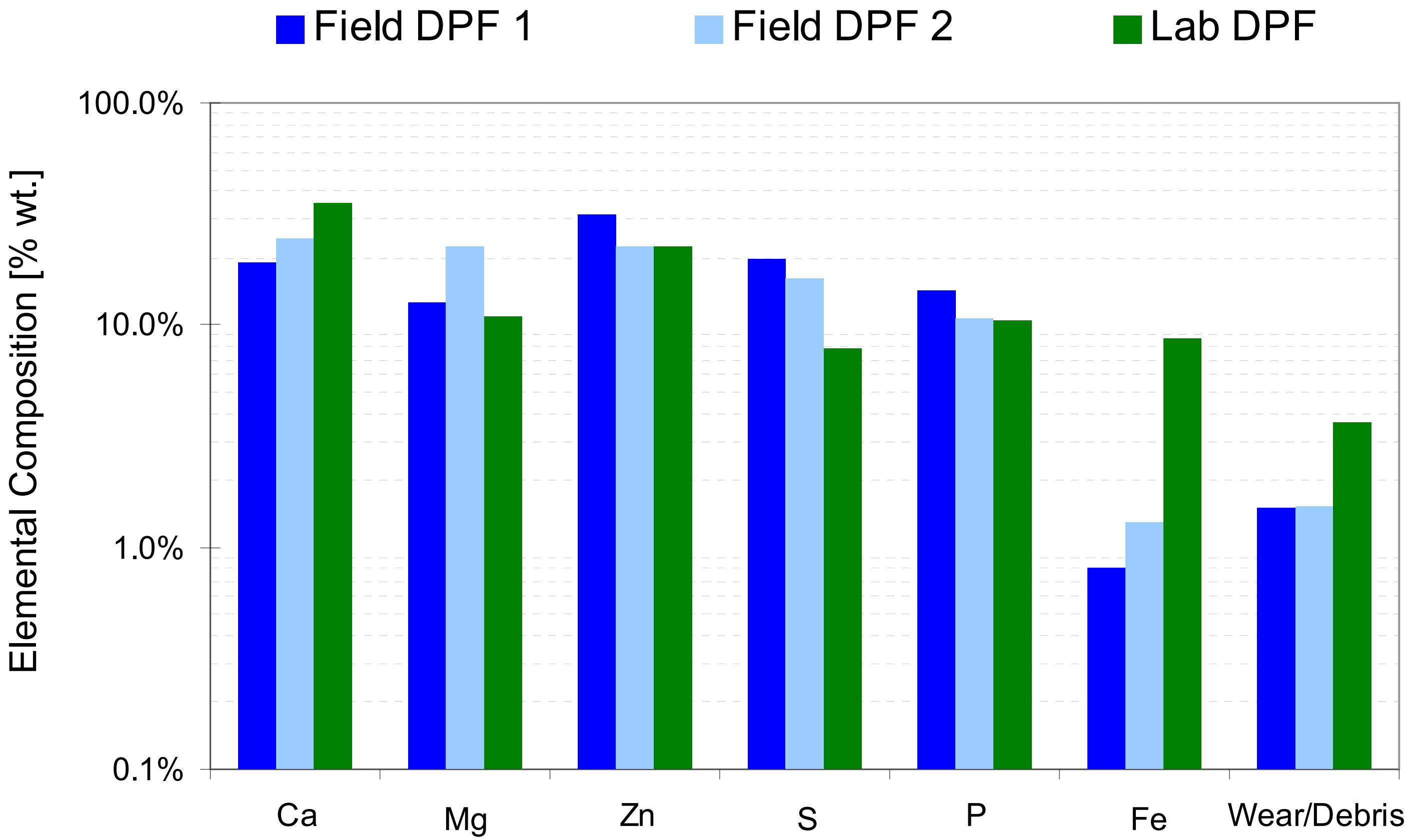
Field DPF: ~180k miles, 6 inch ash plug



Inductively Coupled Plasma (ICP) elemental analysis

- Zn and P levels similar in field and lab ash samples
- Lab ash shows elevated Ca and lower S levels than field ash possibly due to differences in speciated lube oil consumption

Ash Density Affected by Temperature History

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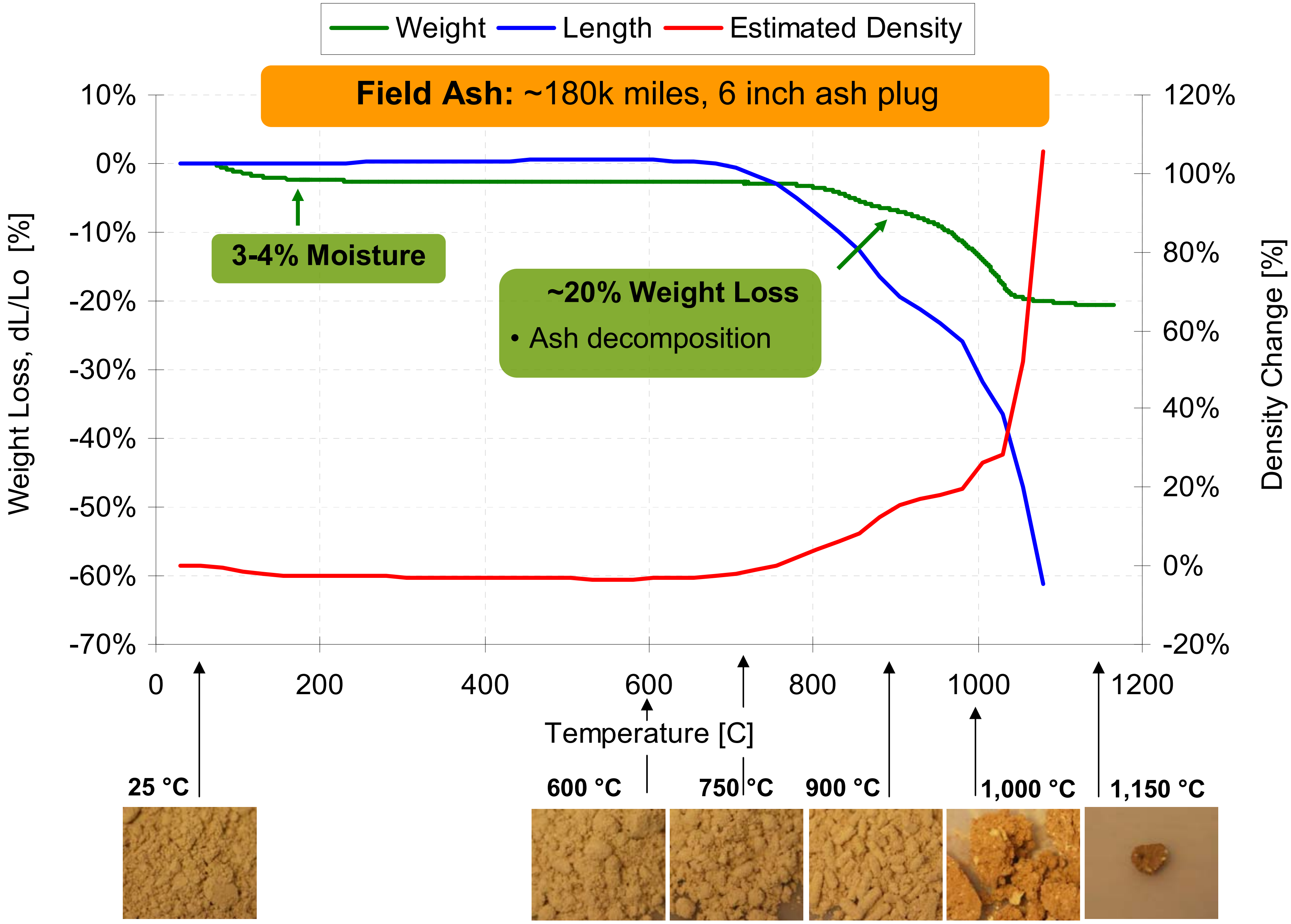

Summary and Conclusions

Accelerated ATS Ash Loading System

- D5.66” x 6” DPFs loaded to 33 g/L ash in 70 - 80 hr
- Emissions (PM and ash) similar to engine and field samples

DPF Performance

- No ash or increase in pressure drop measured in test with base oil
- Ash at 33 g/L increases pressure drop by 1.8X – 1.9X over initial level
- Ash decreases pressure drop sensitivity to low soot loads
- For soot loads (> 3g/l) increase in pressure drop due to additional soot deposition more acute in DPFs containing ash vs. clean DPF

Ash Characteristics

- Packing densities measured from 0.17 – 0.34 g/cm^3 (lab and field ash)
- Similar elemental composition for lab and field ash
- Ash density and composition sensitive to temperatures > 800 °C

Future Work

Targeted experiments to isolate specific additive effects (Ca, Zn, P, etc.)

1. Base oil + detergent additive
2. Base oil + anti-wear additive
3. Specific oil/additive combinations

Relate additives to ash properties affecting DPF performance

1. Physical properties (morphology, packing density) affecting flow
2. Chemical properties affecting catalyst performance

Acknowledgements

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- Cummins	**- Detroit Diesel**	**- Komatsu**
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- Valvoline	***Ford***	

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