THE APPLICATION OF CATALYZED SOOT FILTERS TO DoD DIESEL ENGINES - A STATUS REPORT -

DEER CONFERENCE
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Project Support and Participants

Funding:

DoD's Environmental Security Technology Certification Program (ESTCP)

Cummins Engine Company

Department of Energy

Participants:

Cummins Engine Company, Columbus IN

Naval Facilities Engineering Service Center, Port Hueneme CA

DoD Field Testing Sights: Hill AFB, Fort Irwin, Camp Pendleton

Michigan Technological University

University of Utah

Acknowledgement: Project initiated with support of Dr. Jim Patten and Lou Broering of Cummins Engine Company

Compliant and Exempt DoD Diesel Engines

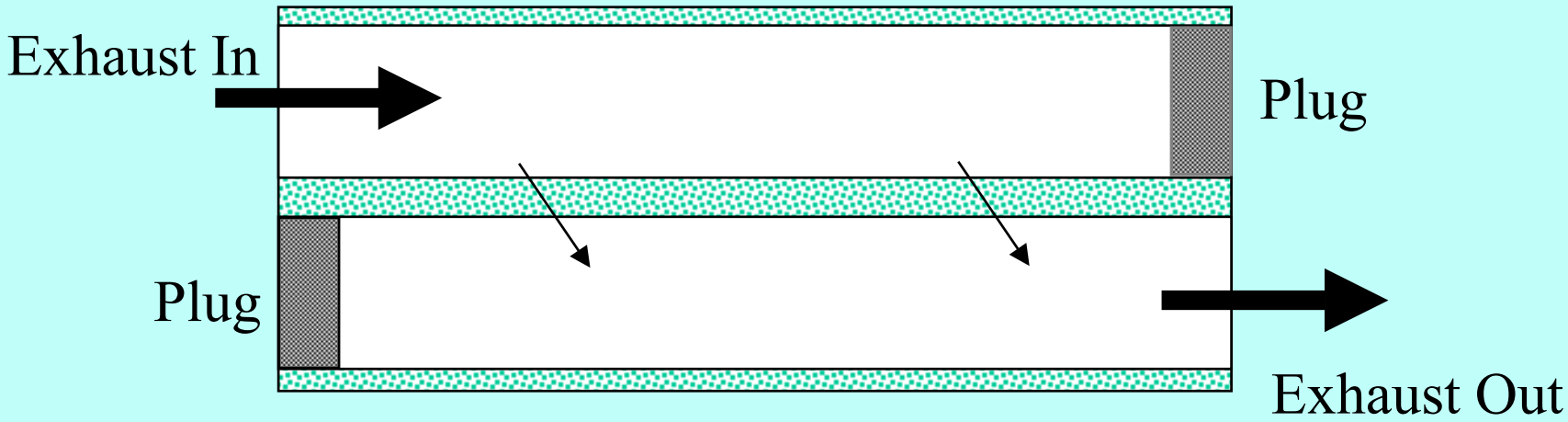
- Compliant Engine Groups
  - Commercial vehicles such as maintenance trucks and buses
  - Non-deployable off-road equipment such as cranes, loaders, earthmovers, and backhoes.
  - Non-deployable marine engines such as port spill containment equipment.
  - Stationary engines such as emergency and peak-shaving generators.
- Exempted Equipment Groups
  - Combat equipment, combat ships and craft, and tactical HUMVEEs, 4x4 trucks, and tanks.

Department of Defense Research, Development, and Implementation of Environmental Technologies

- SERDP - Strategic Environmental Research and Development Program for investigating and developing promising new approaches to minimize or remove major negative environmental impacts on DoD's ability to conduct its mission.
- ESTCP - Environmental Security Technology Certification Program for demonstrating/validating (via full-scale field testing) new environmental technologies to mitigate the impact of DoD operations on the environment.
- Various investigative bodies within each of the services also support and conduct R&D efforts to mitigate the impact of DoD operations on the environment.

Wall flow filter representation

- The engine exhaust enters the filter where it is forced to flow through a porous wall



- Soot collects with a combination of deep-bed filtration and surface filtration on the porous walls

CSF Background

- Particulate filter development programs for over 15 years
- Passive CSFs require no external means for regeneration
  - The catalyst reduces temperature required for soot oxidation
  - Removes the solid portion of the particulate, oxidizes gas CO, HCs
  - Requires no controls or regeneration hardware
- Application requirements
  - Requires that the engine exhaust temperature be periodically high to regenerate the filter
  - Exhaust temperature dependent on engine duty cycle and ambient conditions for regeneration
    - Seasonal variations
    - Not all applications operate with conditions sufficient to insure regeneration
  - Soot oxidation rate dependent on engine out particulate levels
- Active CSFs utilize external means for regeneration

TECHNICAL OBJECTIVES

- Survey and field-screen DoD diesel engine operating systems to establish the applicability of catalyzed soot filters.
- Conduct laboratory testing to improve CSF regeneration criteria.
- Characterize size distribution and chemical composition of PM upstream and downstream of CSF.
- Measure effectiveness of PM reduction in the field using three measurement methods.
- Demonstrate the CSF as an effective, minimum-cost approach for reducing PM, hydrocarbon, and CO emissions from new and retro-fit DoD diesel engines.
- Outline procedures and assist with implementation of the CSFs on DoD diesel engines.

CSF MILESTONES

	SCHEDULED COMPLETION	STATUS
Phase I		
• Conduct CSF calibration tests at Cummins	Apr 00	Complete
• Prepare preliminary list of test platforms (88 systems)	Jul 00	Complete
Phase II		
• Select 20 engine systems for field screening tests	Aug 00	Complete
• Install data loggers and instrumentation	Dec 00	Complete
• Conduct screening tests	Jan 01	Complete
• Perform data analysis	Feb 01	Complete
Phase III		
• Select 8 engine systems for demonstration	Feb 01	Complete
• Complete application engineering	May 01	Complete
• Install CSF at field test sites	Jun 01	Complete
• Install "Active" CSF at Field Test Sites	Oct 01	In Progress
• Complete CSF field demo tests	Jan 02	
Phase IV		
• Issue final report - Assist with CSF implementation	Mar 02	

SUMMARY OF OTHER PROJECT PROGRESS

- **MTU CSF PM2.5 Characterization.**
  - **Particle size distribution measurements complete.**
  - **Ames test complete.**
  - **Initial chemical species characterization - completed May 2000.**
  - **Thesis report of work – 1st phase completed July 2000 (350ppm S, EGR)**
  - **Thesis report of work – 2nd phase nearing completion (15ppm S, EGR)**

- **Oak Ridge National Laboratories**
  - **Particle size distribution - completed.**
  - **Effect of sample dilution on PM2.5 size distribution - completed.**

Existing Diesel Engine System Information

Item	Location	Description	Unit ID	Weight	Engine Manuf.	Engine Model	Engine HP	Intake Type	Engine Serial Number	Engine Nameplate Data	Year of Manuf.	Electronic Engine Controls	Fuel System Type
1	CBC Port Hueneme, Bldg 806	John Deere Backhoe Loader	USN 48 18378	15,858	John Deere	301D	70	Naturally Aspirated	T04030D465416		1994	No	Rotary
2	CBC Port Hueneme, Bldg 806	International Dump Truck-4900, 6X6	USN 96 44857	GR 46,000 SH 21,075	International	DTA-466		Turbo-Water to Air	673538		1993		Inline Pump w/Aneroid
3	CBC Port Hueneme, Bldg 806	Chevy Pickup	USN 94 30533	9200	Chevy	6.2L	155	Naturally Aspirated	1GCHV34J4HJ165807	Model CV30903			Rotary
4	CBC Port Hueneme, H-46	HMMWV	USN 94 50690	GR 7,700 SH 5,200	GM	6.2L 1990		Naturally Aspirated	1GHMRR2563867	1990 MYLGM06.20A83	1993	No - Glow Plugs	Rotary Pump

Emissions Data	Fuel Type	Muffler P/N & Size	Filter Placement Info	Unit Power	Application Potential	Basis For Rating	Reason for Disqualification
	DF-2	20L, 7-1/4D, 3" Inlet/Outlet	2" Diameter Growth Possible	12 Volt	Poor	Low Use, Difficult Installation	Inadequate Filter Installation Space
	DF-2	32L, 8-1/4 X 11W	48L x 13 Diameter Growth Possible	12 Volt	Good	Easy Installation, Difficult To Find High Usage Vehicle	Low Use
1987 H.D. Eng	DF-2	20L, 10 x 5-1/2D, 2.5" End in/Out, 90 inches from Engine, Dual Exhaust	Can move muffler 30" forward, Drive Shaft to Frame Dist. 12"	12 Volt	Good	Easy Installation	Too Old
Exempt	DF-2	30L, 7.5D, Offset in/90 Degree Out	1" Diameter Growth Allowable, 2" clearance to Drive Shaft, 1-14" to Transfer Case	24 Volt	Good	Marginal Installation, Very High Number of Units, Old Version of HMMWV	Being Phased Out

A STUDY OF THE EFFECT OF A CATALYZED PARTICULATE FILTER ON THE EMISSIONS FROM A HEAVY-DUTY DIESEL ENGINE WITH EGR

SAE 2001-01-0910

By

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SAE 2001 World Congress, Cobo Center, Detroit, MI, USA

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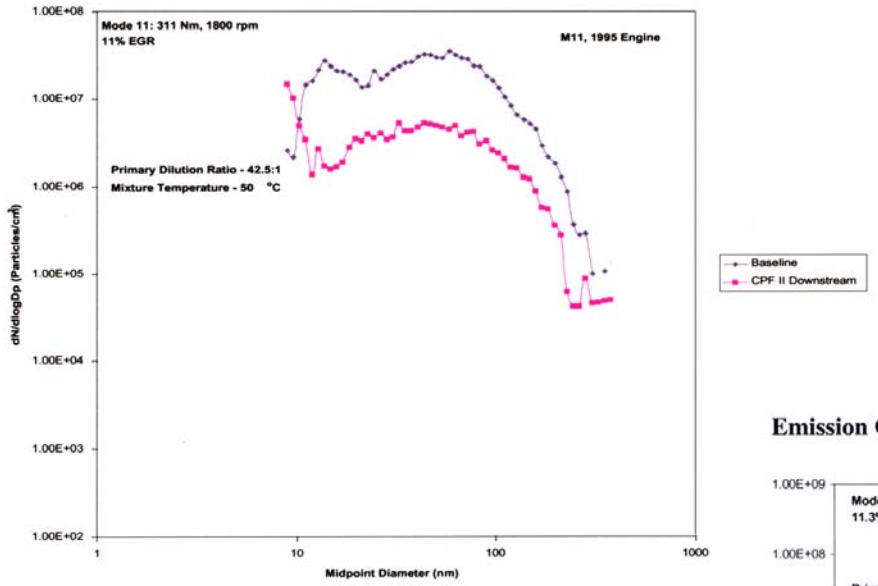
OBJECTIVES

- **Perform a literature review concerning the catalyzed particulate filters (CPF), EGR, particle formation and measurement of particle size distribution.**
- **Determine the filter pressure drop, particulate mass characteristics, filtration efficiency and regeneration efficiency for the CPF at different engine operating conditions to evaluate its performance.**
- **Investigate the effect of CPF on the TPM, SOF, Solids, Sulfates, XOC, NOx, HC, PAH in the SOF and XOC and screening for Mutagenic activity by performing emission characterization in the baseline and downstream of the CPF at two different engine modes.**

EXPERIMENTAL RESULTS AND DISCUSSION

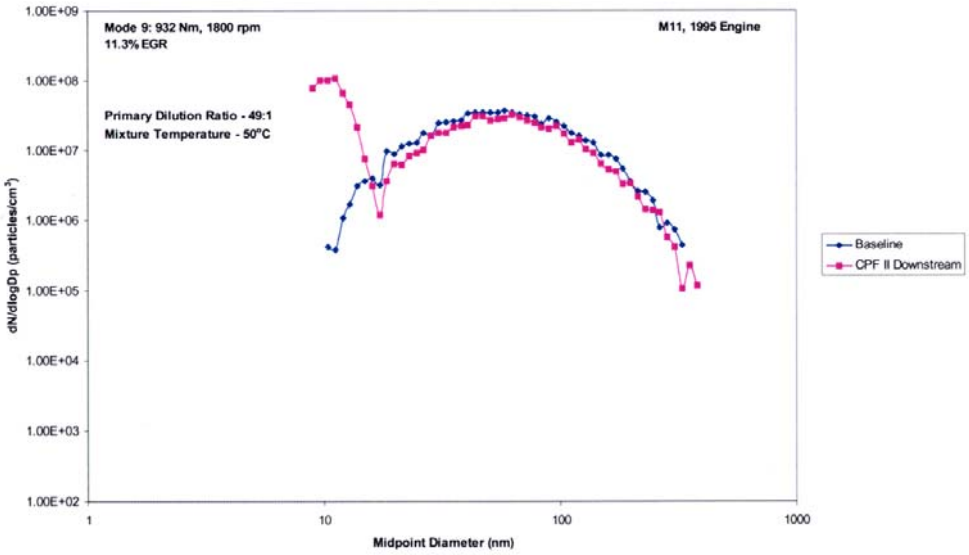
Particle size distribution measurements

Emission Characterization - Comparison of Particle Number Concentrations at Mode 11

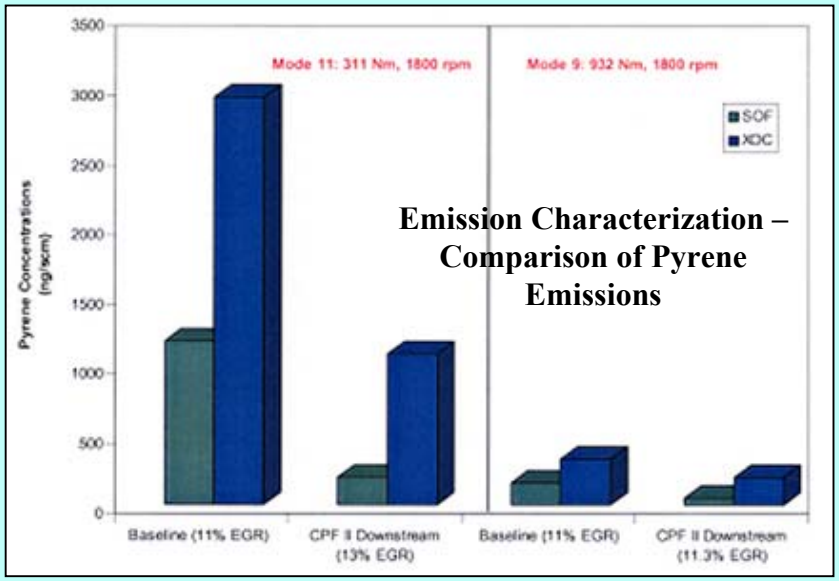


Experimental results and discussion

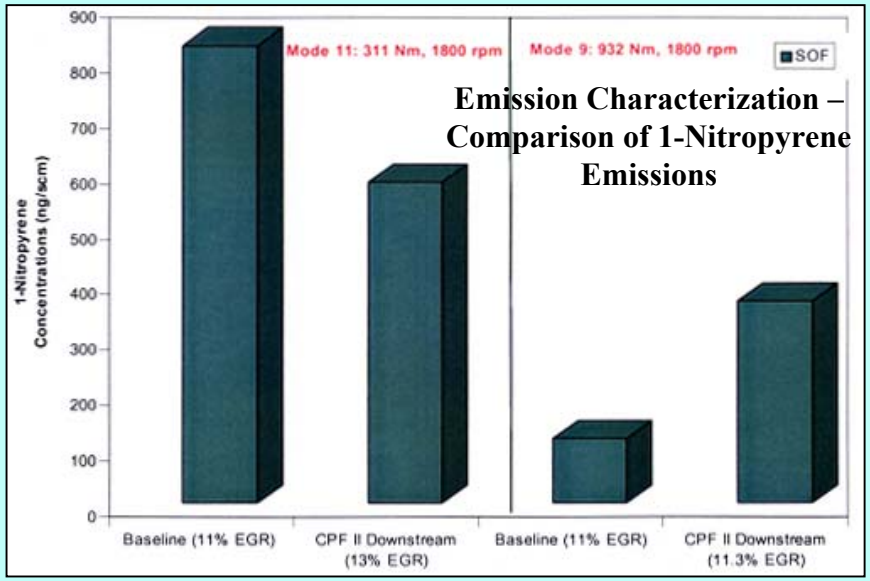
Emission Characterization - Comparison of Particle Number Concentrations at Mode 9



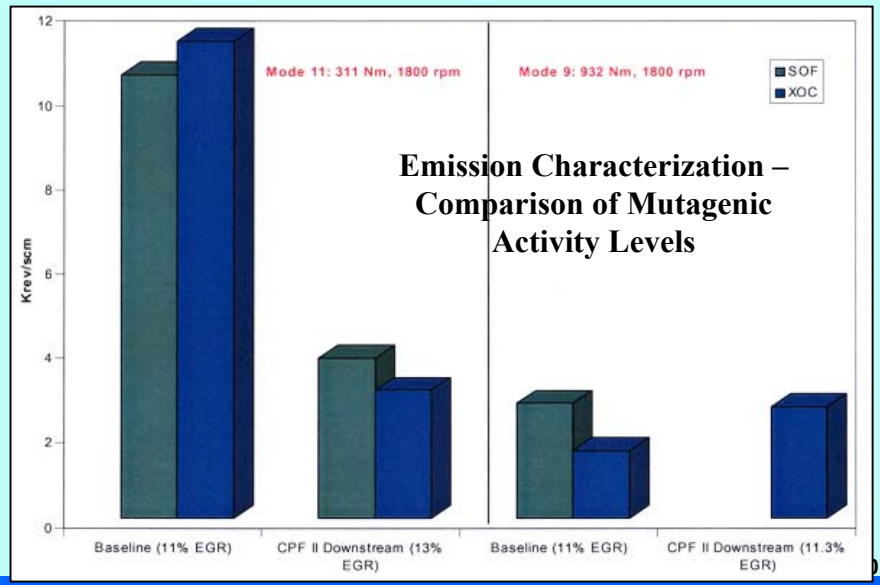
EXPERIMENTAL RESULTS AND DISCUSSION



Emission Characterization – Comparison of Pyrene Emissions

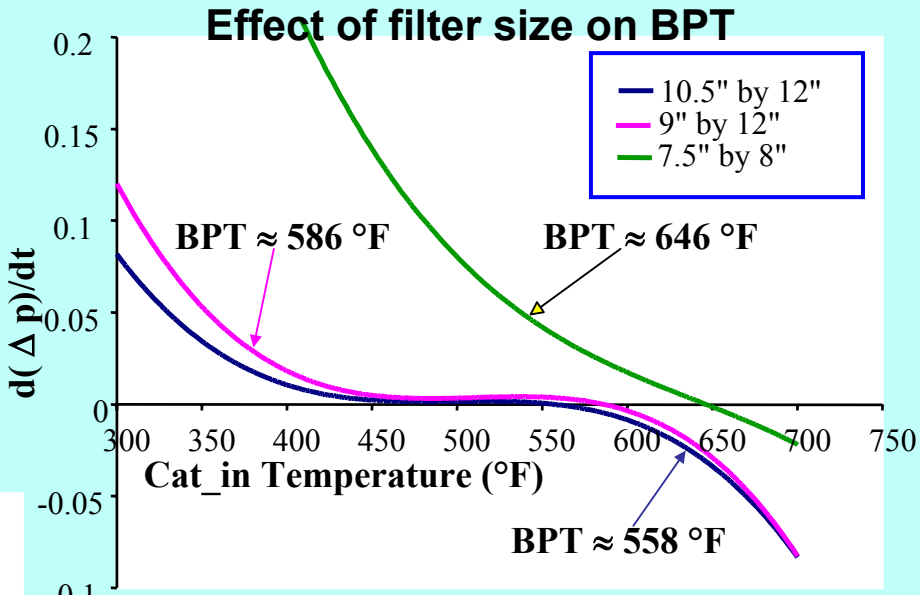


Emission Characterization – Comparison of 1-Nitropyrene Emissions

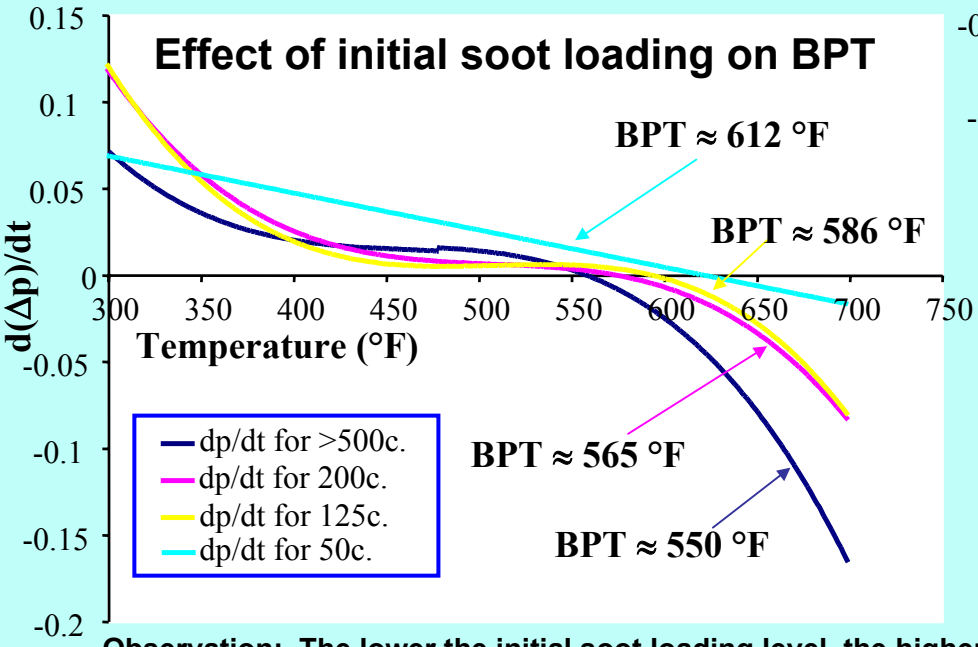


Emission Characterization – Comparison of Mutagenic Activity Levels

Laboratory Testing to Refine Balance Point Temperatures for CSFs

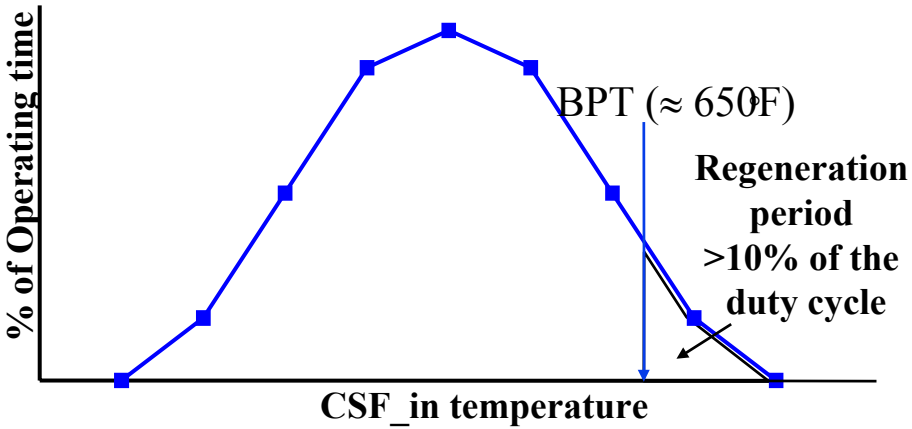


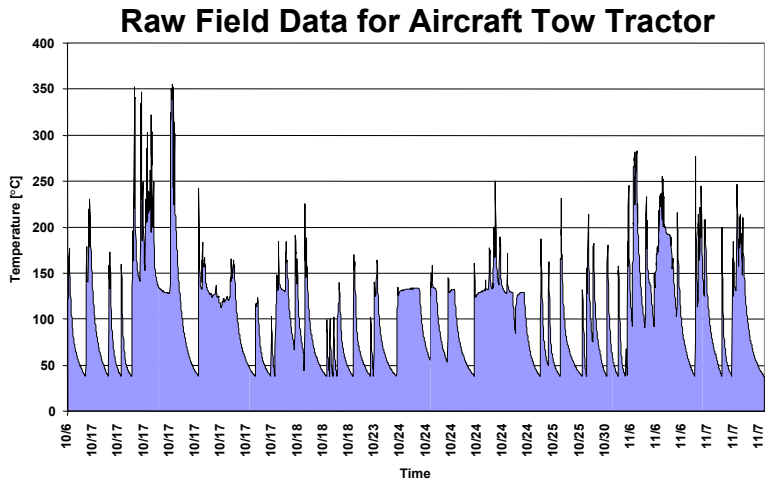
Observation: The lower the filter size, the higher the BPT

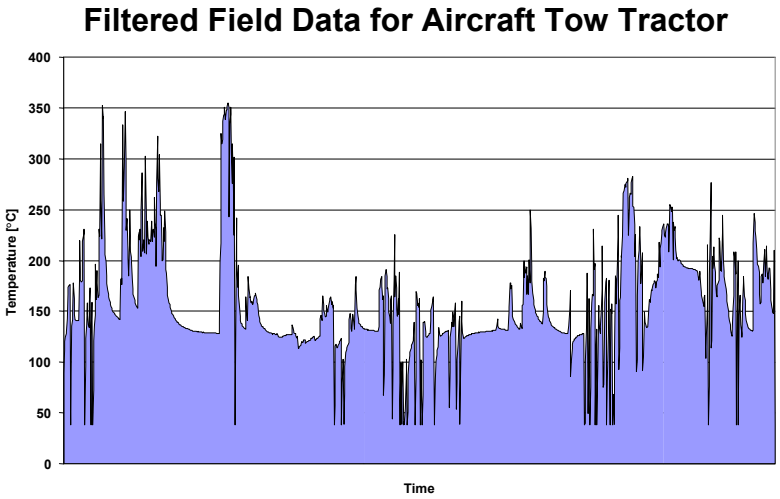


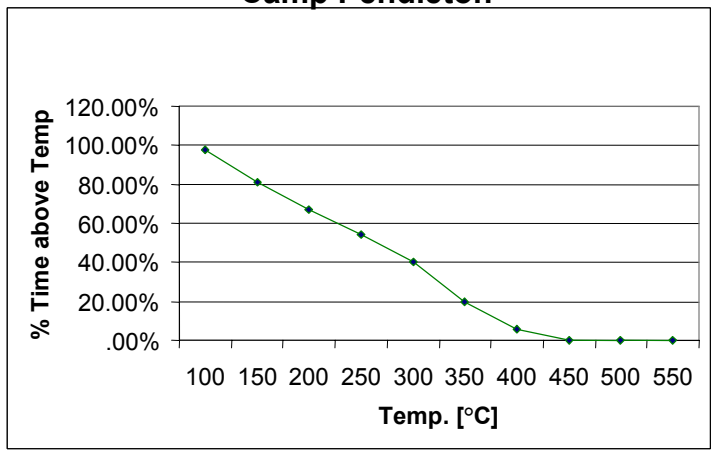
Observation: The lower the initial soot loading level, the higher the BPT

Field Test Data Showing Fraction of Time Exhaust Temperature is Above BPT

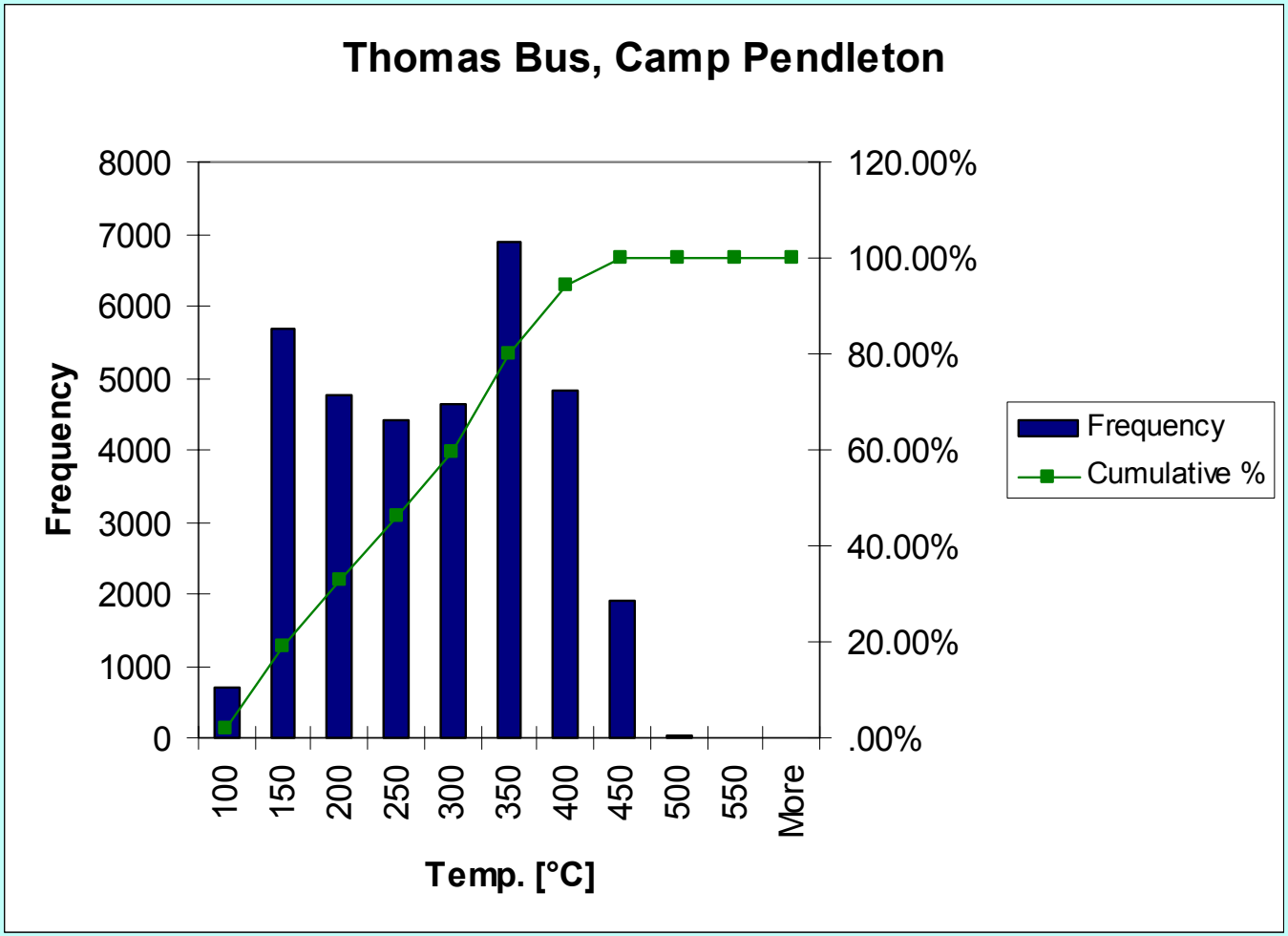








CAMP PENDLETON ANALYSIS CHART from DATA



FIELD SCREENING DATA

Application	Engine	% Time above 650^{0}F
NAS Point Mugu		
Aircraft tow tractor	*Perkins*	*0.93*
Equip. tow tractor	Continental	0
Manlift	Deutz	0
Channel Islands ANG		
Refueling Truck	C8.3-250	0.97
Fort Irwin		
Bluebird Bus	*B5.9-230*	*18.36*
Thomas Bus	*ISB-230*	*17.15*
Stake Truck	*B5.9-175*	*14.85*
Hummer	*GM 6.5L*	*2.87*
Generator	John Deere	1.37
Hemmit Refueler	DDC Silver 92	2.42
Equip. Transporter	DDC Silver 92	11.12

Proposed Active CSF
Passive CSF

FIELD SCREENING DATA
(continued)

Application	*Engine*	*% Time above 650⁰F*
Camp Pendleton		
10 kW Generator	ONAN	0
Bluebird Bus	*B5.9-190*	*6.57*
Thomas Bus	*CAT 7.2L*	*22.8*
PWC San Diego		
Ford 9000 Tractor	*CAT 3406B*	*2.14*
Grove Crane	*C8.3*	*5.19*
Manitowoc Crane	C8.3	0.01
Hill AFB		
15-ton crane	B5.9-177	1.78
Aircraft tow tractor	B5.9?	0.22
Generator B5.9-185	*15.45*	

Proposed Active CSF
Passive CSF

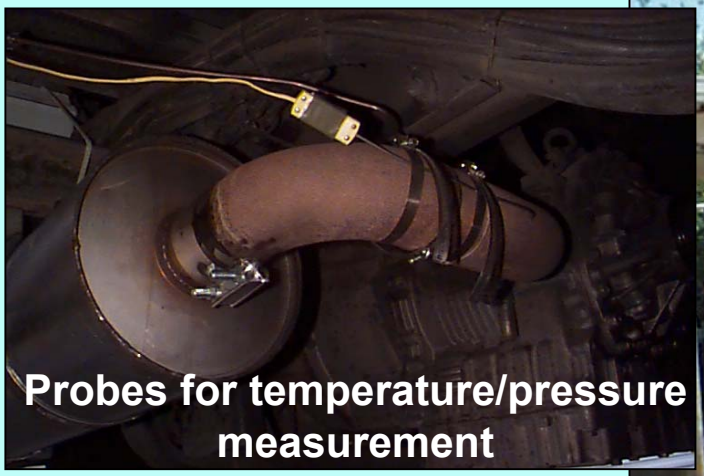
DEMONSTRATION SITE LOCATIONS

- Preliminary engine exhaust testing was completed on a total of 20 engines at the following locations:

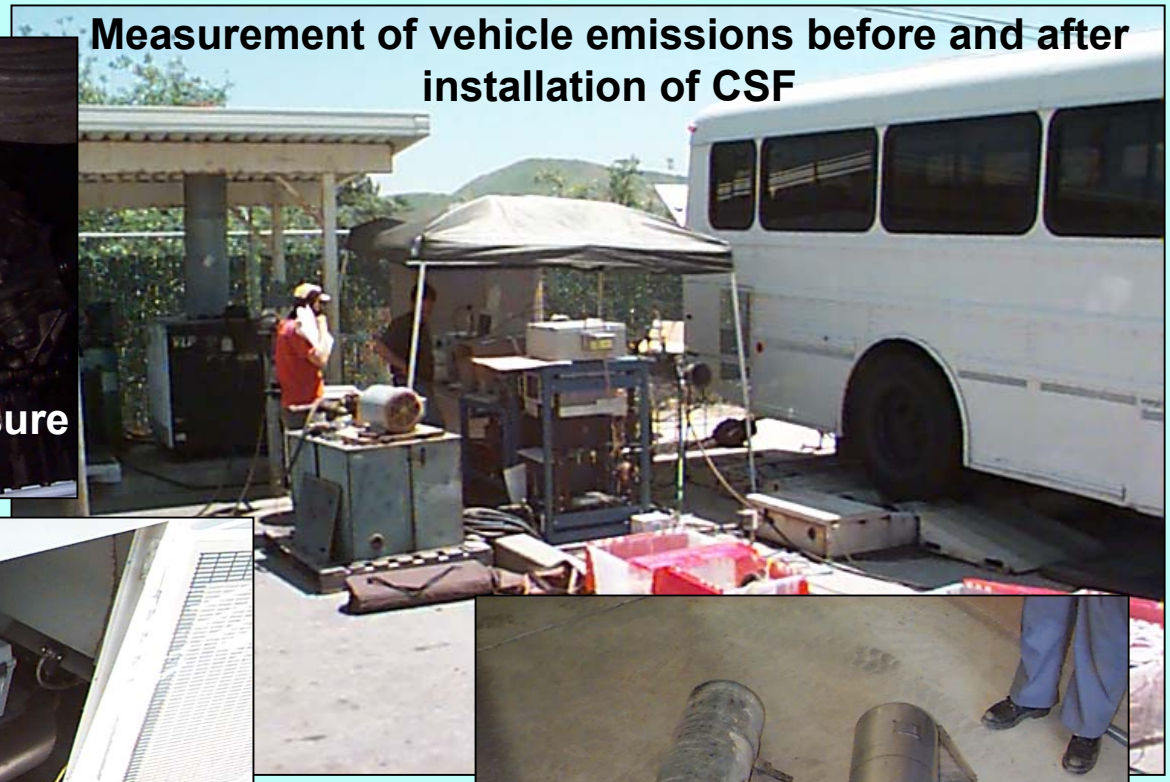
  1. Hill AFB
  2. Channel Islands ANG
  3. PWC San Diego, NAS North Island & NAS Pt. Mugu
  4. Fort Irwin
  5. Camp Pendleton

- Demonstrations on 6 buses and 2 stake trucks will be completed at Camp Pendleton and Fort Irwin.

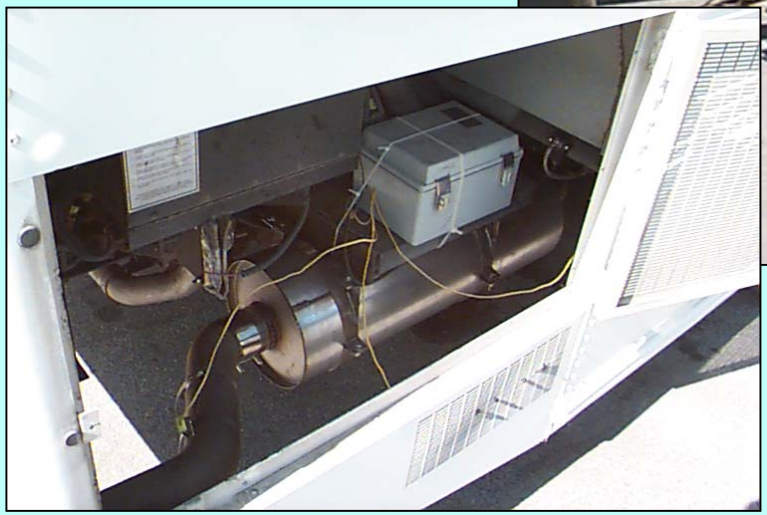
Installing and Measuring PM Emissions from Catalyzed Soot Filters at Camp Pendleton Marine Base (May 2001)



Probes for temperature/pressure measurement



Measurement of vehicle emissions before and after installation of CSF



CSF/Instrumentation package installed

Comparing size of CSF with muffler that it replaced

PM Measurement Methods

- Measuring field performance of CSF with
  - U of U instrumentation
  - U of VA portable dynomometer (DOE)
  - installation on EPA- instrumented truck

Characterization of Particulate Emissions: Size Characterization and Chemical Speciation

Goal

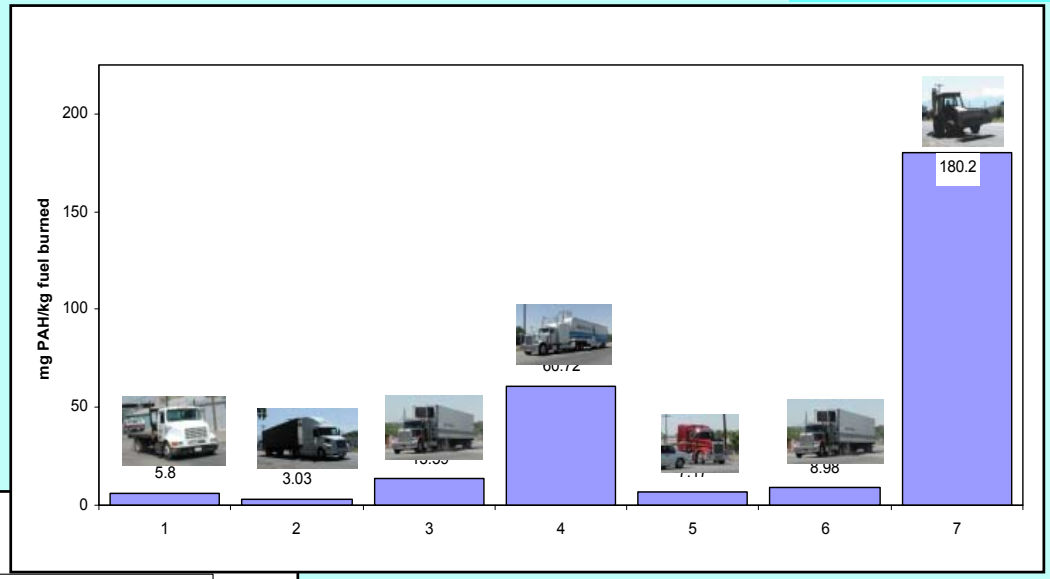
Evaluation of methods to rapidly measure particle size and characteristics for DoD sources including:

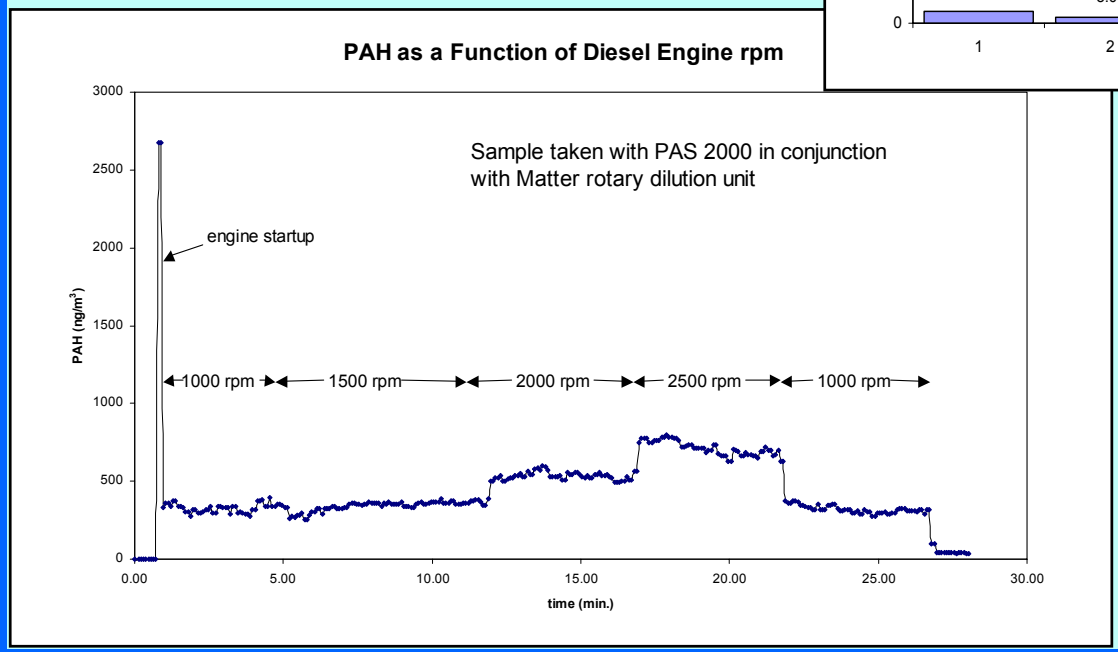
- **Real-time particle-bound polycyclic aromatic hydrocarbons (PAH)s**
- **Real-time elemental carbon carbon (soot) concentration using the Desert Research Institute photoacoustic analyzer**
- **Real-time, single particle composition with the aerosol time of flight mass spectrometer (ATOFMS) Dilution systems**
- **Dilution systems and particle size distributions**

Reasoning

- **Traditional particle characterization involves collecting filter samples and analyzing the filters. This is time consuming, costly, and offers little information on transients.**

Vehicle-Specific PAH Emissions

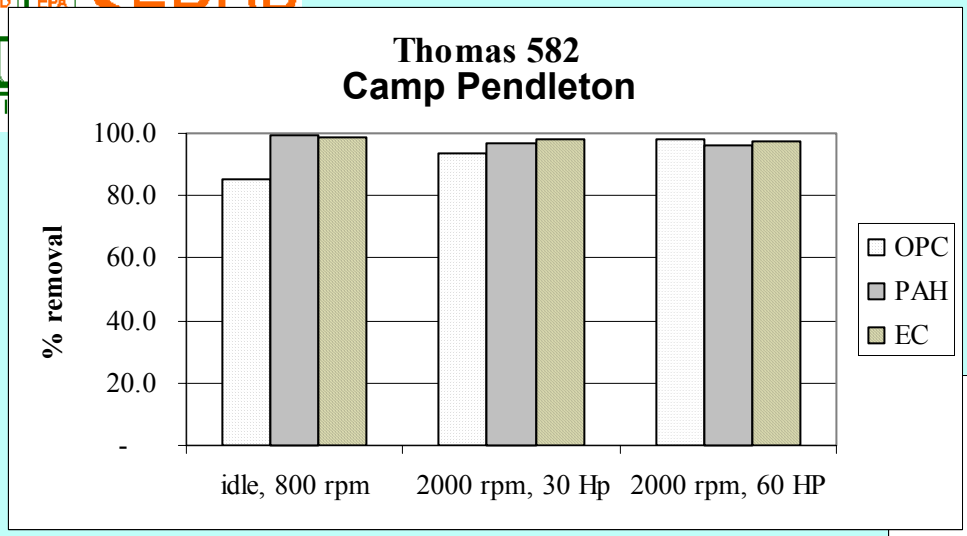


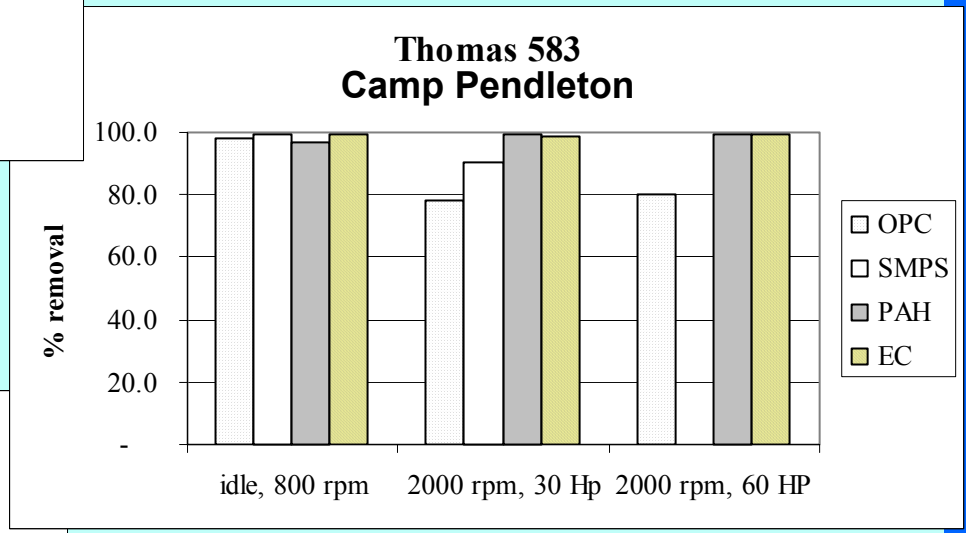


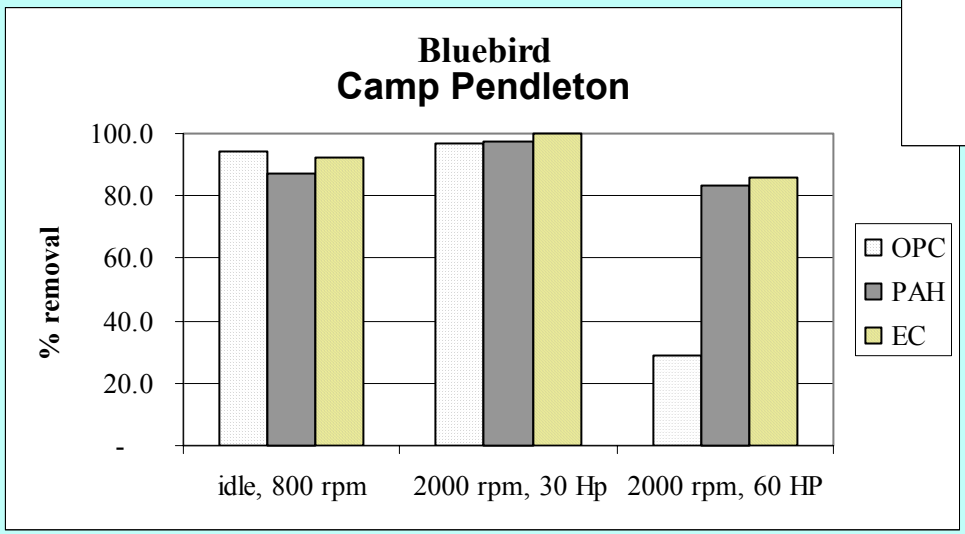
Field Test Results

PM Reduction Using Photo-Electric, Photo-Acoustic, OPC and SMPS Measurements

The University of Utah



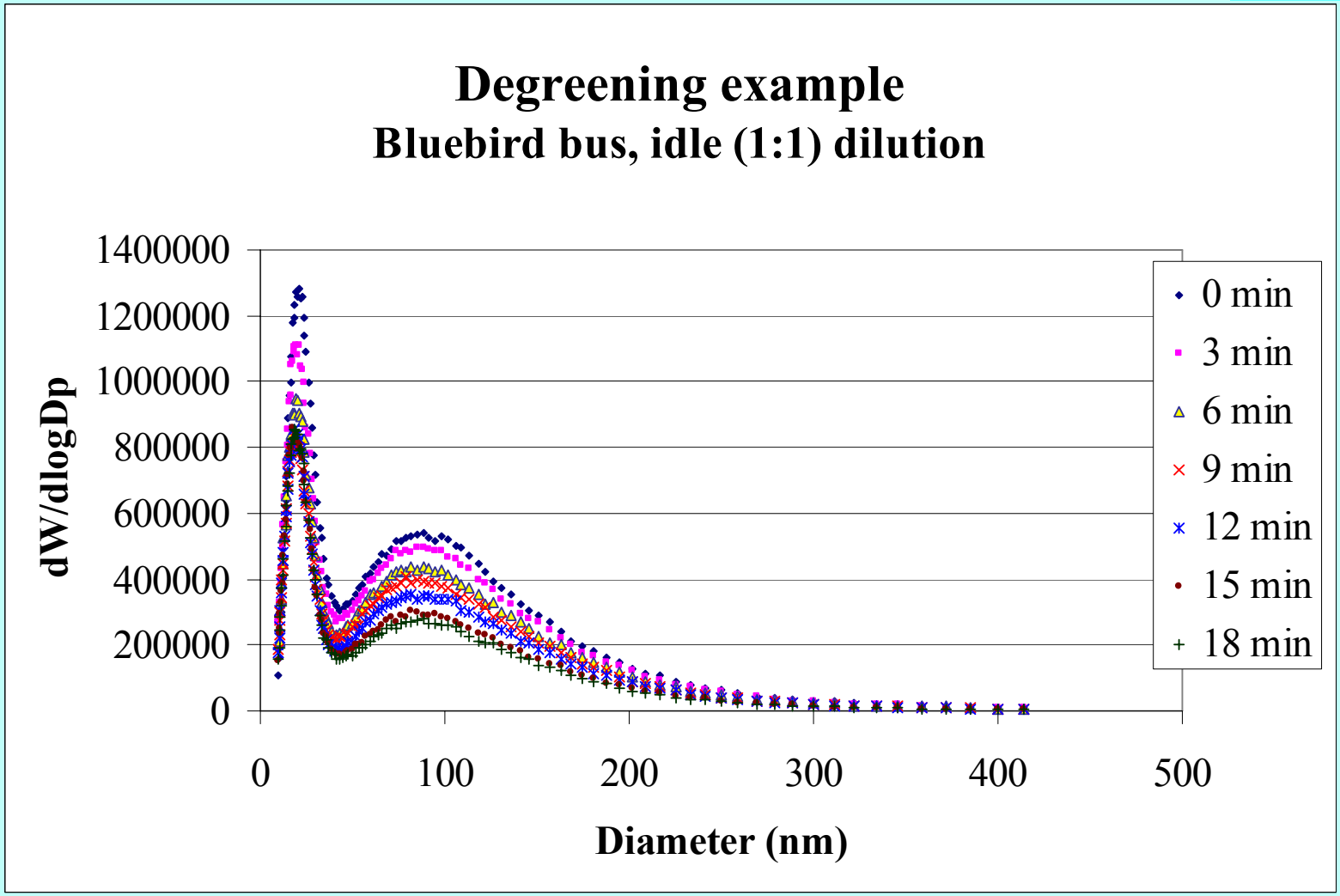




OPC (g/cm³)
PAH (ng/m³)
EC (ug/m³)

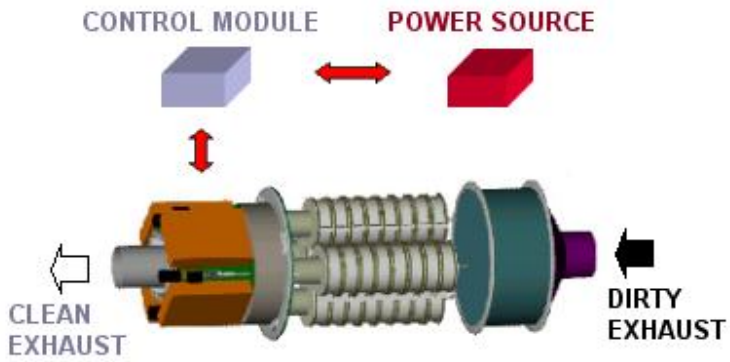
Field Test Results

Particle Size Distribution - SMPS Measurements



Active Soot Filter Investigation

- On-board electrical regeneration
  - segmented metal-fiber substrate
  - segments regenerated separately and sequentially
  - gen-set most promising application



- Off-board electrical regeneration
  - operator plugs vehicle into a regeneration unit after approximately 6-8 hours of operation (i.e. after end of shift)
  - Two types: SiC substrate with upstream heating element or metal oxide fiber wound around cylindrical heating elements
  - operation more suited to fleet vehicles such as airport ground support vehicles

Fiber-wound filter

SUMMARY OF PROJECT PROGRESS

- Surveyed 88 DoD diesel engine systems
- Performed exhaust screening tests on 20 DoD engine systems
- Completed laboratory tests refining CSF regeneration requirements
- Completed laboratory testing characterizing PM emissions from CSF for standard diesel fuel (350 ppm S)
- In process of completing laboratory testing characterizing PM emissions from CSF for low-sulfur diesel fuel (15 ppm S)
- Installed eight “passive” CSFs for field tests
- Four (4) "active” CSFs to be installed for field tests
- Measuring field performance of CSF with (a) U of U instrumentation, (b) U of VA portable dynomometer (DOE), (c) installation on EPA-instrumented truck.
- In process of identifying DoD implementation sites for CSFs.

CSF emission reduction potential

- Engine and CSF emission data for EPA transient cycle using a 1993 C8.3-275hp transit bus engine

Emission	Total Particulate	Soluble Organic Fraction	Total Hydrocarbon	Carbon Monoxide
Engine Out (gm/hp-hr)	0.09	0.05	0.18	0.69
Soot Filter Out (gm/hp-hr)	0.02	0.01	0.05	0.21
Reduction (%)	80	78	70	70