Retrofit Diesel Particulate Filter Application Considerations and Experience

International Diesel Retrofit Advisory Committee

June 5, 2001
California

Presentation Outline

- Introduction
- Key Considerations of a Diesel Particulate Filter Retrofit Control Program
- Operating Experience with Retrofit Diesel Particulate Filters
- Conclusions
- Discussion of Diesel Particulate Filter Applications Matrix

Introduction

- Retrofitting Existing Diesel Engines with Diesel Particulate Filters Is an Available Strategy to Reduce Emissions Including PM Mass and Number, CO, HC, and Toxic HC
- A Growing Number of Programs and Applications Have Been Successfully Completed
- Test Programs Are Undertaken to Gain Experience and Identify Problems and Challenges
- Technology Development Continues to Expand the Range of Applications Available for Retrofit
- Some Applications May Be More Suitable for Replacement with Diesel Engine Replacement/ Diesel Particulate Filter or Alternative Fuel Engine/Catalyst
- A Successful Retrofit Program Must Be Properly Designed and Implemented

Key Considerations of a Proper Retrofit Control Program

- The Condition of the Engine Is an Important Factor in Making a Decision Whether to Retrofit Control Technology
- Retrofit at the Time Of Engine Rebuild Can Be Advantageous
- For Filter Retrofit, Vehicle Application, Exhaust Temperature (Duty Cycle), Engine-Out PM Emissions, Fuel Sulfur Level, and Regeneration Strategy Must Be Properly Matched

Engine Exhaust Temperature/Time Profile and Engine-Out PM Emissions Are Critical Factors

Key Considerations of a Proper Retrofit Control Program (cont.)

- Retrofit Technology Check List
  - Size
    - Properly Sized Control Technologies Ensure Low Back Pressure and Maximum Performance
  - Vehicle Integration
    - Is An Important Aspect of Control Technology Retrofit and Has Been Successfully Accomplished on Both On- and Off-Road Vehicles (muffler replacement or in-line installation)

Key Considerations of a Proper Retrofit Control Program (cont.)

- Retrofit Technology Check List (cont.)
  - Fuel Quality
    - For PM Control, <15 ppm Allows for Maximum Emission Control Performance and Best Filter Regeneration Characteristics
  - Maintenance
    - Vehicles to Be Retrofitted Should Be Properly and Regularly Maintained
    - Retrofit Technology Should Be Maintained per Manufacturer's Recommended Procedures

Retrofit Experience

- Mining
- Materials Handling
- Truck and Bus
- Marine Vessels and Locomotives
- Stationary Diesel Engines

Selection of A Regeneration Strategy

- Application and Duty Cycle
- Engine Out Emission
- Vehicle/Engine Condition
- Fuel Sulfur Level
- Maintenance and Operational Procedures

Catalyst-Assist Strategies Have Been Proven in a Wide Range of Vehicle Applications

Regeneration Strategies Used to Date In Retrofit Applications

- Engine Reliant
  - Mining and Construction
  - Relies Solely on Engine Exhaust Gas Temperature
  - Applicable in Limited Circumstances
- Catalyst-Assist
  - Mining, Construction, Onroad, Locomotive, Marine, and Stationary
  - Promotes the Oxidation of Collected Particulate at Lower Temperatures
  - Several Manufacturers Indicate that Exhaust Temperatures Must Exceed in the Range of 250 to 275 oC for Over 30% to 50% of the Time

Regeneration Strategies Used to Date In Retrofit Applications (cont.)

- Electric Heater-Assist
  - Mining, Construction, and Materials Handling
  - Shore Power (on- or off-board)
  - Performed Between Shifts
- Fuel Burner-Assist
  - Stationary
  - Inline, Full Flow Fuel Burner
- Intake/Exhaust Throttling
  - Mining and Construction
  - Increases Exhaust Temperature
  - Limited Use
- Exchange and Off-Board Regeneration
  - Mining and Materials Handling

Emerging Regeneration Strategies and/or Enhancements In Retrofit Applications

- Fuel Injection/Catalyst-Assist
  - Construction and Onroad
  - Fuel Injected Over a Catalysts to Increase Exhaust Gas Temperature
  - Peugeot Has 10's of Thousands Passenger Cars Equipped Commercially
- New Substrates
- Higher Activity Catalyst Formulations
- Combinations of the Above

Goal: To Extent the Range of Applications Available for Filter Retrofit

Overview of Retrofit Programs

- The Number and Scope of Retrofit Programs Is Rapidly Growing (Over 50,000 Filters Retrofitted Worldwide)
  - North America (California, New York, New England, Mexico, and elsewhere)
  - Europe (Austria, Finland, France, Germany, Sweden, Switzerland, and United Kingdom)
  - Asia (Hong Kong, Korea, Japan, and Taiwan)
  - Latin America (El Salvador and Nicaragua)

Examples of Established Successful Diesel Particulate Filter Retrofit Applications

- Construction and Mining
  - Haulage Trucks, Loaders, Scrapers, Bulldozers, and Utility Vehicles
- Buses
  - Europe, California, and New York
  - OEs Offering as an Option
- Refuse Vehicles
  - California and Europe
- Trains (<3,000 hp)
  - Europe
- School Buses
  - California (1986 and newer to Date)

Examples of Established Successful Diesel Particulate Filter Retrofit Applications (cont.)

- Fleet Vehicles
  - California, and Europe
- Stationary Engines
  - Europe, Taiwan, and the U.S.
- Other Applications Include
  - Forklift Trucks, Skid Steer Loaders, Marine

Diesel Particulate Filter Retrofit Durability

Vehicle Application	Engine Displacement (l) and Power (hp)		Accumulated Distance (mi)	PM Reduction Efficiency (%)	
				Euro ESC[1]	US FTP[2]
Intercity Train	14	430	372,902	89	99
Airport Bus	10	292	357,531	80	n.a.
Express Bus	10	368	304,598	94	94
Mail truck	7	236	294,469	78	93
City Bus	11	260	142,205	93	98
Refuse Truck	7	235	128,342	93	n.a.
Refuse Truck	7	235	65,743	92	n.a.
		Averages:	194,456	88	96

Intercity Train Has Accumulated Over 1,000,000 Miles

Diesel Particulate Filter Retrofit Case Studies – Lessons Learned and Solutions

- Application
  - Transit Bus in Europe
- Problem Identified
  - Poor Flow Distribution
- Solution
  - Redesign Inlet and Outlet
- Result
  - Operating Successfully for Over One Year

Diesel Particulate Filter Retrofit Case Studies – Lessons Learned and Solutions (cont.)

- Application
  - On- and Off-Road Vehicles
- Problem Identified
  - Low Exhaust Gas Temperature
- Solution
  - Insulate Exhaust System
- Result
  - Operating Successfully for Several Years In Some Instances

Diesel Particulate Filter Retrofit Case Studies – Lessons Learned and Solutions (cont.)

- Application
  - Older Model Year European Bus
- Problem Identified
  - Limited Space and Small Filter Volume
- Solution
  - Redesigned Filter System to Incorporate Two Smaller Filters (Increased Total Filter Volume)
- Result
  - Operating Successfully for Over 5 Months

Diesel Particulate Filter Retrofit Case Studies – Lessons Learned and Solutions (cont.)

- Application
  - Urban Bus
- Problem Identified
  - Plugged Filter Due to Turbocharger Failure
- Solution
  - Replaced Turbocharger
- Result
  - Operating Successfully for Over 2 Months

Diesel Particulate Filter Retrofit Case Studies – Lessons Learned and Solutions (cont.)

- Application
  - Urban Bus
- Problem Identified
  - Incorrect Mechanical Installation Caused Mechanical Filter Failure
- Solution
  - Trained Installers to Insure Proper Installation
- Result
  - New Filter Being Properly Installed

Diesel Particulate Filter Retrofit Case Studies – Lessons Learned and Solutions (cont.)

- Application
  - European Urban Buses
- Problem Identified
  - Low Exhaust Temperatures
- Solution
  - Improved Catalysts Formulation and Established More Rigorous Maintenance Requirements
- Result
  - Several Hundred Buses Operating Successfully for Over a Year

Diesel Particulate Filter Retrofit Case Studies – Lessons Learned and Solutions (cont.)

- Application
  - Urban Buses
- Problem Identified
  - Low Exhaust Temperatures and High Engine-Out PM Emissions
- Solution
  - Advanced Filter Design and Reduce Engine-Out PM Emissions
- Result
  - Continuing Development Work

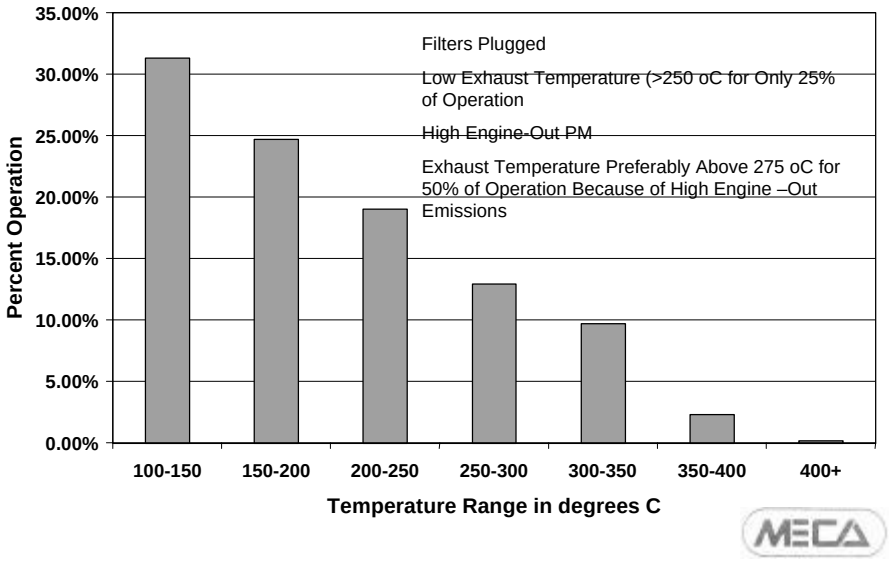
Diesel Particulate Filter Retrofit Case Studies – Lessons Learned and Solutions (cont.)

- Application
  - Urban Buses
- Problem Identified
  - Low Ambient Temperatures Combined with 200 ppm S Fuel
- Solution
  - Low Sulfur Fuel
- Result
  - Buses Operating Successfully for Over 2-3 Years

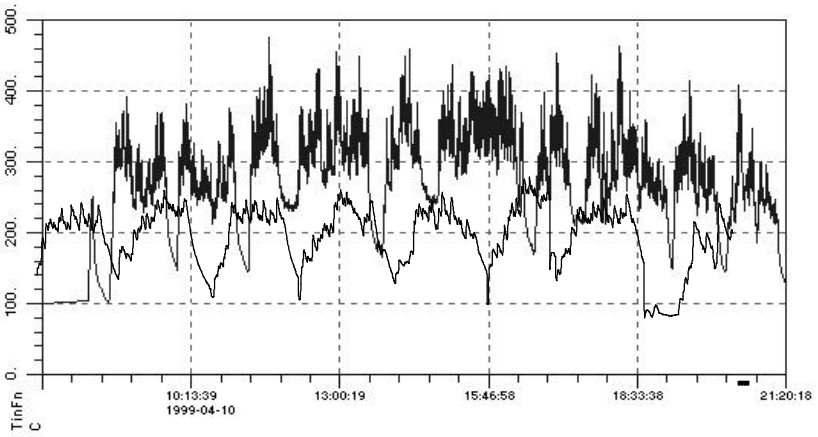
Diesel Particulate Filter Retrofit Case Studies – Lessons Learned and Solutions (cont.)

- Application
  - School Bus
- Problem Identified
  - Incorrectly Rebuilt Engine
- Solution
  - Rebuilt Engine Correctly
- Result
  - Operating Successfully for Over 3 Months

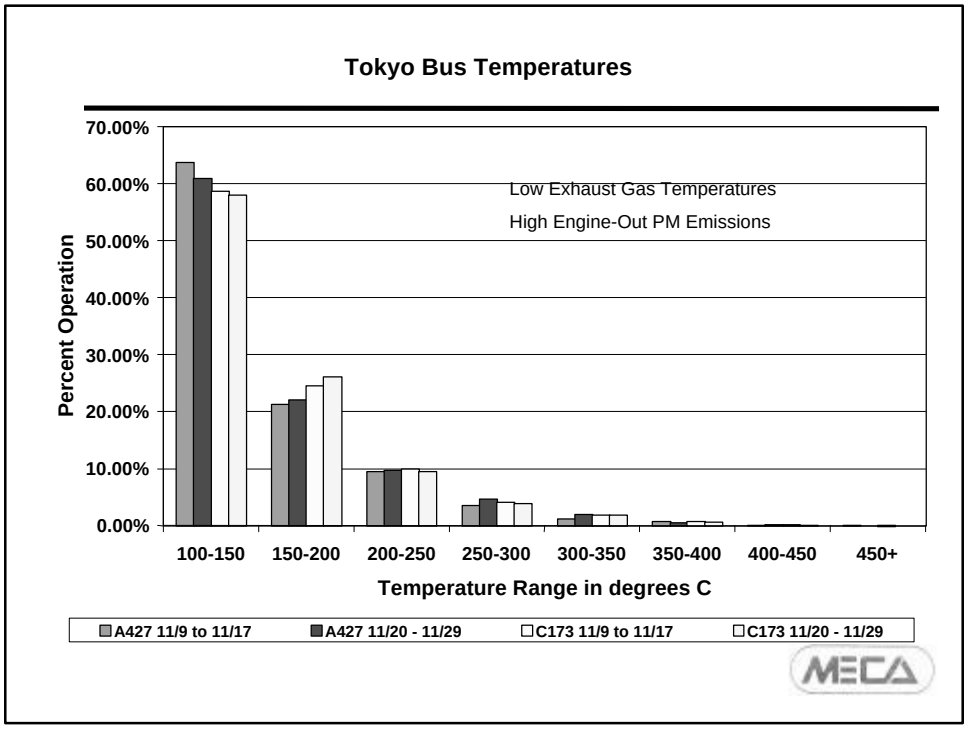
1978 Caterpillar 3208 School Bus

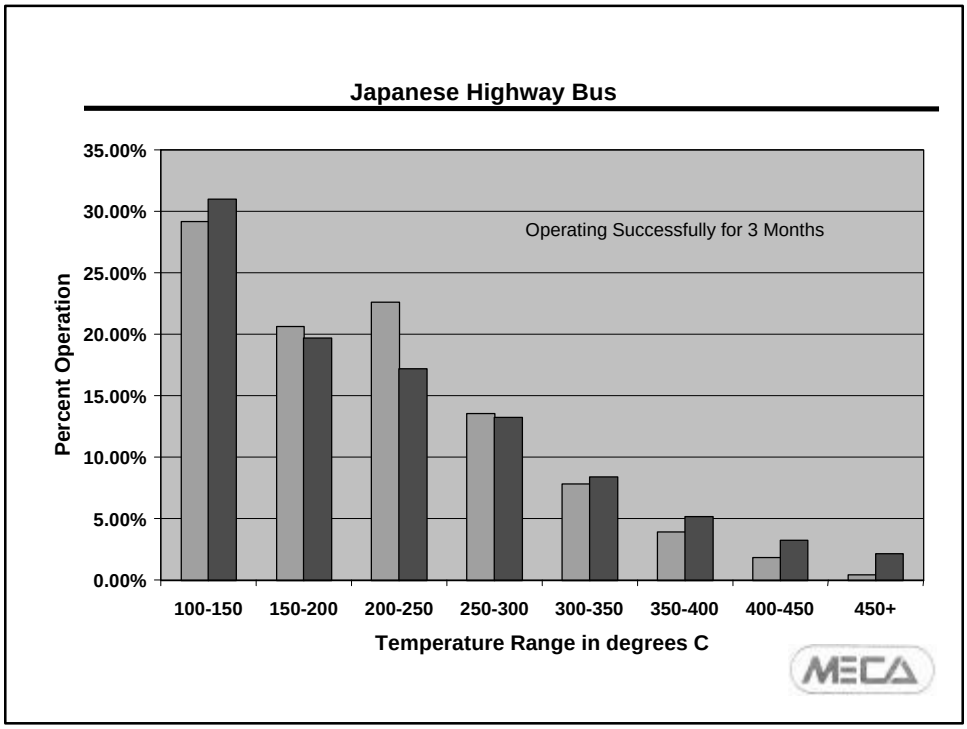


Temperature Comparison of US Bus and European Bus Fuel ULSF



U.S. Bus Operates at Higher Exhaust Gas Temperatures


Tokyo Bus Temperatures
70.00%
60.00%
50.00%
40.00%
30.00%
20.00%
10.00%
0.00%
Percent Operation
Low Exhaust Gas Temperatures
High Engine-Out PM Emissions
100-150
150-200
200-250
250-300
300-350
350-400
400-450
450+
Temperature Range in degrees C
A427 11/9 to 11/17
A427 11/20 - 11/29
C173 11/9 to 11/17
C173 11/20 - 11/29
MECA


Japanese Highway Bus
35.00%
30.00%
25.00%
20.00%
15.00%
10.00%
5.00%
0.00%
Percent Operation
Operating Successfully for 3 Months
100-150
150-200
200-250
250-300
300-350
350-400
400-450
450+
Temperature Range in degrees C
MECA

Conclusions

- A Variety of Demonstrated Diesel Particulate Filter Retrofit Applications Have Been Successfully Demonstrated to Significantly Reduce PM Mass and Number, HC, CO, Toxic Emissions from a Wide Range of Existing HDDEs
- A Growing Number of Retrofit Programs Are Being Successfully Implemented
- Test Programs Are Undertaken to Identify Problems and Challenges with the Objective of Defining Solutions
- Technology Development Continues to Expand the Range of Applications Available for Retrofit
- Some Applications May Be More Suitable for Replacement with Diesel Engine Replacement/ Diesel Particulate Filter or Alternative Fuel Engine/Catalyst
- A Successful Retrofit Program Must Be Properly Designed and Implemented

Applications Matrices

- Based on MECA Members' Experience to Date and Engineering Judgment
- Off-Road Matrix Based on Fewer Applications
- "Living" Document
- IDRAC Members and Other Stakeholders Input Is Needed

Applications Matrices (cont.)

- Legend Based On:

10: Based on past experience and/ or known vehicle and engine operation, filters can be retrofitted with no anticipated problems.

8-9: Based on past experience and/or known vehicle operation, filters can be retrofitted with no anticipated problems. However, there may be limited exceptions, e.g. specific applications regarding duty cycles, vehicle integration, etc., that may cause problems or require the use of emerging technologies.

6-7: Filter retrofit is more challenging or the application looks promising but more experience or the development of new systems is needed.

5: Little or no experience, but using engineering judgment indicates that it is possible either with existing technologies or technologies being developed.

3-4: Little or no experience, but using engineering judgment indicates that it appears challenging with existing technologies or emerging technologies.

2: Filter retrofit is unlikely.

1: Based on experience and/or engineering judgment, filter retrofit is not possible.

Applications Matrices (cont.)

Retrofit Analysis				
			Probability	
Application	***Common Engines***	***Past Experience***	***(1-10)***	***Remarks***
School Bus	CAT 3208			
	<1988		5,6-7	
	1988 - 1990	CA School Bus	5,6-7	
	>1991		8-9, 10	
	CAT 3116			
	<1988		5,6-7	
	1988 - 1990		5,6-7	
	>1991	CA School Bus	8-9,10	
	CAT 3126			
	1988 - 1990		8-9	
	>1991	Engine Testing	10	
	Navistar 530			
	<1988		6	
	1988 - 1990		6	
	>1991	CA School Bus	6	
	Navistar 530 E			
	<1991	CA School Bus	10	
	Navistar 466			
	<1988	CA School Bus	6-7	
	1988 - 1990		6-7	
	>1991	CA School Bus	10	
	DDC 6L-71			
	<1988	CA School Bus	2-3	dirty, 2 stroke, cold
	1988 - 1990		2-3	dirty, 2 stroke, cold
	>1991		2-3	dirty, 2 stroke, cold