Retrofit Emission Controls for On-Road and Off-Road Diesel Engines

September 18, 2007

Manufacturers of Emission Controls Association (MECA)
www.meca.org
www.dieselretrofit.org

MECA Background

• Founded in 1976 to be the technical spokesperson for the mobile source emission control industry (54 member companies)

• Member companies have over 35 years of experience and a proven track record of success in developing and manufacturing emission control technology

• Members cover diverse range of emission control technologies for both new and existing engines/vehicles:
  • Catalytic converters (all fuels)
  • Diesel particulate filters
  • Exhaust components/exhaust system integration
  • Sensors

• Emission control technology information available on two websites:
  • www.meca.org
  • www.dieselretrofit.org
  • Contact: Dr. Joe Kubsh (Executive Director) in Washington, D.C. (phone: 202-296-4797, e-mail: jkubsh@meca.org)
Outline

- Diesel Retrofit Technology Overview
- Retrofit Application Engineering
- Installation of Retrofit Devices
- Diesel Particulate Filter Maintenance

Diesel Retrofit Technology Overview
Strategies to Reduce Emissions from In-Use Diesel Engines

- Retrofit – installing verified emission control devices on an existing diesel engine
- Refuel
- Repair/Rebuild
- Repower
- Replace

Experience with Diesel Retrofits Spans a Variety of On-Road Vehicle Applications...
... Construction Equipment...

... Mining...
... and Other Off-Road Vehicle and Stationary Engine Applications

Wall-Flow Filters Offer the Highest PM Filtration Efficiency

- >85% PM reduction
- Catalyzed filters require operation on ULSD
- Large reduction in toxics from catalyzed filters
- ARB Level 3 filters include passive & active regen.
- >200,000 retrofits worldwide
- >4 million OE applications
- Same technology as on 2007 OE trucks

Passively regenerated filters employ catalysts and available exhaust heat to burn captured soot – specified exhaust temp. requirements
DPFs with Active Soot Regeneration Available for Retrofits

- Suited for on- and off-road applications with low exhaust temperatures, including construction equipment, locomotives, and marine engines
- Example: Uncatalyzed wall-flow filter with electrical regeneration
- Example: Uncatalyzed wall-flow filter with a fuel burner

Backpressure Monitors/Loggers

- BP monitors emerging with added features
  - Extended datalogging capability (1-2 yrs)
    - BP and temperature
  - Multi-light displays to indicate system faults, warnings, and alarm conditions
  - Real-time monitoring
- Systems come with software to allow data analysis
Flow-Through Filter Technologies Emerging for Diesel Retrofits

- 50-75% PM reduction (ARB Level 2)
- Can be catalyzed or used with a DOC
- Has applicability on older engines
- Resistant to plugging
- Ash cleaning generally not necessary due to open structure

Metal Substrate with Sintered Metal Sheets

Diesel Oxidation Catalysts

- 25-40% PM reduction ("soluble" PM species are oxidized)
- Large reduction in toxics
- DOCs have been retrofitted on on- and off-road vehicles for over 30 years
- Nearly universal application with >1 million retrofits worldwide
- Tens of millions of OE applications

Flow through monolith with catalytic coating

CO
Aldehydes
HC
PAH
SO₂
NOx
CO₂
H₂O
SO₂/SO₃
NOx

Diesel Oxidation Catalysts
Closed Crankcase Ventilation Can Provide Additional PM Control

- Most existing diesel engines vent crankcase emissions directly to the atmosphere
- Crankcase PM emission reductions provided by CCV technologies range from 5 to 10%
- CCVs direct filtered air back to the engine air intake; lube oil returned to oil sump

Mexico City Pilot Retrofit Project Confirmed
Retrofit Performance on 20 Urban Buses

- Pilot project sponsors included U.S. EPA
- Project completed in late 2006
- 1991 buses with mechanical injection systems retrofit with DOCs and fueled with ultra-low sulfur diesel fuel (15 ppm S max.)
  - 20-30% reduction in PM, 50-70% reduction in CO
- 2001 buses with electronic injection systems retrofit with passive DPFs and fueled with ultra-low sulfur diesel fuel
  - 90% reduction in PM, 90% reduction in CO
Integrated Solutions for Combined NOx/PM Reductions Emerging for Retrofits

- Lean NOx catalyst + DPF
- Urea Selective Catalytic Reduction (SCR) catalyst + DPF
- Low-pressure Exhaust Gas Recirculation (EGR) + DPF
- Emulsified diesel fuel + DOC (or DPF)

Lean NOx Catalyst + DPF

- Diesel fuel used as a reductant with a lean NOx catalyst
Urea SCR Catalyst + DPF

- Urea-water solution used as a reductant with an SCR catalyst
- DOC+SCR verified for limited off-road applications; additional SCR verifications expected for both on-road & off-road engines

Urea SCR Catalyst + DPF (60+% NOx reduction)

Low-Pressure EGR + DPF

- Cleaned exhaust gas is recirculated to engine air intake to cool engine combustion temperature

Low-Pressure EGR + DPF (40-50% NOx reduction)
Emulsified Diesel Fuel + DOC (or DPF)

- Emulsion of fuel+water lowers engine combustion temperatures and improved fuel/air mixing

Key Technical Considerations for Successful Retrofit Projects

- Application engineering – matching the right technology to the vehicle or equipment
  - Vehicle should be well maintained before considering retrofit
- Proper professional installation
- Maintenance – vehicle/equipment and retrofit device may require frequent inspection and maintenance
- On-vehicle monitors – provide important user feedback on performance

Successful Retrofits Require a Cooperative Effort Between Fleet Owners, Operators, and Technology Providers
Retrofit Application Engineering

Opportunity Definition

- Information Profile/Documentation
- Fleet Analysis
  - Engine/Vehicle/Make/Model/Year
  - Engine Type/Configuration
  - Exhaust System Details
  - Mounting Hardware
  - Maintenance History
Control Technology Assessment

- ARB Verification Listing Review
  (www.arb.ca.gov/diesel/verdev/verdev.htm)
  - Level 1 Verified Technologies (≥ 25% PM reduction)
  - Level 2 Verified Technologies (≥ 50% PM reduction)
  - Level 3 Verified Technologies (≥ 85% PM reduction)
- Best available Control Technology (BACT) Review
  - Select highest level PM reduction technology available
    (Level 3, 2, or 1) which is verified/approved for specific
    engine families and operating conditions
- Assess Exhaust Temperature/Duty Cycle Requirements
  - Match of control technology level to engine/vehicle
    operation
  - Determine exhaust temperature/duty cycle datalogging
    need

Exhaust Temperature/Duty Cycle Assessment

- Provide Datalogging Capability
  - Datalogger Kit
    - Hardware
    - Installation/operations manual
    - Software
    - Instructions/Data form
- Complete Datalogging
  - Temperature sampling
    frequencies of 2-5 seconds typical
    over multiple days of operation
  - Data taken and provided to
    control technology supplier
Exhaust Temperature/Duty Cycle Assessment

- Data Analysis
  - Data imported into supplier database for analysis and storage
  - Analysis/assessment for proper temperature criteria
- Feedback Response
  Documented to Customer

Control Technology Sales/Application

- Product Selection/Supply
  - Sales/Application Literature
- Installation/Maintenance
  - Owner’s Manual
    Installation, warranty and maintenance procedures
- Application Documentation Files
  - Specific control technology match to engine/vehicle application
Challenges for Off-Road Retrofits

- Higher emissions than on-road heavy-duty engines (uncontrolled before 1996)
- More diverse engine/equipment applications than on-road
  - More older equipment
  - Wide horsepower range
  - Equipment stability
- More rigorous operating environment (vibrations, dust, uneven surfaces)
  - Can require extensive use of high-grade vibration isolators, especially in track-drive equipment

Challenges for Off-Road Retrofits

- Packaging constraints
  - Maintaining driver visibility
- Availability of clean fuel
  - ULSD allows for maximum PM control
- Need for more preventative equipment maintenance
  - Air filters, injectors, and turbochargers
  - Basic inspection and maintenance of installations
- Must be mindful of not taking short-cuts to get equipment retrofitted quickly
Installation of Retrofit Devices

DOCs

- Represent a new installation
  - Support of unit is critical
  - Requires adequate space to install
  - Adaptable to most engines
Converter Installation – Underchassis

(Note that flex pipes may not be allowed in some retrofit installations)

Converter Mufflers

• Direct fit simply installs in place of the original muffler
  - should have all the features of the original muffler
  - saves labor, reduces hardware, and insures correct fit
• Generic converter mufflers may be used with a specialized pipe installation kit
  - can be difficult to obtain replacement pipes
Diesel Particulate Filters

- Most feature a more generic design & removable filter centerbody for maintenance
- DPF centerbody is heavy – proper support is vital
- Inlet and outlet sections rotate to facilitate fit

DPF – Highway Underchassis

- Flex / Bellows between engine and DPF
- Insulation as instructed by manufacturer
- Universal Mounting Clamp
- Clamp Hangers
- Vibration Dampers as indicated by manufacturer
Proper Retrofit Installation (On-Road)

Proper Retrofit Installation (On-Road) – Vertical Installation
Off-Road Horizontal and Vertical Filter Installations Possible

Diesel Particulate Filter Maintenance
Why Clean DPFs?

- Soot collected in the filter must be periodically combusted (like a self-cleaning oven)
  - If insufficient high-temperature events occur, PM can collect in the DPF and require physical removal
- Inorganic ash does not combust and will collect in the DPF over time
  - Ash must be cleaned out periodically to avoid substrate damage and elevated engine backpressure
  - Ash sources include lubricant additives and wear metals from the engine/exhaust

DPF Maintenance
DPF Maintenance

• Inspect the installation for problems and repair if necessary – supports, clamps, vibration dampeners, etc.
• Inspect the BP monitor function and perform any specified maintenance
• Filters are not maintenance free – every diesel particulate filter requires periodic maintenance regardless of brand or mileage or vehicle hours
• Care must be taken when handling DPFs to protect DPF from damage and protect personnel

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<td>Delivery Fleets and Non-road</td>
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DPF Cleaning Stations

• DPF cleaning station designed to safely perform regeneration or maintenance on all DPFs
• Effective way to remove ash and improve DPF durability
DPF Cleaning Stations

- Typical DPF cleaning station
  - Three-step system of vacuum–heat–vacuum
  - Vacuum system removes soot and ash from filters
  - Does not allow contaminants to escape into the air
  - Clean cordierite & silicon carbide filters between 3 and 20 liters

Disposal of Soot and Ash

Captured in tail pipe . . . Collected in filter bag . . .

Sealed in containers . . .

and sent to hazardous waste facility (depending on local regulations).
Other Diesel Retrofit Maintenance Items

- Periodic inspections should include mounting brackets & clamps; presence of soot in the tailpipe of a DPF-equipped vehicle; condensation in tubing associated with pressure sensors/monitors used with DPFs
- DOCs  
  - Generally maintenance free; periodic inspections recommended
- Crankcase Filters  
  - Filter change generally required at normal oil change intervals
- Low Pressure EGR  
  - Regular inspections  
  - Secondary filter needs replacement – 6-12 month intervals typical

Diesel Retrofit Summary

- A variety of retrofit technologies have been verified by both the U.S. EPA and California ARB for reducing PM and NOx emissions from existing on-road and off-road diesel engines
- Significant experience with retrofit technologies exists for on-road vehicles and this retrofit experience is growing for many off-road applications
- Application engineering is a necessary step to matching the vehicle with the correct retrofit solution