MINING DIESEL
**mdec**
EMISSIONS COUNCIL

# 15th ANNUAL MDEC CONFERENCE
## Sheraton Parkway, Toronto North, Canada
## October 6 – 9, 2009

# MDEC WORKSHOP
## Advanced Diesel Engines and Emission Control Technologies for Underground Mines

**PRESENTED BY: CEP,Cummins, DCL, ECS, Kubota, NRCan &Toromont CAT**

**COORDINATED BY: Mahe Gangal, NRCan**

## OCTOBER 6, 2009

MINING DIESEL **mdec** EMISSIONS COUNCIL

# Diesel Workshop

## Advanced Diesel Engines and Emission Control Technologies for Underground Mines

Sheraton Parkway, Toronto North
Ontario, Canada

Markham Room

Tuesday, October 6, 2009

| | |
|---|---|
| **07:45 – 08:30** | **Registration** |
| | Welcome – Mahe Gangal<br>Introduction of speakers – JP Ouellette |
| 08:30 – 10:00 | Cummins tier 4 engine solutions, Evelynn Stirling (Cummins Inc.) |
| **10:00 – 10:20** | **Coffee Break** |
| 10:20 – 11:50 | Caterpillar tier 4 engines and the next emission regulation hurdle<br>Terry Harkness (Toromont CAT) |
| 11:50 – 12:15 | Review of underground mine regulation, Mahe Gangal (NRCan) |
| **12:15 – 13:00** | **Lunch (Markham Room)** |
| | Introduction of speakers – John Stekar |
| 13:00 – 14:00 | Selection, operation and maintenance of control technologies,<br>Paul Turpin (DCL International Inc.) |
| 14:00 – 15:00 | Installation and evaluation of control technologies, John Stekar<br>(Catalytic Exhaust Products Limited) |
| **15:00 – 15:20** | **Coffee Break** |
| 15:20 – 16:20 | Catalyst and DPF performance monitoring, Ted Tadrous<br>(Engine Control Systems Limited) |
| 16:20 – 16:30 | Discussion and Conclusion |

MINING DIESEL **mdec** EMISSIONS COUNCIL

# Diesel Workshop

## Advanced Diesel Engines and Emission Control Technologies for Underground Mines

Sheraton Parkway, Toronto North
Ontario, Canada

Markham Room

Tuesday, October 6, 2009

**CONTENTS**

**MDEC - 2009**

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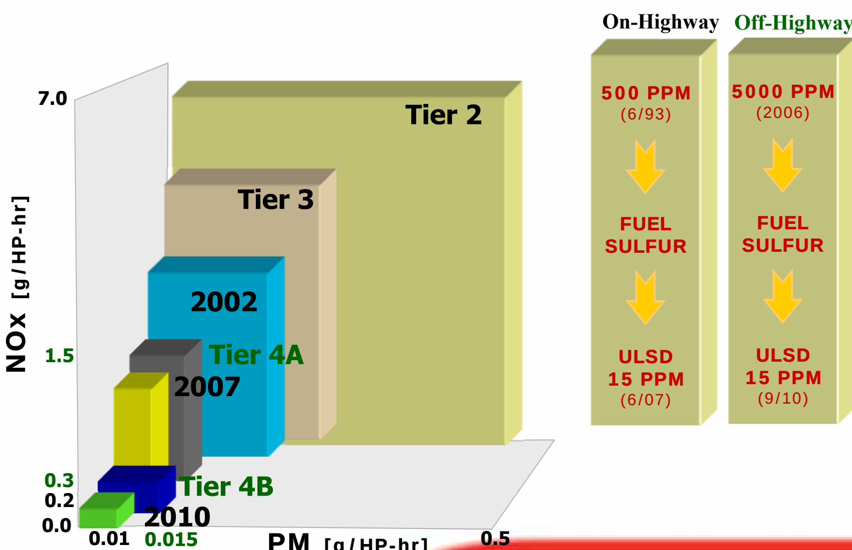
# Cummins Tier 4 Technology Development

## Agenda

- Overview - Non Road Emissions Standards
- Cummins Technology Development Status
- Leveraging Cummins Inc. to Delivery the Best Solution

# Overview of Off-Highway Emission Standards

## Evolution of Emissions Standards



# Nonroad Emissions Standards - US

## MOBILE OFF-HIGHWAY EMISSIONS REGULATIONS SCHEDULES

NOx / HC / CO / PM (g/kW-hr) [Conversion: (g/kW-hr) x 0.7457 = g/bhp-hr]
(NOx+HC) / CO / PM (g/kW-hr) [Conversion: (g/kW-hr) x 0.7457 = g/bhp-hr]

U.S. EPA

| kW | (HP) | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 - 18 | (0 - 24) | | ( 7.5 ) / 8.0 / 0.80 | | | ( 7.5 ) / 6.6 / 0.40 | | | | | | | | | |
| 19 - 36 | (25 - 48) | ( 7.5 ) / 5.5 / 0.60 | | | | ( 7.5 ) / 5.5 / 0.30 | | | | | ( 4.7 ) / 5.0 / 0.03 | | | | |
| 37 - 55 | (49 - 74) | ( 7.5 ) / 5.0 / 0.40 | | | | ( 4.7 ) / 5.0 / 0.30 | | | | | | | | | |
| 56 - 74 | (75 - 99) | | | | | ( 4.7 ) / 5.0 / 0.40 | | | | 3.4 / 0.19 / 5.0 / 0.02 | | | 0.40 / 0.19 / 5.0 / 0.02 | | |
| 75 - 129 | (100 - 173) | | | | | ( 4.0 ) / 5.0 / 0.30 | | | | | | | | | |
| 130 - 560 | (174 - 751) | | | | | ( 4.0 ) / 3.5 / 0.20 | | | 2.0 / 0.19 / 3.5 / 0.02 | | | 0.40 / 0.19 / 3.5 / 0.02 | | | |
| >560* | (>751)* | | | | | ( 6.4 ) / 3.5 / 0.20 | | | 3.5 / 0.40 / 3.5 / 0.10<br>*0.67 / 0.40 / 3.5 / 0.10*[a] | | | | 3.5 / 0.19 / 3.5 / 0.04<br>*0.67/ 0.19 / 3.5 / 0.03*[b] | | |
| | | Tier 1 | | Tier 2 | | Tier 3 | | | Tier 4A | | | | Tier 4B | | |

Focus of PPT work

*a. Applies to portable power generation >1200hp.*
*b. Applies to portable power generation >751hp.*

US & Europe emissions requirements are aligned – Japan requirements not yet defined

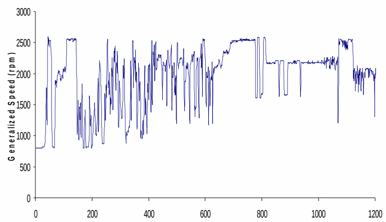
# Emissions Overview

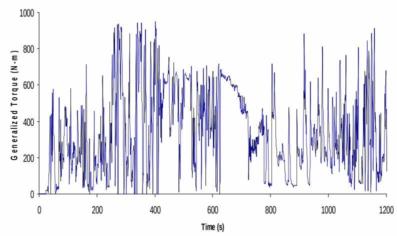
| Emissions Regulations | | Emiss Level | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| EPA Emissions Regulations | | 24-48 HP | Tier 2 | | Tier 4 Int | | | | | Tier 4 | | |
| | | 49-74 HP | Tier 2 | | Tier 3 | | | | Tier 4 | | | |
| | | 75-99 HP | Tier 2 | | Tier 3 | | | | Tier 4 Int | | | Tier 4 |
| | | 100-173 HP | Tier 2 | Tier 3 | | | | | Tier 4 Int | | | Tier 4 |
| | | 174-751 HP | Tier 3 | | | | | Tier 4 Int | | | Tier 4 | |
| EU Emissions Regulations | | 24-48 HP | Stage 2 | Stage 3 | | | | | | | | |
| | | 49-74 HP | Stage 2 | | Stage 3 | | | | | Stage 3a | | |
| | | 75-99 HP | Stage 2 | | Stage 3 | | | | Stage 3a | | | Stage 4 |
| | | 100-173 HP | Stage 2 | Stage 3 | | | | | Stage 3a | | | Stage 4 |
| | | 174-751 HP | Stage 3 | | | | | Stage 3a | | | Stage 4 | |
| JMLIT Emissions Regulations | | 24-48 HP | Tier 2 | Tier 3 | | | | | | | | |
| | | 49-74 HP | Tier 2 | | Tier 3 | | | | | Tier 4 | | |
| | | 75-99 HP | Tier 2 | | Tier 3 | | | | Tier 4 Int | | | Tier 4 |
| | | 100-173 HP | Tier 2 | Tier 3 | | | | | Tier 4 Int | | | Tier 4 |
| | | 174-751 HP | Tier 3 | | | | | Tier 4 Int | | | Tier 4 | |
| China Emissions Regulations | | All HP | Stage 1 | | | Stage 2 | | | | | Stage 3A? | |
| India Emissions Regulations | | All HP | | Stage 1 | | | Stage 3A (Like Tier 2) | | | | | ? |
| Korea Emissions Regulations | | All HP | Tier 2 | | | | | Tier 3? | | | | |
| Latin America Emissions | | Currently No Regs in LAmerica | | | Tier 2? | | | | | ? | | |

## Nonroad Emissions Standards - US

- New transient certification test
- Nonroad diesel fuel quality changes
  - 500 ppm sulfur in 2007
  - 15 ppm sulfur in 2010

NRTC




## EPA Tier 4 System Emission Compliance Responsibility

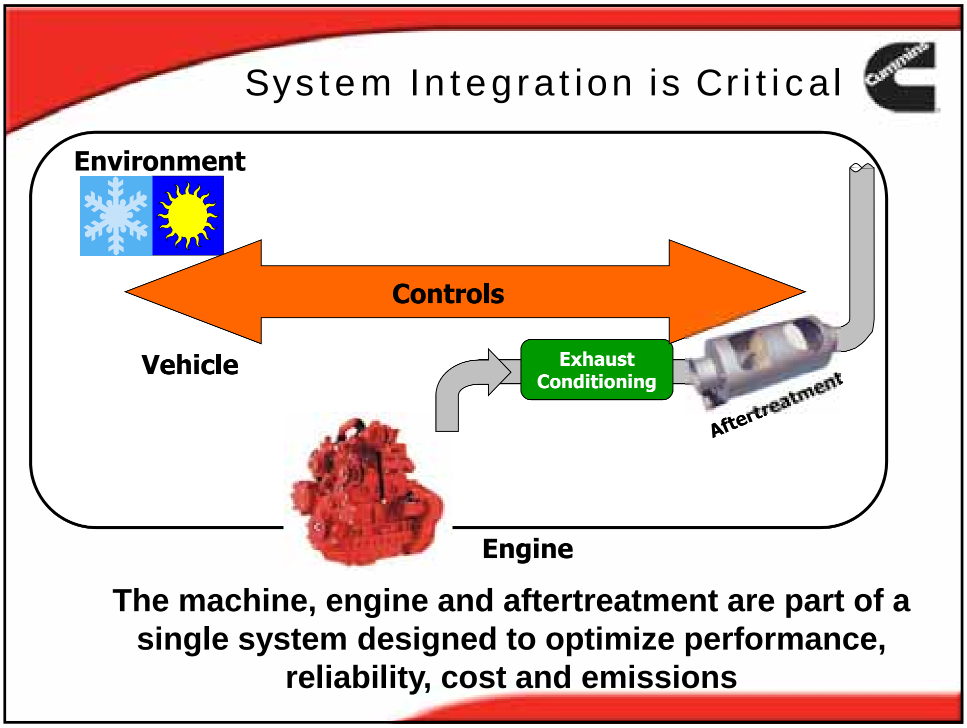
- **Engine Manufacturer** – certify the system (engine & aftertreatment) and provide installation instructions to ensure the system will be compliant when installed. Cummins will specify aftertreatment components which are certified for given engines.
- **Equipment Manufacturer** - follow engine manufacturer installation requirements.
- **End user** – use specified fuel and filters, and follow specified maintenance requirements.

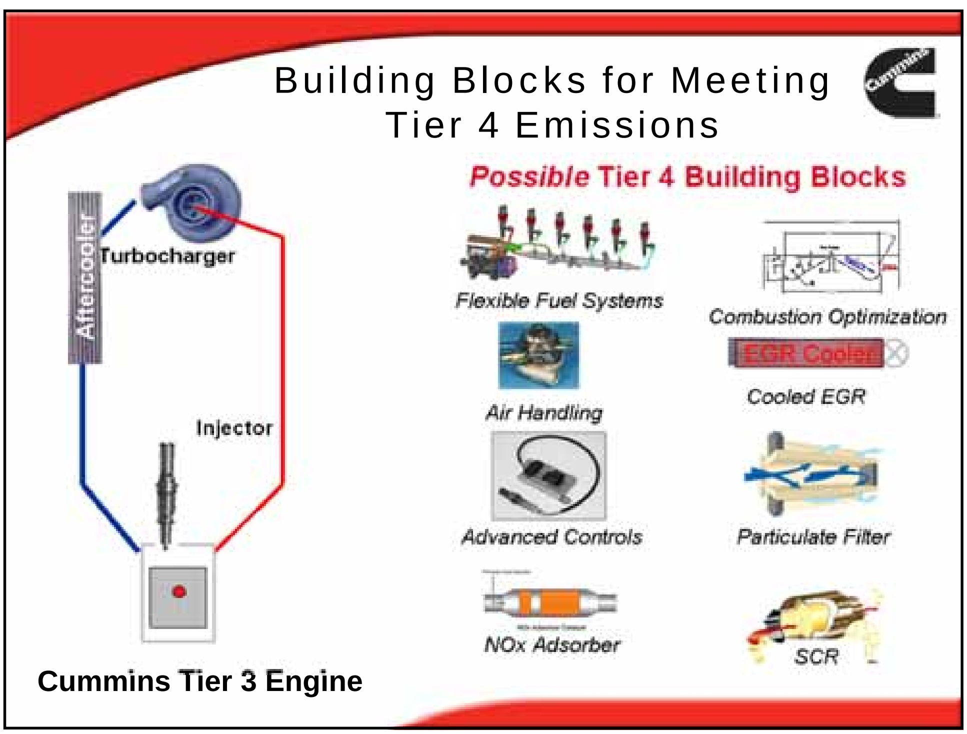
Engine & AT useful life = 10 yrs/8000 hrs

# Cummins Approach to Technology Development

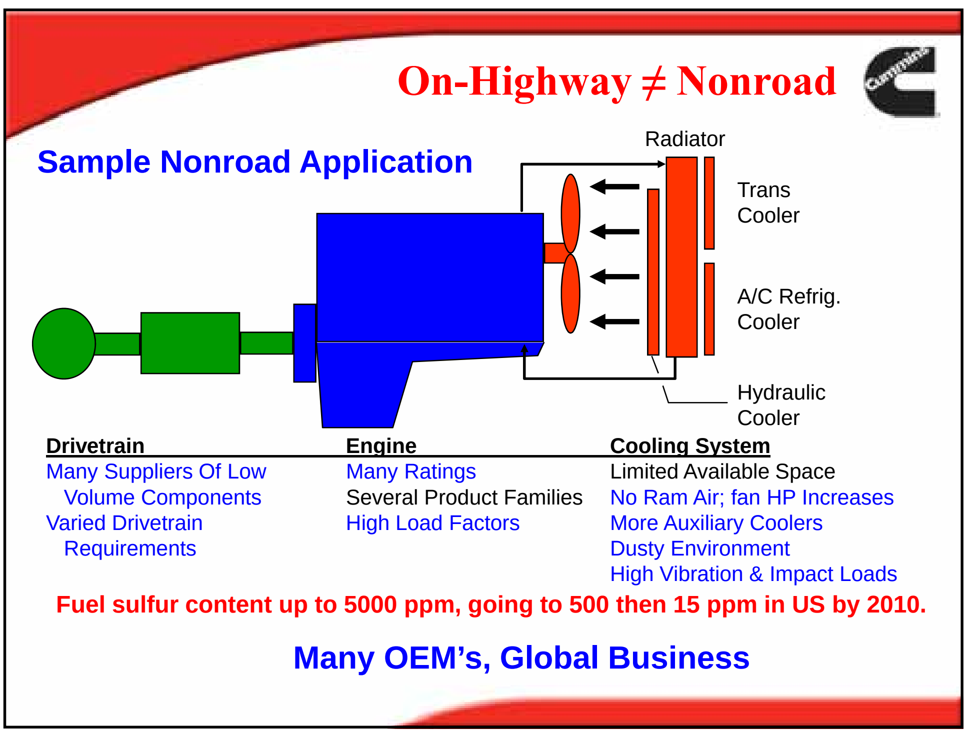
## Our Products Must Meet Customer Requirements

- High Performance
- Highly Sociable
- Low Initial Cost
- High Aesthetics
- High Efficiency
- Low Maintenance
- Reliable and Durable
- Connected and Integrated


System Integration is Critical
Environment
Controls
Vehicle
Exhaust Conditioning
Aftertreatment
Engine
The machine, engine and aftertreatment are part of a single system designed to optimize performance, reliability, cost and emissions


Building Blocks for Meeting Tier 4 Emissions
Possible Tier 4 Building Blocks
Aftercooler
Turbocharger
Injector
Cummins Tier 3 Engine
Flexible Fuel Systems
Combustion Optimization
EGR Cooler
Cooled EGR
Air Handling
Advanced Controls
Particulate Filter
NOx Adsorber
SCR


On-Highway ≠ Nonroad


On-Highway ≠ Nonroad
Sample Nonroad Application
Radiator
Trans
Cooler
A/C Refrig.
Cooler
Hydraulic
Cooler
Drivetrain
Many Suppliers Of Low
Volume Components
Varied Drivetrain
Requirements
Engine
Many Ratings
Several Product Families
High Load Factors
Cooling System
Limited Available Space
No Ram Air; fan HP Increases
More Auxiliary Coolers
Dusty Environment
High Vibration & Impact Loads
Fuel sulfur content up to 5000 ppm, going to 500 then 15 ppm in US by 2010.
Many OEM's, Global Business

## Key Tier 4 Development Areas

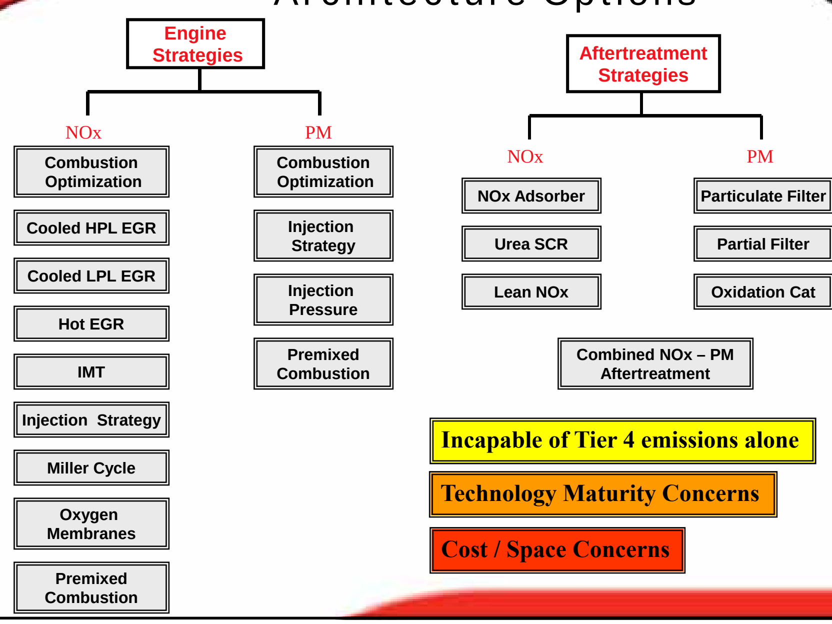
Heat Rejection
- Minimization
- Optimization of cooling systems

Application Variation
- Robust to installation variation
- Cost impact for vehicle installation

Environmental Robustness
- Dust/Dirt
- Surface temperature requirements
- Vibration/Shock

Develop a solution with the lowest initial and life-cycle cost

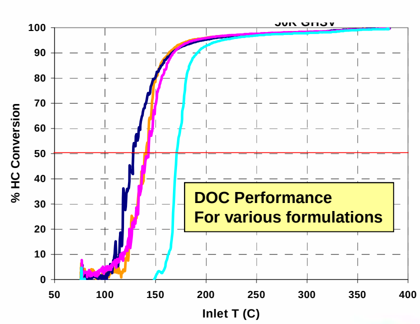
## Tier 4A 75 – 560 kW Architecture Options



## AT System Technologies Options

- For PM Reduction
  - Diesel Oxidation Catalyst (DOC)
  - Partial Filtration
  - Full Filtration
- For NOx Reduction
  - HC-Based NOx Catalysis
  - Urea-Based Selective Catalytic Reduction (SCR)

## Diesel Oxidation Catalyst: Overview



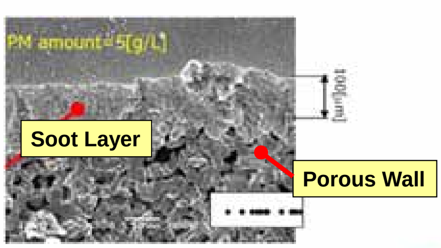

- An oxidation catalyst consists of a special catalytic coating on a honeycomb support.
- HC conversion efficiency is good above a light off temperature.
- DOCs reduce particulate emissions

## Partial Filter: Overview


- A partial filter consists of a mesh, fleece, or foam (metal or ceramic) for collecting particles
- Since this structure is fairly open, pressure drop of this filter is lower than for full filtration.
- A partial filter can reduce PM emissions

## Wall Flow Particulate Filter

- A full filter consists of a porous ceramic honeycomb for collecting particles in the exhaust gas.
- The filter can be coated with precious metal for enhancing oxidation of hydrocarbons promoting low temperature oxidation of soot.
- Full filters reduce PM

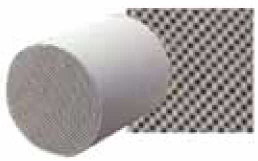


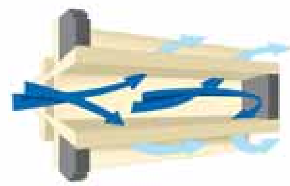

## How The Cummins Particulate Filter Works…

Soot particles are produced by incomplete combustion of the diesel fuel – what we call smoke today

The PM filter removes soot particles from the exhaust by passing the exhaust gases through a ceramic wall-flow filter

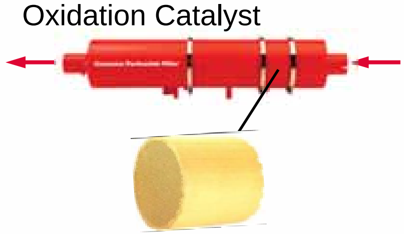
The soot is later oxidized in the filter to form invisible carbon dioxide, giving clean exhaust at the tailpipe



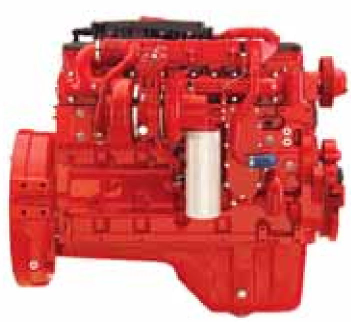


## How The Cummins Particulate Filter Works…

Critical role of Diesel Oxidation Catalyst



Precious Metal Coating



Diesel Oxidation Catalyst

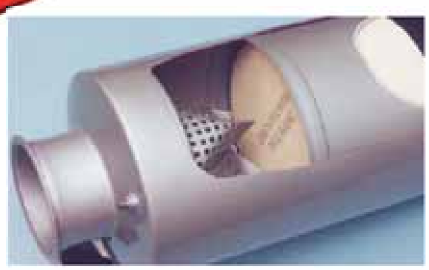
1. Oxidize NO to $NO_2$ – $NO_2$ is critical for **Passive Regeneration**
2. Oxidize dosed fuel to produce heat for **Active Regeneration**

## AT System Technologies Options

- For PM Reduction
  - Diesel Oxidation Catalyst (DOC)
  - Partial Filtration
  - Full Filtration

- For NOx Reduction
  - HC-Based NOx Catalysis
  - Urea-Based Selective Catalytic Reduction (SCR)

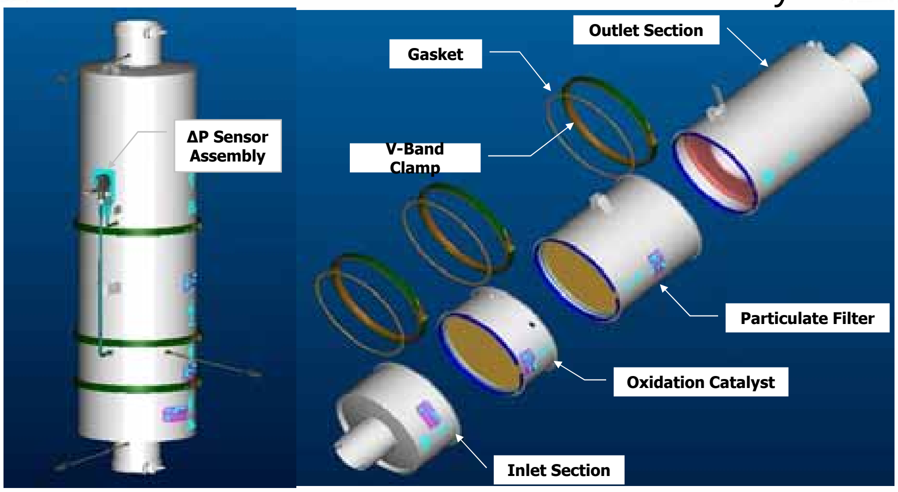
## Urea Based SCR: Overview



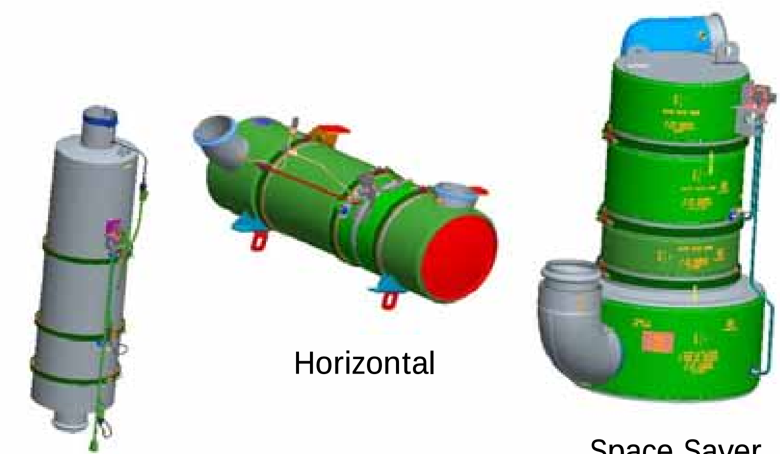
- A vanadia or zeolite based catalytic coating is applied to a honeycomb substrate
- A urea-water solution (“AdBlue”) is used as a reagent for converting NOx to N2

- The urea is converted to ammonia in the exhaust above 200 deg C
- NOx conversion efficiency is high above 250 deg C.
- Provides NOx reduction

## Cummins 2007 Automotive Particulate Filter Assembly

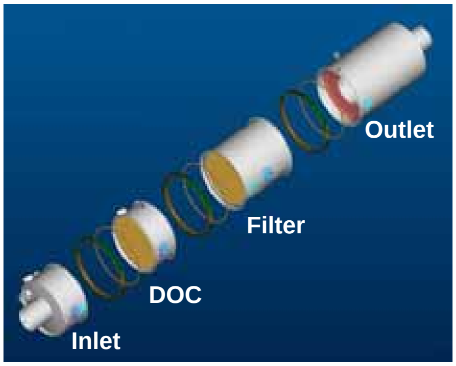



## Exhaust Package Variants



## Particulate Filter Maintenance

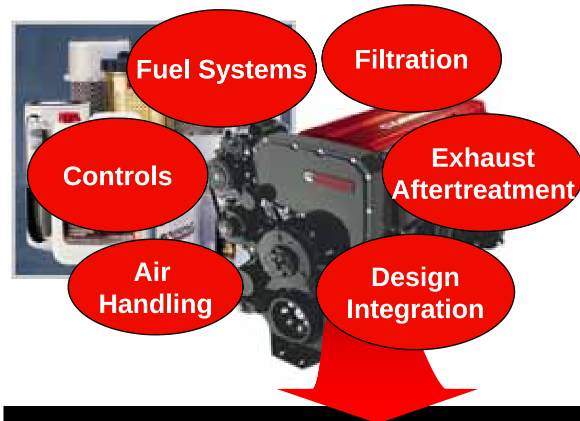
- Particulate Filter Design is modular approach to allow for normal ash cleaning
- Normal Ash cleaning provided via cleaning machine
- Recon Option available for normal Ash cleaning




## System Integration

Leveraging Cummins to deliver to the Best Solution

## Future Solutions Demand System Integration

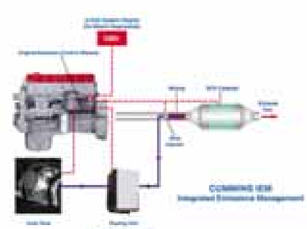



***Cummins family of companies deliver integrated solutions***

## Cummins Worldwide Experience with These Technologies

Cooled EGR & Flexible Fuel Systems – US on-highway since 2002

PM Filter – Retrofit since 2002
- US on-highway in 2007



SCR – Retrofit since 1998
- Euro IV ISB in 2006

## Summary

- Cummins Tier 4 work has been underway since 2004
- We are leveraging our on-highway experience with these potential technologies while using standard tools and processes to ensure we select the right technology for off-highway
- Cummins Inc. is uniquely positioned to deliver an integrated and optimized system for Tier 4

## Questions?

CANMET Mining and Mineral Sciences Laboratories

# Review of Underground Mines Regulation

**15th Annual MDEC Conference**

## Workshop

**October 6, 2009**

**Richmond Hill, Ontario**

**Mahe Gangal, NRCan**

MMSL 09-129(OP)

1

Natural Resources Canada — Ressources naturelles Canada — Canada

CANMET Mining and Mineral Sciences Laboratories

# Contents

- Regulations – Non-gassy underground mines
  - Diesel machines
  - Engine ventilation rates
  - Fuel requirements
  - DPM exposure limits
  - Gaseous exposure limits
- Engine approval procedures

(These notes are for general information only, please contact chief inspectors of mines for the latest regulations)

2

Natural Resources Canada — Ressources naturelles Canada — Canada

# U/G Mine Regulations in Canada

- Provinces & Territories jurisdiction
  - 9 Provinces (PEI does not have mines)
  - 3 Territories

Exemption

- Crown Corporation mines and uranium mines are under the jurisdiction of Federal Government





CANMET Mining and Mineral Sciences Laboratories

# National Standards of Canada for Underground Diesel Machines

- Non-Rail-Bound Diesel-Powered Machines for Use in Non-Gassy Underground Mines, CAN/CSA-M424.2-M90
- Prepared by the Technical Committee on Underground Diesel Equipment
  - Chief inspectors, Labour, Mine operators, Manufacturers, NRCan



Natural Resources Canada Ressources naturelles Canada
Canada

CANMET Mining and Mineral Sciences Laboratories

# Diesel Machine Standard

- Published by Canadian Standard Association (CSA)
- Fire prevention
- Equipment lighting
- Steering
- Electrical & hydraulic systems
- Minimum emission standard
- Minimum ventilation requirement

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# Diesel Engine Approval Requirements

- Dynamometer emissions tests
- Undiluted exhaust gas not to exceed
  - 2,500 ppm of CO
  - 1,500 ppm of NOx
  - 150 mg/m$^3$ of DPM
  - Within the full design range of engine output
- Fuel deration for altitude

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# Diesel Engine Approval Requirements

- Exhaust treatment systems may result in reduced ventilation assessments, provided
  - treatment does not deteriorate with use
  - suitable procedures maintain the device(s)
- Ventilation requirement is based on a dilution ratio of (EQI/3)

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# Exhaust Toxicity Criterion

## Exhaust Quality Index (EQI)

$$\frac{CO}{50}+\frac{NO}{25}+\frac{DPM}{2}+1.5\left[\frac{SO_2}{3}+\frac{DPM}{2}\right]+1.2\left[\frac{NO_2}{3}+\frac{DPM}{2}\right]$$

**DPM (mg/m$^3$) and gas concentrations (ppm) are measured in raw exhaust gas**

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# Dynamometer Laboratory Engine Testing

- Confirmation of engine power and fuel rate
- Setting of engine intake vacuum and exhaust back-pressure
- Raw exhaust measurement of CO and $NO_X$ within the engine operating range to determine Pass/Fail condition
- Steady state testing at about 20 mode points
- Measure engine parameters, CO, $CO_2$, NO, $NO_2$,and DPM
- Calculate $SO_2$, EQI, and ventilation at all mode points
- The highest calculated ventilation rate is the minimum ventilation rate for the engine







# Vent Rate for a CANMET Approved Engine

Engine Manufacturer: **Perkins**
Engine Model: **1106D-E66TA/C6.6 (3418/2200)**
Governing Standard: **CSA M424.2-90 (Non-Gassy Mines)**

| Certificate Number | Engine Rating and Measured Fuel Rate at Sea Level | Sulphur in Fuel - %wt. | Ventilation Prescription* | |
|---|---|---|---|---|
| | | | CFM | $m^3$/min |
| 1200 | 182 HP @ 2,200 RPM, 69.5 lb/hr | 0.05 | 15,900 | 450.2 |
| | | 0.10 | 17,100 | 484.2 |
| | | 0.20 | 19,500 | 552.2 |
| | | 0.25 | 20,700 | 586.2 |
| | | 0.50 | 26,600 | 753.2 |

*These CSA ventilation rates are suitable for low sulphur fuel if permitted by the appropriate regulatory authority.

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| Province/ Territory | Engine Certification CSA | MSHA | Ventilation/Notes |
|---|---|---|---|
| British Columbia | Yes | -- | Ventilation as per CSA standard. Minimum of 0.06 $m^3$/kWs. |
| Alberta | Yes | -- | Ventilation as per CSA standard. Minimum volume of 1.9 m3/s at active headings. |
| Saskatchewan | (see notes) | -- | Ventilation as per CANMET engine approval, or a minimum of 0.063 $m^3$/kWs. |
| Manitoba | Yes | Yes | Ventilation as per CANMET or MSHA approval. Minimum of 0.092 $m^3$/kWs for non-approved engine. For multi-engines, ventilation using 100/75/50 rule and minimum ventilation of 0.045 $m^3$/kWs. |
| Ontario | -- | -- | Minimum ventilation of 0.06 $m^3$/kWs |
| Quebec | Yes | (see notes) | Ventilation as per CANMET or Part 31/32 of MSHA (not the current part 7). Minimum of 0.092 $m^3$/kWs for non-approved engine. For MSHA engines, ventilation using 100/75/50 rule and minimum ventilation of 0.045 $m^3$/kWs. |

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## Diesel Engine Certification / Ventilation Requirements

| Province/ Territory | Engine Certification CSA | MSHA | Ventilation/Notes |
|---|---|---|---|
| New Brunswick | Yes | Yes | Certification required for engines above 75 kW. Minimum ventilation of 0.067 $m^3$/kWs. |
| Nova Scotia | Yes | Yes | A Certificate that machine exceeds better level of safety for non-coal is also acceptable. |
| Newfoundland & Labrador | -- | -- | Requires diesel machine specifications, and written approval from the chief inspector of mines. Minimum ventilation of 0.047 $m^3$/kWs. |
| Northwest Territories & Nunavut | -- | -- | Requires a permit from the chief inspector. Minimum ventilation of 0.06 $m^3$/kWs. |
| Yukon | Yes | -- | Other similar approvals may also be accepted by the chief inspector of mines. Minimum ventilation of 0.047 $m^3$/kWs. |

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# CGSB Fuel Specifications for Flash Point and Sulphur Content

| Fuel Standards | Maximum Sulphur, % | Minimum Flash Point, °C |
|---|---|---|
| *3.16-M86/M88, Regular<br>Special | 0.50<br>0.25 | 40<br>52 |
| *3.16-99, Special-LS | 0.05 | 52 |
| **3.517-93, A-LS | 0.05 | 40 |

* Mining Diesel Fuel ** Automotive LS Fuel

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## Diesel Fuel Requirements

| Province/ Territory | Sulphur, % Maximum | Flash point, °C Minimum |
|---|---|---|
| British Columbia | CAN/CGSB-3.16-M88, Mining Diesel Fuel | |
| Alberta | CAN/CGSB-3.16-M99, Mining Diesel Fuel | |
| Saskatchewan | 0.05 | 52 |
| Manitoba | CAN/CGSB-3.16-99, Mining Diesel Fuel, Special-LS, or CAN/CGSB-3.517-93, Automotive Low Sulphur Diesel Fuel, type A-LS | |
| Ontario | CAN/CGSB-3.16-99, Mining Diesel Fuel, Special-LS, or CAN/CGSB-3.517, Automotive Low Sulphur Diesel Fuel, type A-LS | |
| Quebec | 0.05 | -- |
| New Brunswick | -- | -- |
| Nova Scotia | CAN/CGSB-3.517-2007 (for ambient temperature above 30 °C use CAN/CGSB-Spec 3.16-99, Mining Diesel Fuel, Special-LS with flash point higher by 10 °C | |
| Newfoundland & Labrador | 3-GP-6 or latest version of CGSB fuel standard Mining Diesel Fuel | |
| Northwest Territories and Nunavut | 0.25 | 43 |
| Yukon | 0.25 | 52 |

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# Advantages of Low Sulphur Fuel

- Reduces $SO_2$ and DPM concentrations
- Sulphate fraction of DPM is reduced by 80% by reducing fuel sulphur from 0.25% to 0.05%
- Increases the effectiveness of emission control technologies
- Ventilation rate increases with the increase of fuel sulphur content





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**DPM Exposure Limits ($mg/m^3$)**

| | |
|---|---|
| British Columbia | 1.5 |
| Alberta | ACGIH |
| Saskatchewan | No limit value |
| Manitoba | ACGIH |
| Ontario | 1.5 |
| Quebec | 0.6 |
| New Brunswick | 1.5 |
| Nova Scotia | 1.5 |
| NFLD & Labrador | ACGIH |
| Northwest & Nunavut | 1.5 |
| Yukon | 1.5 |

* ACGIH does not specify any DPM limit value



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## Time Weighted Average Gaseous Exposure Limits in ppm

| | CO | $CO_2$ | NO | $NO_2$ | $SO_2$ |
|---|---|---|---|---|---|
| British Columbia | 25 | 5,000 | 25 | 3 | 2 |
| Alberta | 25 | 5,000 | 25 | 3 | 2 |
| Saskatchewan | 25 | 5,000 | 25 | 2 | 2 |
| Manitoba | 20 | 5,000 | 25 | 3 | 2 |
| Ontario | 25 | 5,000 | 25 | 3 | 2 |
| Quebec | 35 | 5,000 | 25 | 3 | 2 |
| New Brunswick | 25 | 5,000 | 25 | 3 | 2 |
| Nova Scotia | 25 | 5,000 | 25 | 3 | 2 |
| NFLD & Labrador | 25 | 5,000 | 25 | 3 | 2 |
| Northwest & Nunavut | 25 | 5,000 | 25 | 3 | 2 |
| Yukon | 50 | 5,000 | 25 | 5 | 5 |

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## Short Term Gaseous Exposure Limits in ppm

| | CO | $CO_2$ | NO | $NO_2$ | $SO_2$ |
|---|---|---|---|---|---|
| British Columbia | -- | 30,000 | -- | 5 | 5 |
| Alberta | -- | 30,000 | -- | 5 | 5 |
| Saskatchewan | 190 | 30,000 | 38 | 5 | 5 |
| Manitoba | -- | 30,000 | -- | 5 | 5 |
| Ontario | 100 | 30,000 | -- | 5 | 5 |
| Quebec | 200 | 30,000 | -- | -- | 5 |
| New Brunswick | -- | 30,000 | -- | 5 | 5 |
| Nova Scotia | -- | 30,000 | -- | 5 | 5 |
| NFLD & Labrador | -- | 30,000 | -- | 5 | 5 |
| Northwest & Nunavut | -- | 30,000 | -- | 5 | 5 |
| Yukon | 400 | 15,000 | 35 | -- | 5 |

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## Engine Approval Procedures

- Manufacturer makes an application to NRCan/CANMET-MMSL
- NRCan provides an agreement letter with test details and other requirements
- Applicant sends an engine to the test laboratory with required documents
- Test engine should be ready for testing as received (broken-in, meets engine spec.)
- Testing proceeds as per the required standard



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## Engine Approval Procedures

- If the engine does not meet the requirements of the standard, the engine is not approved
  - The applicant is provided the reasons, and corrective actions are discussed
  - The engine can be resubmitted for testing, if desired, after making proper changes to the engine

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# Engine Approval Procedures

- If the engine meets the requirements of the standard, the engine is approved
  - Test report and engine approval provided
  - Ventilation rates are posted on the NRCan website, and a list is provided to the Chief Inspector of Mines
  - Laboratory testing for CSA, MSHA and other standards can be done at the same time, if required

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# List of Approved Diesel Engines

**English version:**
**http://www.diesel.NRCan.gc.ca**

**French version:**
**http://www.diesel.RNCan.gc.ca**

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# Thank You !

# MDEC WORKSHOP 2009

Selection, Operation and Maintenance of Control Technologies

October 6, 2009

Presented by: Paul Turpin
DCL International Inc.

## Selection

- Requirements
  - Application Information
  - Performance
  - Temperature Tracing
- Selection
  - Diesel Oxidation Catalysts
  - Diesel Particulate Filters

# Requirements – Application Information

- Before deciding on the most suitable control technology for the application, the following information should be provided:
  - Engine model
  - Engine power
  - Engine tier level/family number (for diesel particulate filter systems)
  - Application details (production, utility, etc.)
  - Fuel sulphur level

Courtesy DCL

Courtesy Kubota Canada

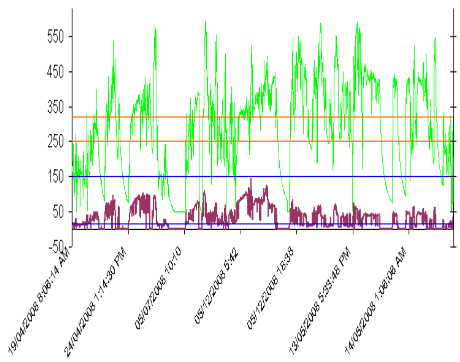
# Requirements - Performance

- What pollutants need to be reduced? How much?

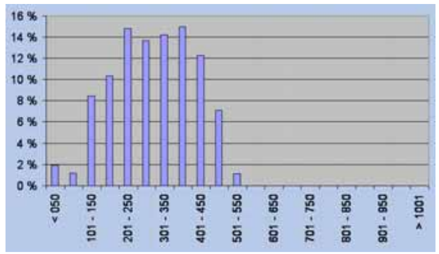
| Characteristics | Diesel Oxidation Catalyst | Diesel Particulate Filter (PM coated) | Diesel Particulate Filter (BM coated) | Diesel Particulate Filter (Uncoated) |
|---|---|---|---|---|
| DPM Efficiency | 10-30% | >90% | >90% | >90% |
| CO Efficiency | 60-95% | >90% | minimal | n/a |
| HC Efficiency | 50-80% | >80% | minimal | n/a |
| $NO_2$ Increase | Yes | Yes | No | No |
| Typical Balance Point /Operating Temperature | 320 - 425°F (160 - 220°C) | 510-680°F (265-360°C) | 715-825°F (380-440°C) | ~1115°F (600°C) |
| Typical Fresh Backpressure | 5-10"$H_2O$ (1.25 - 2.5kPa) | 20-30"$H_2O$ (5 -7.5kPa) | 20-30"$H_2O$ (5 - 7.5kPa) | 20-30"$H_2O$ (5 - 7.5kPa) |

## Requirements – Temperature Tracing

- Where a diesel particulate filter (DPF) is required, a temperature trace may be requested to review the duty cycle.




Temperature Trace



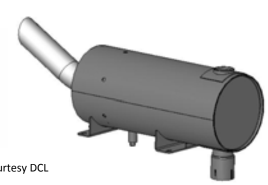

Temperature Analysis

## Selection - Diesel Oxidation Catalysts

- Design considerations:
  - Substrate material: ceramic or metallic.
  - Cell density: typically 200cpsi.
  - Catalyst loading.
  - Catalyst/substrate volume.
  - Package: muffler or standard design.

Courtesy DCL

Courtesy NGK

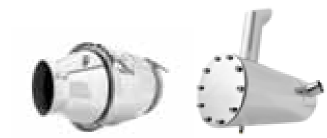


Courtesy DCL

## Selection – Diesel Particulate Filters

- Design considerations:
  - Substrate material: Cordierite or SiC.
  - Cell density: typically 100 or200cpsi.
  - Regeneration Strategy: Passive or Active
  - Catalyst coating.
  - Filter volume.
  - Package: muffler or standard design.


Courtesy NGK


Courtesy DCL

## Contents – Operation and Maintenance

- Operation of Control Technologies
  - Diesel Oxidation Catalysts
  - Passive Diesel Particulate Filters
  - Active Diesel Particulate Filters
- Maintenance of Control Technologies
  - Routine Maintenance
  - Periodical Maintenance

# Operation - Diesel Oxidation Catalysts

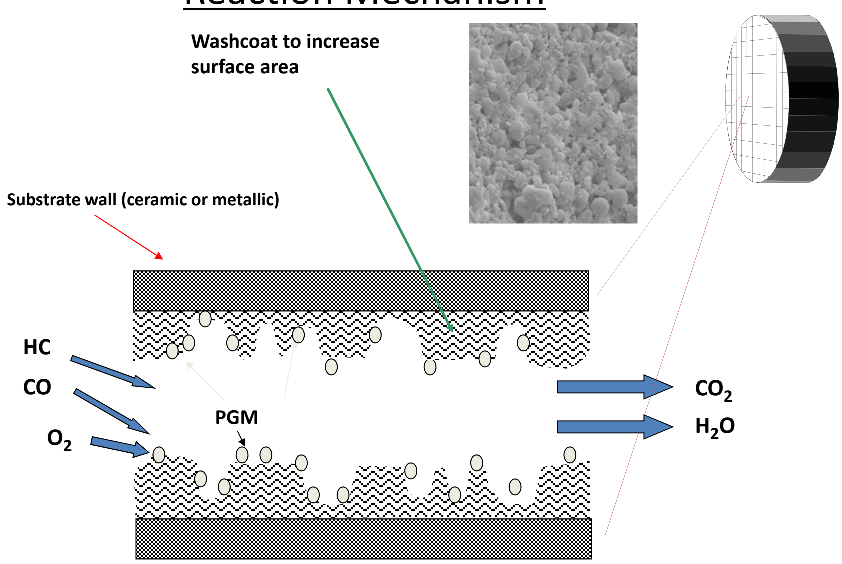
- A precious metal catalyst (Pt or Pt/Pd) coating is applied to a supporting substrate.
- The substrate may be made of ceramic or metal.

Note: definition of a catalyst is a substance that speeds up a chemical reaction without itself undergoing any permanent chemical change.


Courtesy of NGK

# Operation - Diesel Oxidation Catalysts

## Reaction Mechanism



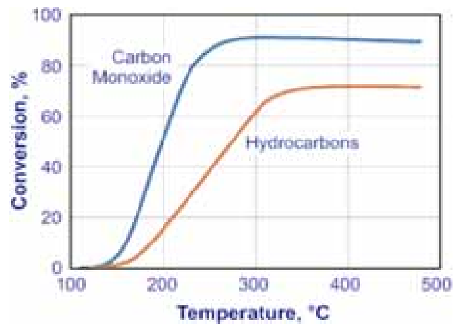
## Operation - Diesel Oxidation Catalysts

- A DOC oxidizes the following pollutants into harmless byproducts:
  - Carbon monoxide (CO).
  - Hydrocarbons (HC).
  - Soluble organic fraction (SOF).
- In the reaction, CO is oxidized to form carbon dioxide ($CO_2$) and hydrocarbons are oxidized to form $CO_2$ and water vapour ($H_2O$).

## Operation - Diesel Oxidation Catalysts

- When sulfur is present in the fuel, the DOC will eventually also oxidize compounds like sulfur dioxide into the less desirable byproduct, sulfuric acid ($H_2SO_4$).
- $H_2SO_4$ when emitted will mix with air, decreasing the temperature of the particles and combine with water molecules forming (liquid) particles known as sulfate particulates.
- Another reaction taking place is the oxidation of NO to $NO_2$.

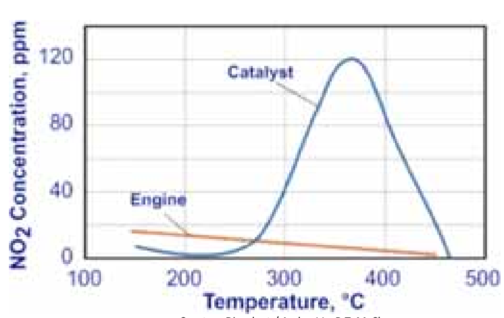
## Operation - Diesel Oxidation Catalysts




Courtesy Dieselnet

- Typical conversion efficiencies for PGM catalysts.
- Peak efficiencies and light-off temperatures will shift with changes in areas such as catalyst loading, substrate cell density, and catalyst volume.

## Operation - Diesel Oxidation Catalysts

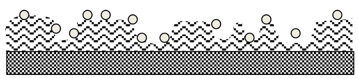
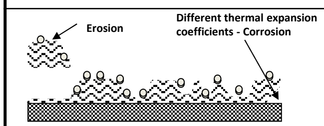
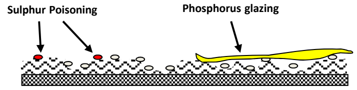



Courtesy Dieselnet / Ambs, J.L., B.T. McClure

- Pre and Post catalyst $NO_2$ concentrations for PGM catalysts.
- The decrease in $NO_2$ is the result of the reaction between NO, $O_2$ and $NO_2$ reaching its thermodynamic equilibrium.

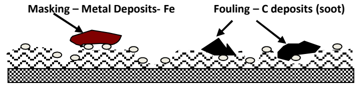
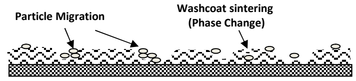
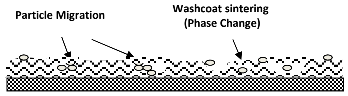
# Operation - Diesel Oxidation Catalysts

## Catalyst Deterioration

| | |
|---|---|
|  | <u>Ideal Surface</u><br>•Good adhesion<br>•Well-dispersed particles<br>•Similar thermal expansion coefficients of substrate and washcoat |
|   | <u>Attrition</u> |
|   | <u>Poisoning</u><br>•Sulfur poisoning (reversible) greater than 600 ° C (1110 ° F)<br>•Lube oil poisoning – Phosphorus poisoning (irreversible); caused by ZDDP (Zinc dialkyl dithio phosphate) |

# Operation - Diesel Oxidation Catalysts

## Catalyst Deterioration

| | |
|---|---|
|   | <u>Masking/Fouling</u><br>•Soot (Reversible) greater than 550 ° C (1020 ° F) |
|   | <u>Sintering</u><br>•High temperature sintering: complete collapse of washcoat<br>•Loss of surface area from 200m$^2$/g to 5 m$^2$/g (1100 ° C/2010 ° F) |
|   | |

# Operation - Diesel Particulate Filters

- A device used to remove particulate matter from diesel engine exhaust.
- Honeycomb-like channels are alternately plugged to force exhaust through porous filter walls.
- Exhaust gas flows through the filter media trapping particulate and inorganic based exhaust constituents.
- To prevent damage to the engine and filter, collected material must be removed.

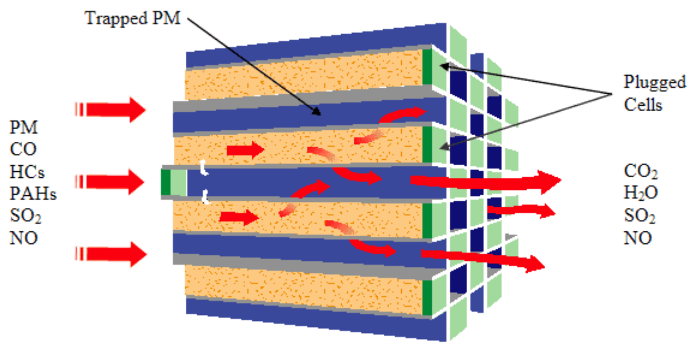
Courtesy Corning Inc.

Courtesy NGK

# Operation - Diesel Particulate Filters

- Different methods are used to remove the collected particulate and regenerate the filter; some regeneration methods are:
  - Coating the filter with a catalyst.
  - Using a catalyst upstream of the filter.
  - Employing a fuel borne catalyst.
  - Engine management.
  - A fuel burner.
  - Electrical heating (on-board or off-board).
- Regeneration methods are classified as passive and active.

# Operation - Diesel Particulate Filters




Courtesy of MECA

# Operation - Diesel Particulate Filters

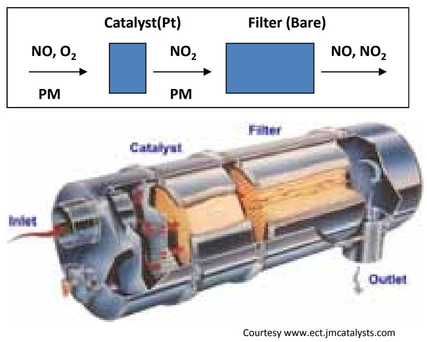
## Filter Balance Point (B.P.)


Balance Point: (PM Consumed) = (PM In) - (PM Out)

Back-Pressure Increases: (PM Consumed) < (PM In) - (PM Out)

Back-Pressure Decreases: (PM Consumed) > (PM In) - (PM Out)

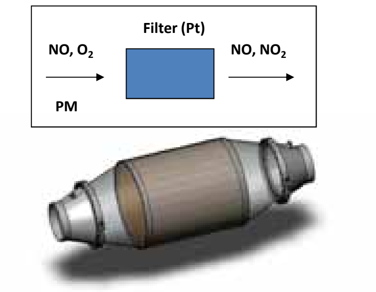
## Operation – Passive Diesel Particulate Filters

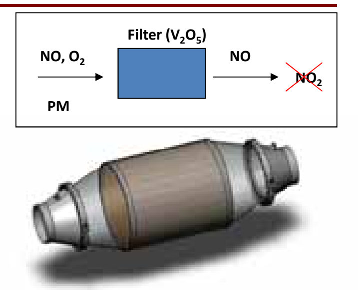



Unpredictable in NO2 output

→Generally high

→Higher in CCRT



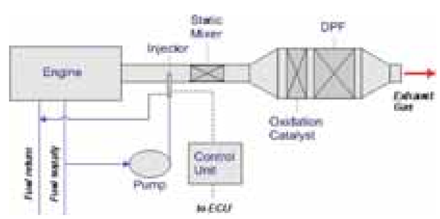

## Operation – Passive Diesel Particulate Filters

- Soot regeneration temperature is 550-600 ° C but can be reduced significantly when filter block is coated with oxidation catalyst
- Soot regeneration rate is enhanced by adding special ingredient to wash-coat composition - promoters

## Operation – Passive Diesel Particulate Filters

- Two oxidation mechanisms;
  - $NO_2$ Oxidation
    - High loading DOC is upstream the DPF to produce $NO_2$ from the ~90% engine out NO
    - $NO_2$ oxidizes soot at low temperatures: 270-320 °C
    - $NO_2$ consumption depends on soot load and that makes tailpipe $NO_2$ emissions uncontrolled
  - $O_2$ Oxidation
    - Two catalyst families;
      - Precious Metal Catalyst: reduce BPT to 280-350 °C
      - Base Metal Catalyst: reduce BPT to 375-420 °C
    - Fuel Born Catalyst (Additives)

## Operation – Active Diesel Particulate Filters




Courtesy Dieselnet

Courtesy Engine Control Systems Ltd.

## Operation – Active Diesel Particulate Filters

- On-board automated active (passive forced regeneration)
  - Diesel burner is triggered by DPF differential pressure at target engine modes
  - Diesel fuel post injection (manifold) to produce exothermic condition over heavy loaded DOC to force the DPF regeneration
- Off-board manual active – Shift End
  - Diesel Burner is triggered manually at the end of each shift
  - Electrical Heater is triggered manually at the end of each shift

## Operation – Diesel Particulate Filters

### Media Failure Modes

| Media | Max. T ($^oC$) | Failure Modes |
|---|---|---|
| Cordierite (porous ceramic) | 1050-1100 | Ash-media interaction |
| | 1400 | Melting |
| | - | Cracking |
| Silicon Carbide | 1300-1400 | Ash-media interaction |
| | 2400 | Melting/Sublimation |
| | - | Cracking |

# Operation – Diesel Particulate Filters

## Ash and Its Effects

- Remember: DPFs collect diesel particulate matter and inorganic based exhaust constituents.
- Inorganic based exhaust constituents are typically known as ash.
- Ash does not oxidize into a gaseous state.
- Ash forms oxides and sulfates which are stored within the DPF.

# Operation – Diesel Particulate Filters

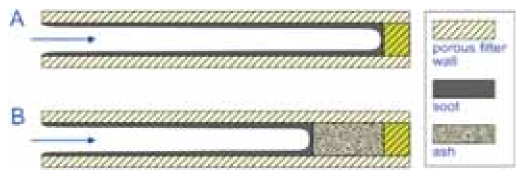
## Ash and Its Effects

- Source of ash:
  - Exhaust system.
  - Engine metals and engine component wear.
  - Crankcase lubrication oil.
  - By-products of diesel fuel additives.
  - Operating environment.

## Operation – Diesel Particulate Filters

### Ash and Its Effects

- Ash will gradually accumulate within the DPF.
- As ash accumulates the pressure drop across the DPF will increase which results in:
  - gradual degradation of diesel engine performance.
  - increased fuel consumption.
  - increased oil consumption.
  - high oil temperatures.
  - high coolant temperatures.
- Ash containing phosphorus may increase oxidation temperatures of due to poisoning of the catalyst.




Courtesy Dieselnet

## Maintenance of Control Technologies

### - Keeping Records -

- It is important to record the following details:
  - At installation:
    - Engine hours.
    - Part and serial number of the device.
    - Serial number of backpressure measurement device (where applicable).
  - During Maintenance:
    - Engine hours.
    - Maintenance performed and any observations.

# Maintenance of Control Technologies

## Routine Maintenance

- **ALWAYS** follow the recommended directions in maintenance manuals provided by the device manufacturer.
- Where a backpressure monitor is used **ALWAYS** react to any warnings.
- The following operations should be done routinely:
  - Visually inspect the exhaust system for leaks and external damage to the exhaust system.
  - Manually check the backpressure.
  - If a backpressure monitor is used, remove the pressure transmitter and apply a pressure to the line.

# Maintenance of Control Technologies

## Routine Maintenance

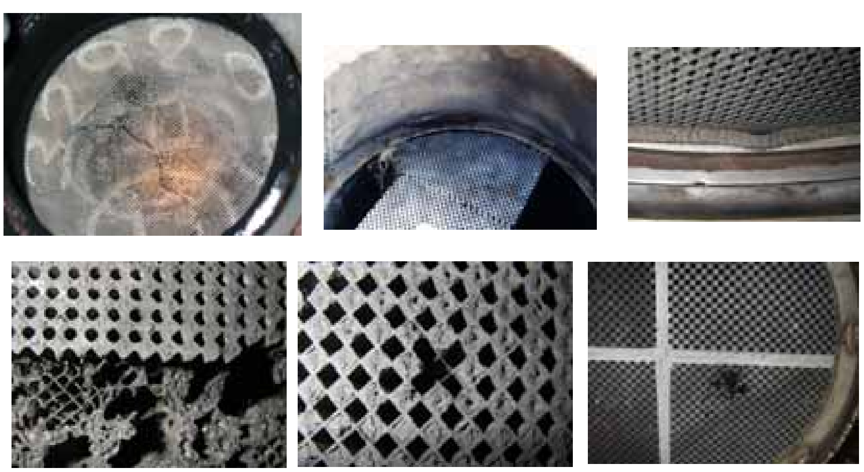
# Maintenance of Control Technologies

## Periodic Maintenance

- The following operations should be done periodically or as per the device manufacturers maintenance schedule:
  - Remove the device.
  - Visually inspect the device.
  - If device is lightly caked with soot, manually blow compressed air through the filter.
  - If device is heavily caked with soot, the filter should be cleaned by a thermal kiln cleaning operation.
  - After any operation, always inspect the device before re-installing.

# Maintenance of Control Technologies

## Periodic Maintenance



# Maintenance of Control Technologies
## Removal of DPF/DOC Centre Body

**Design A**

1) Carefully support bottom of DPF/DOC to prevent accidental drop damage.
2) Remove nuts from clamp bolts of V-band clamps which connect end cones to DPF/DOC. Use mallet or prying tool to loosen V-band clamps.
3) Separate DPF/DOC center body from the end cones and remove.
4) Place DPF/DOC on a flat surface and block DPF/DOC center body to prevent movement.
5) Remove end cone gaskets. Scrape old gasket material from end cone and center body flanges (if applicable).

# Maintenance of Control Technologies
## Removal of DPF/DOC Centre Body

**Design B**

1) Remove nuts from end discs and separate end discs.
2) After Inspection of filter if thorough cleaning is required remove the unit.
3) Place DPF/DOC on a flat surface and block to prevent movement.
4) Remove end disc gaskets. Scrape old gasket material from end cone and center body flanges (if applicable).

# Maintenance of Control Technologies

## Pre-cleaning Inspection

- With the DPF/DOC dismantled, check the condition of the end cones/discs, end cone exhaust pipe clamps, end cone flange surfaces, test ports/plugs, end cone gasket surfaces, V-band clamps, bolts and nuts. Replace the end cone gaskets and replace/repair any other damaged components.
- Check the condition of DPF/DOC canning metal outer shell.
- Check the condition of the DPF/DOC end cone to center body flange surfaces. Check for corrosion, possible warping and any other damage.
- Check the DPF inlet and outlet face seals to make sure that they are not damaged, loose or missing.
- Check the DPF inlet and outlet faces for visible channel plug damage or pitting.

# Maintenance of Control Technologies

## Pre-cleaning Inspection

- Check the inlet face of the DPF/DOC inlet face for DPM plugging. Channel plugging indicates an excessive DPM loading.
- For segmented DPF check the condition of cemented seams.
- Check the DPF outlet face for DPM spotting.

# Maintenance of Control Technologies

## Manual Cleaning Procedure - Safety Equipment

- **ALWAYS** follow safety procedures as per your jurisdiction.

1) Wear soil resistant clothing or disposable coveralls.
2) Leather gloves.
3) Appropriate respirator.
4) Safety glasses with safety face shield.
5) Perform cleaning operation is a well ventilated area with adequate lighting.

# Maintenance of Control Technologies

## Manual DPF/DOC Ash Removal

Cleaning of DPF/DOC center body

1) Weigh the DPF/DOC center body and record.
2) Where applicable, install end cone and V-band clamp onto inlet end.
3) Install vacuum cleaner hose onto inlet end cone.
4) Divide the outlet face into quadrants using a fine tip marker or tape.
5) Working one quadrant at a time (using rubber tipped or flexible tube air nozzle) blow compressed air into each open channel of the DPF/DOC outlet face. Pulse the rubber tipped air nozzle on/off when directed into each individual channel as required to clear the channel of particulate matter and as required.
6) Channels located at the periphery of DPF/DOC outlet face may require additional effort to remove higher DPM/Ash mass versus the centre of the outlet face.
7) After initial cleaning, remove inlet end cone and vacuum hose from inlet face and inspect inlet face with flashlight. If compacted DPM "straws" are observed emitting from channels repeat cleaning procedure. Concentrate air flow into channels where DPM "straws" are observed.
8) Weigh the DPF/DOC center body and record.

# Maintenance of Control Technologies

## Manual DPF/DOC Ash Removal Procedure Step 2

Thermal Kiln Heating of DPF/DOC Center Body

1) Install 4 metal or ceramic spacers (2.0” high by 2.0” long) oriented to allow DPF/DOC center body to be situated above the kiln floor. This will allow upward air flow through the DPF/DOC substrate.
2) Install DPF/DOC center body into kiln outlet face down.
3) Heating cycle should consist of a 2 to 4 hour minimum “ramp up” segment which will gradually raise the kiln temperature to approximately 650ºC to 700ºC maximum or as directed by the device manufacturer.
4) Ramp up segment to be followed by a “constant heat” segment where kiln temperature is held constant at approximately 650ºC to 700ºC maximum for a 2 to 4 hour minimum time period or as directed by the device manufacturer.
5) Constant heat segment to be followed by “cooling” segment where kiln temperature is gradually reduced from 700ºC maximum to ambient. It is best to allow the DPF/DOC to fully cool down to ambient temperatures naturally in the kiln. Do not attempt to speed the cooling segment.
6) Remove DPF/DOC from kiln.
7) Weigh the DPF/DOC center body and record.
8) Perform cleaning with compressed air as per previous slide.

# Maintenance of Control Technologies

Courtesy SPX Corp.

Courtesy FSX Inc.

# Maintenance of Control Technologies

## Post-cleaning DPF Inspection Methods

- 1) if DPM spotting on the outlet face was found earlier during pre-cleaning inspection, the DPF should be internally inspected. DPM spotting is indicative of internal DPF damage. Low engine exhaust gas restriction, visible PM on exhaust tailpipe and poor engine performance are other telltale signs.
- 2) gently use the .060"/045" probing rods in the area of DPM spotting. The probing rod should be able to easily slide the entire depth of the filter inlet/outlet channel without restriction.
- 3) place a high intensity spotlight in close proximity to the filter inlet/outlet face. Visually inspect the opposite face for any leakage of bright light indicative of channel damage.
- 4) alternately the DPF core may have to be inspected by use of bore scopes, endoscopes, x-ray and airflow testing to determine channel damage.
- 5) measurement of CO % reduction efficiencies on a periodic basis (in the case of catalyzed DPF) will determine condition of precious metal coating.

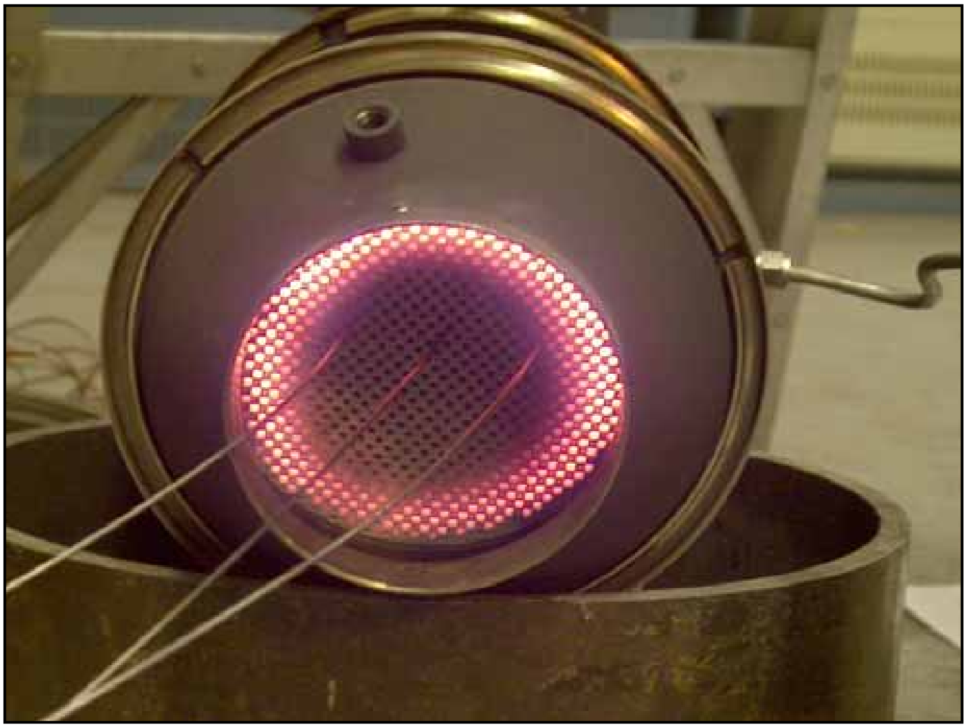
# Maintenance of Control Technologies

## Post-cleaning DPF/DOC Inspection Tools

- 1) .060" and .045" probing rods for 100 cell and 200 cell DPF densities.
- 2) High intensity spot light (15,000,000 candlepower +).
- 3) Bore scope with flexible .045" probe.
- 4) Contract X-ray inspection services.
- 5) Contract ultra sound inspection services.
- 6) Portable CO analyzer (0 – 2000 ppm)

# Maintenance of Control Technologies

Courtesy of www.olympus-ims.com



# Installation & Evaluation of Control Technologies

**By**

**Catalytic Exhaust Products Ltd.**
**John Stekar**
**Bob Mojaverian**

MDEC Presentation

October 2009

## Evaluation of Control Technologies:

- Introduction
- Data Logger Setup
- Data Logger Installation
- Data & Analysis Charts
- Evaluation of Data
- Data Logging Issues

## 1. Introduction:

- Data Loggers are installed on an engine to monitor the exhaust temperature and/or pressure.
- It is important to understand the exhaust temperature profile before installing an emission control device.
- Insufficient exhaust temperatures in some cases may lead to premature plugging and increased maintenance to keep the filter clean and engine running.
- A data logger is a device used to record the exhaust temperature during engine operation.
- The loggers are installed close to the location where the emission control device is going to be installed,
- The loggers report several days of data to provide a reasonable sample size.
- The vehicle must operate under ‘normal operating conditions’ so that an accurate picture of the exhaust temperature profile is obtained.
- The reports contain a column of date stamp, a column of temperature in ºC or ºF, and may contain a column of pressure in mbar or INHG


## Introduction (continued)

- The data logger could be set to sample every few seconds
- Some loggers report based on sample frequency, i.e. showing a number of times the logger has detected a temperature in the exhaust pipe per day.
- The data loggers are shipped to the mine site for data collection and then sent back. The data then downloaded and analyzed and reported to the mine site.
- The analysis will include charts showing the type of emission control devices suitable for the application based on temperature profile.


Data-logger temperature
sensor

## Data Logger Set up:

- There are different methods to set up a data logger.
- Generally the logger should be setup  so it start after installation and as close as possible to the timing when the vehicle is in operation and the engine running.
- Some data loggers are set up with time delays
- Some data loggers are set up with temperature trigger point
- Some data loggers are set up with manual start button

## Data Logger Parts:

The sensor should be installed as close to the location where the emission control device is going to be installed using the supplied items listed:

1. 1/8” NPTF test port (Stainless Steel 303 Alloy)
2. 1/8” NPTM test port plug (Brass)
3. 3/16” outside diameter thermocouple test probe and 1/8” NPTM threaded nut (brass)
4. 14 gauge thermocouple wire (connected to test probe and data logger)
5. Data logger with protective housing 4”x4”x2.5” grey plastic sealed electrical box (with removable top)

# Data Logger Installation:

Installation Steps:

a) Drill a 15/32” diameter hole in exhaust pipe in an area where the inlet of an emission control device will be located.

b) Weld the 1/8” NPTF test port into the 15/32” hole.

c) Remove the 1/8” brass plug from the test port

d) Install the thermocouple probe, NOTE: Do not bend the probe, cut short or pinch the thermocouple probe wire; The tip of the probe should be in the middle of the pipe (not touching the inside walls).

e) Hand tight the probe nut and then ½ turn with ½” wrench.

f) The mounting location of the data logger housing should be free of hazards such as excess moisture, water, heat, vibration, dust, etc… The installer need to support the data logger housing and excess wire to the vehicle chassis using tie-raps etc.

g) The installer must manually trigger the data logger to start recording engine exhaust gas temperature.

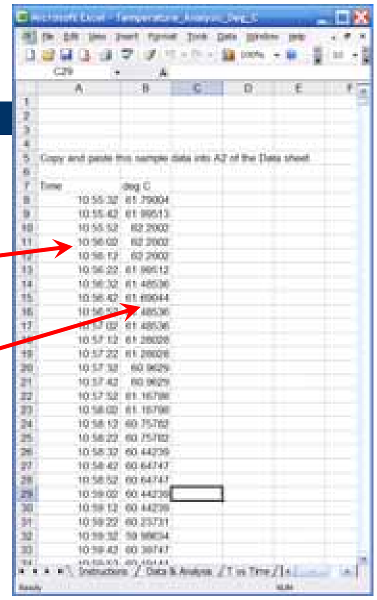
# Evaluation

- When the data loggers are sent back the data is downloaded to a computer for analysis.
- A total of 43,200 data point will be collected over a period of 3 days or 72 hours.
- The data is recorded every 6 seconds
- The data logger will automatically shut down after it reaches 43,200 points
- The duty cycle of a vehicle can be detected from the analysis charts. This duty cycle then is compared with the balance point on available product by emission control device manufacturer. If the application percentage duty cycle is higher than the balance point of the device, then the application pass the test and we can install the device on this vehicle.
- The duty cycle of the vehicle and the route it travels should not change drastically or else new data logging may be required, or other measures such as more regeneration cycles may be required.

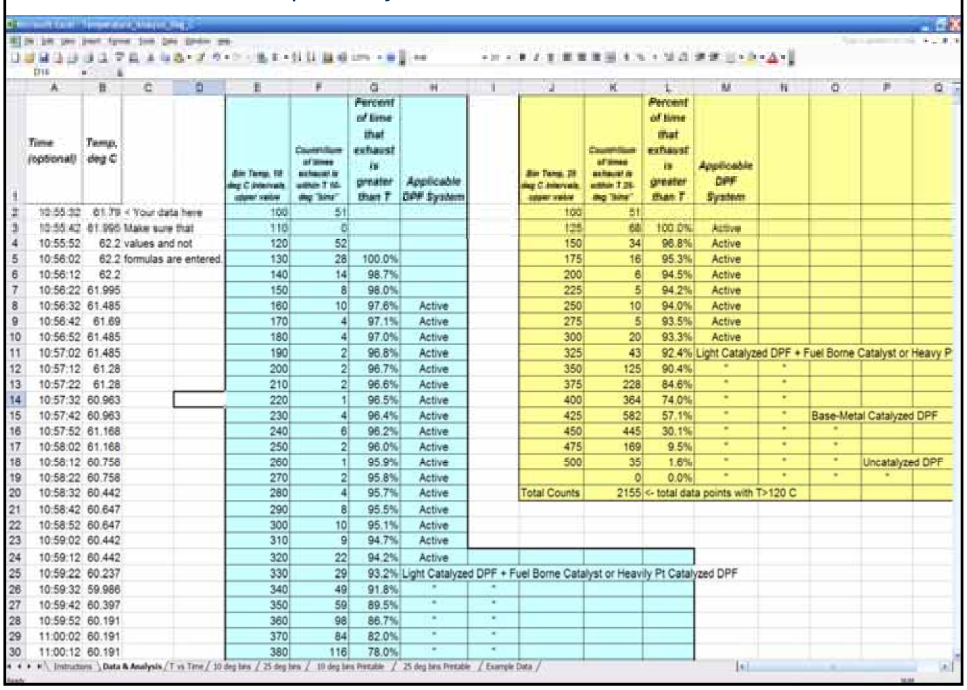
Raw data downloaded into a computer program

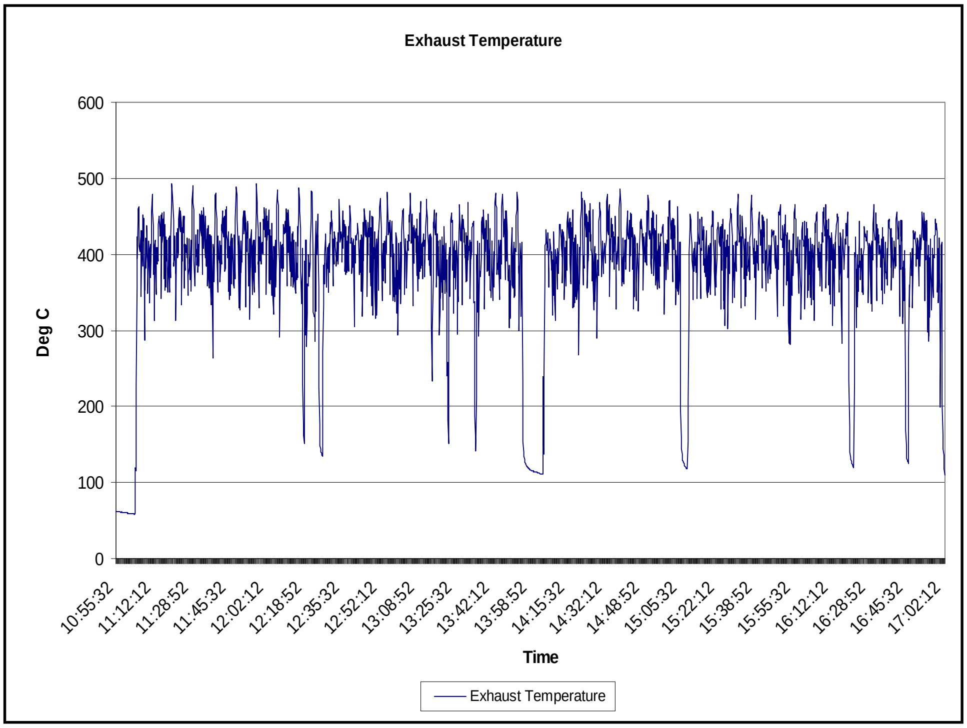
Time stamp

Temperature readings

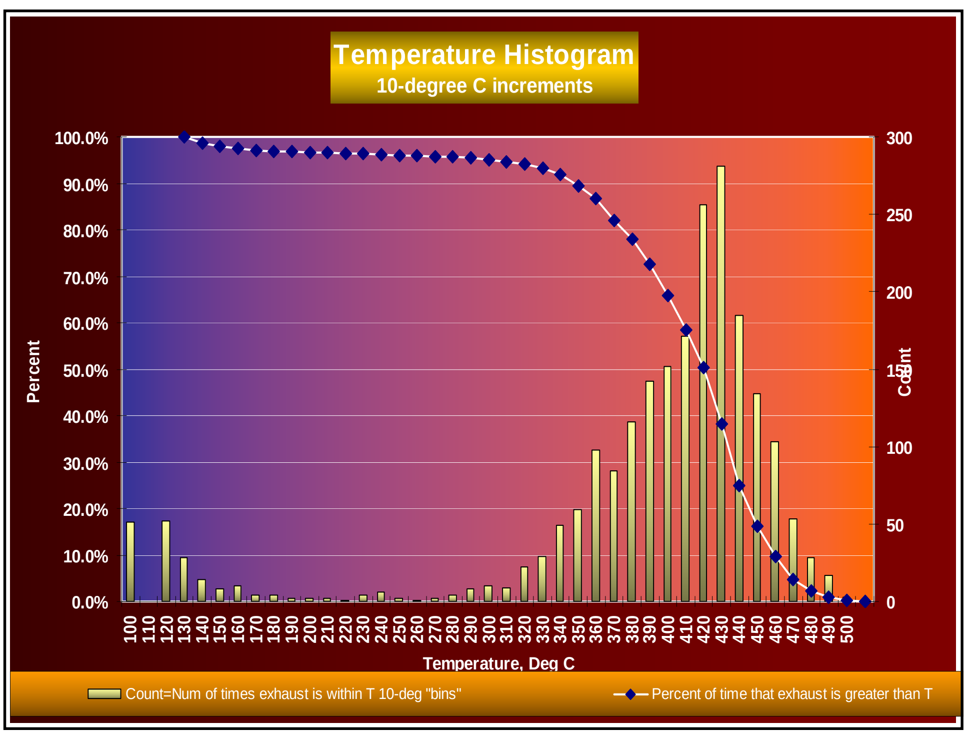



Sample analysis tool shown below





Exhaust Temperature
600
500
400
300
200
100
0
Deg C
10:55:32
11:12:12
11:28:52
11:45:32
12:02:12
12:18:52
12:35:32
12:52:12
13:08:52
13:25:32
13:42:12
13:58:52
14:15:32
14:32:12
14:48:52
15:05:32
15:22:12
15:38:52
15:55:32
16:12:12
16:28:52
16:45:32
17:02:12
Time
Exhaust Temperature

Temperature Histogram
10-degree C increments
100.0%
90.0%
80.0%
70.0%
60.0%
50.0%
40.0%
30.0%
20.0%
10.0%
0.0%
Percent
300
250
200
150
100
50
0
Count
100 110 120 130 140 150 160 170 180 190 200 210 220 230 240 250 260 270 280 290 300 310 320 330 340 350 360 370 380 390 400 410 420 430 440 450 460 470 480 490 500
Temperature, Deg C
Count=Num of times exhaust is within T 10-deg "bins"
Percent of time that exhaust is greater than T

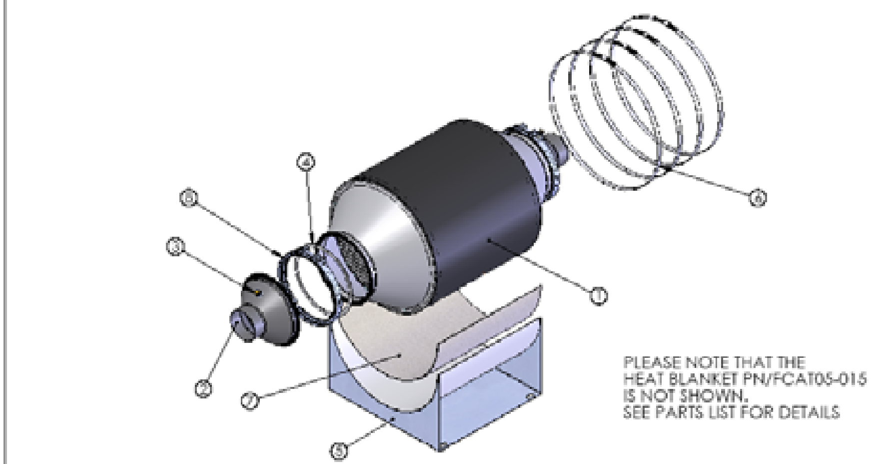
## Data Logging Issues

Repeatability of data may not be 100% due to:

- Seasonal temperature changes,
- Vehicle routing changes,
- Change of the vehicle operation
- Change of the vehicle operators,
- Engine wear and tear,
- Change of engine fuels and lubes
- Other variables, etc..

## Installation of Passive Control Technologies:

- Location of the emission control device
- Exhaust pipe materials
- Heat insulation of exhaust system
- Vibration isolators & flex pipes
- Sound attenuation of control devices
- Recommended exhaust clamp types
- Exhaust back pressure kit




| ITEM NO. | PART NUMBER | DISCRIPTION | 1515SXS/QTY. |
|---|---|---|---|
| 1 | 1515SXS-400 | 1515SXS-SC FILTER CORE | 1 |
| 2 | B-150 | FILTER END CONE-5.0 IN/OUT | 2 |
| 8 | B-200 | 1/8 NPTM BRASS PLUG | 2 |
| 4 | B-100 | END CONE GASKET | 2 |
| 5 | 1515SXS-CRADLE | 1515SXS FILTER CRADLE | 1 |
| 6 | TRIDON HAS-270 | CRADLE HOSE CLAMPS | 4 |
| 7 | 1515SXS-CPF400 | THERMAL LAYER | 1 |
| 8 | B-300 | END CONE V-BAND CLAMP | 2 |

CATALYTIC EXHAUST PRODUCTS LIMITED

COMPONENTS,1515SXS

B DWG. NO. 1515SXS

## Location of Control Devices

- Emission control device should be installed as close to the engine as possible. We recommend maximum 30" away from exhaust manifold outlet or turbocharger outlet.
- In general for mining DPF applications horizontal installations are preferred to vertical installations due to stress concentration on face seals and mounting brackets.
- The control device should not be in contact with any structural members of the mining vehicle
- Avoid locating control device in close proximity to electrical components, fuel lines, fuel tanks, hydraulic systems, or any combustible materials.
- Shielding should be provided to protect the emission control device from rock falls and other forms of impact.
- Use the directional arrow on the DOC/DPF identification label to correctly orient the engine exhaust gas flow direction.

## Exhaust Pipe Materials

To minimize corrosion scaling of exhaust pipe inside walls the following material are recommended:

1. Aluminized Steel
2. Stainless Steel 409 Alloy
3. Stainless Steel 304, 316, 321
4. Stainless Steel 439, 441

## Heat Insulation of Exhaust System

- Exhaust system including engine exhaust manifold and turbochargers should be fully covered with commercially available heat blankets.
- Exhaust system heat loss can be reduced by 15 to 30 degrees Celsius using commercially available heat blanket.
- Commercially available heat blankets will improve DPF regeneration passivity in comparison to bare pipe or partially insulated exhaust pipes.

## Vibration Isolators & Flex Pipes

- There are different types of commercially available vibration isolators.
- We recommend the use of rubberized grommets with metal sleeves, quantity of 4 minimum
- Alternately we recommend spring type (wire) vibration isolators for high temperature applications.
- Flex pipe length should be 3 to 5 times exhaust pipe outside diameter.
- Flex pipe should not carry the weight of the control device, it has to move freely.
- Braided or double braided flex hose connectors are better suited and more reliable in comparison to corrugated or bellows flex connectors.

## Sound Attenuation of Control Device

- The control device will also act as a muffler and reduce exhaust noise levels by approximately 12 to 15 dBA.
- Add on mufflers are available to improve sound level attenuation.
- Sound level attenuation of control devices (DPF) will increase with PM loading.

## Recommended Exhaust Clamp Types

1. Nelson Accuseal Flat Band Clamps
2. Nelson Wide Band Lap Clamps

Recommend Accuseal Flat Band/Wide Band bolt torque setting is 45 ft-lb.

Finished clamp installation should allow for a gap of 1/8” to ¼” at the gap between the band curls of the exhaust clamps

The above clamps allow for ease of disassembly without pinching or distorting the ID/OD connections of the exhaust pipe, flex connector or control device.

# Exhaust Back Pressure Kit

- To monitor the engine exhaust gas back pressure restriction
- To advise equipment operator or service mechanics of high exhaust back pressure restriction.
- The kit consist of the following components:

1. 0-60 ”H2O gauge for equipment operators dash
2. Pressure switch (NO/NC) with adjustable trigger point to activate buzzer and/or warning light.
3. Filter for PM and water removal. Needs to be cleaned every schedule maintenance interval.
4. Interconnecting plastic hose, metal tubing and fittings.


CATALYTIC
EXHAUST

# MDEC

**Mining Diesel Emissions Council**

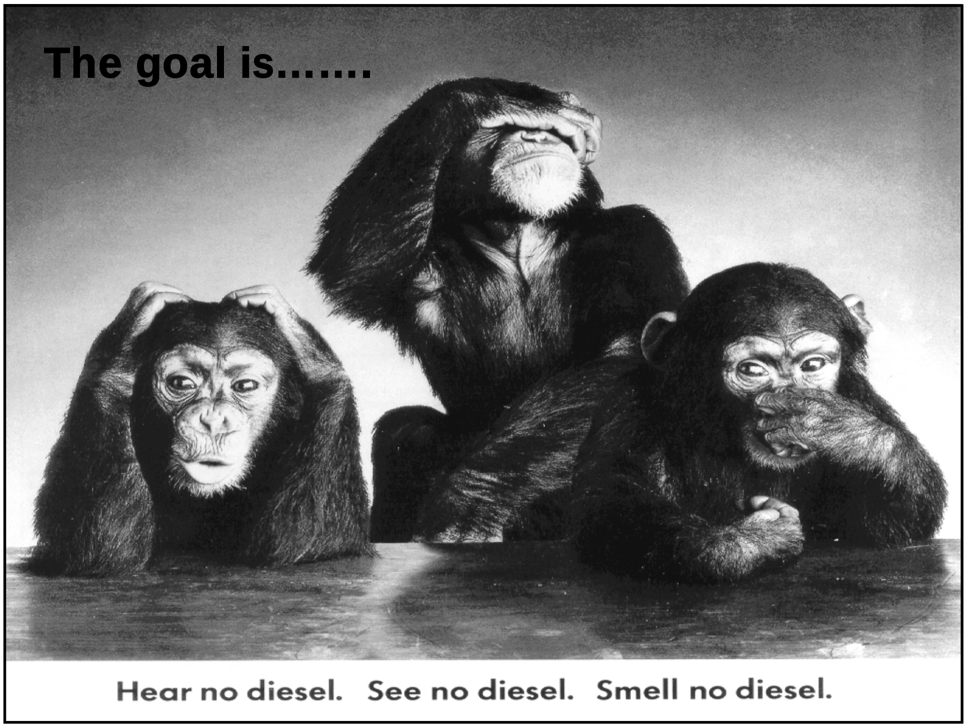
**October 6th 2009**

# WORKSHOP

## Diesel Particulate Filter

### Catalyst & DPF Performance Monitoring

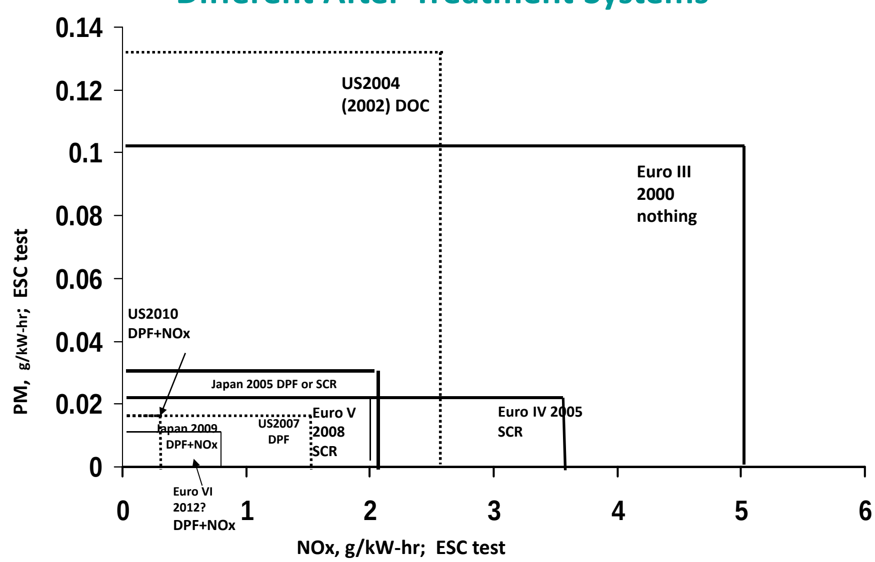
**Presented By Ted N Tadrous**
**Engine Control Systems Limited**



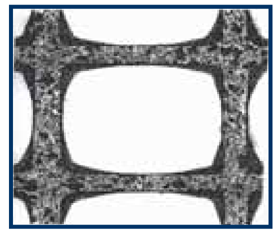

# HD Diesel Emissions Limits

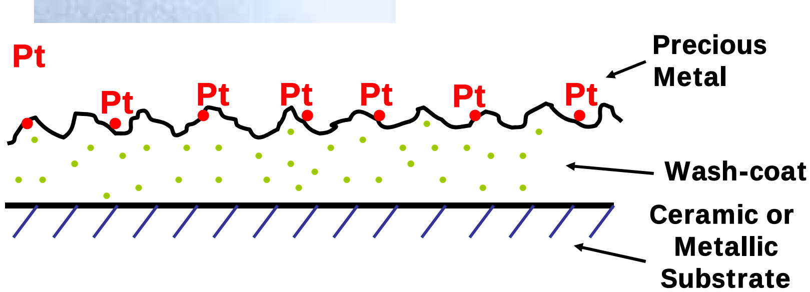
## Various Engines In-Service

### Different After-Treatment Systems

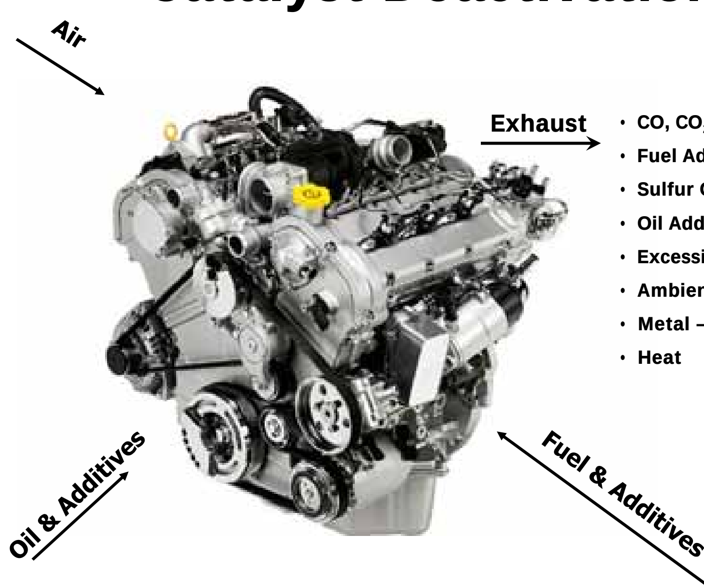


# Wash-Coat Illustration






# Catalyst Deactivation




- $CO$, $CO_2$, HC, NOx, PM & $H_2O$
- Fuel Additives Substances
- Sulfur Oxides
- Oil Additives Substances
- Excessive HC
- Ambient Substances
- Metal – Engine Wear
- Heat

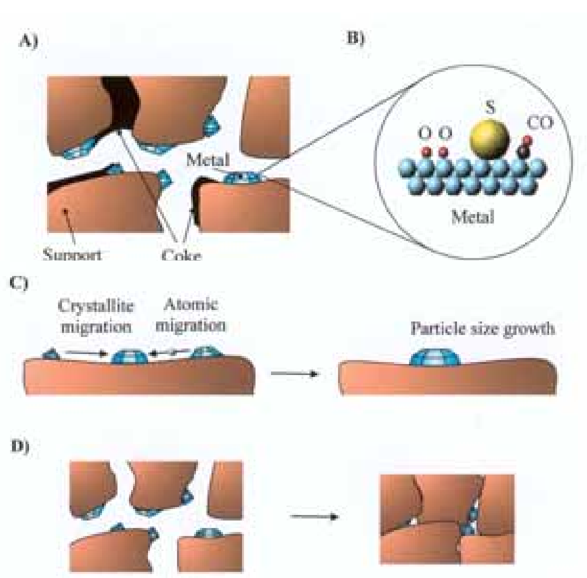
# Catalyst Deactivation Mechanisms

**Deactivation by thermal degradation and sintering**
- Pore blockage,
- Encapsulation of metal particles,
- Volatilization of active compounds,
- Metal-metal or metal-wash-coat interactions

**Deactivation by poisoning**
- Selectivity / competing reactions (Sulfur, Additives, ….)
- Wash-Coat reaction with additives (fuel & lube oil)
- Wash-Coat reaction with ambient aerosol substance

**Deactivation by Masking Active Sites**
- Hydrocarbon fouling
- Coke formation
- Covered with combustion residues deposit
- Covered with soot
- Covered with mechanical wear

# Catalyst Deactivation Mechanisms




**Deactivation Mechanisms:**

A. Coke formation,

B. Poisoning,

C. Sintering of the active metal particles, and

D. Sintering and solid-solid phase transitions of the wash-coat and encapsulation of active metal particles

(cf. Suhonen 2002).

## Performance Monitoring - DOC

- **Performance Monitoring - @ Every Scheduled PM**
  - Visual inspection – Look for cracks or push-out
  - Run CO measurement (before & after) at a repeatable condition

- **Alarming Symptoms for Deteriorating Performance**
  - Increased odor smell
  - Random black smoke puffs
  - Loss of engine power
  - Rattling noise

- **Performance Recovery**
  - With exception to the rattling noise, heat treatment is more likely will rejuvenate the DOC performance
    - Use well ventilated kiln set at 5ºC/min ramp up & down
    - Soak at kiln temperature of 650ºC
    - Consult with your system supplier for guidelines on maximum temperatures

## Performance Monitoring - DPF

- **Performance Monitoring**
  - @ Every Scheduled PM; Visual inspection – Look for cracks or push-out
  - Use a reliable Multi-Level Backpressure Alarm device
  - Data log your duty cycle (exhaust temp & backpressure) – As part of the Alarm device or periodically using a data logger
  - Monitor the backpressure trend
  - Schedule periodic cleaning and DO NOT wait for the alarm

- **Alarming Symptoms for Deteriorating Performance**
  - Increased odor smell
  - Random black smoke puffs
  - Frequent BP alarm events
  - Loss of engine power
  - Rattling noise

- **Performance Recovery**
  - Except for the rattling noise, heat treatment is more likely to rejuvenate the DPF performance
    - Back flush the DPF in sealed container when its core temperature <50ºC
    - Use well ventilated kiln set at 5ºC/min ramp up & down
    - Soak at kiln temperature of 650ºC
    - Back flush the DPF in sealed container when its core temperature <50oC
    - Repeat above steps till weight DPF stabilize
    - Consult with your system supplier for guidelines

# Performance Monitoring - DPF


**Performance Monitoring**

- Visual inspection @ Every Scheduled PM– Look for cracks or push-out
- Use a reliable Multi-Level Backpressure Alarm device
- Data log your duty cycle (exhaust temp & backpressure) – As part of the Alarm device or periodically using a data logger
- Monitor the backpressure trend
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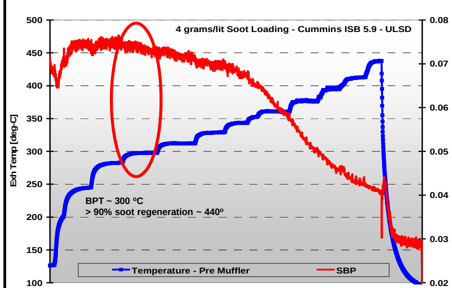
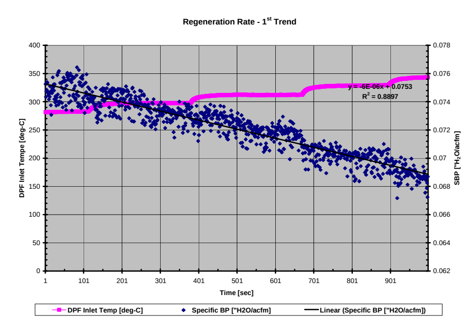
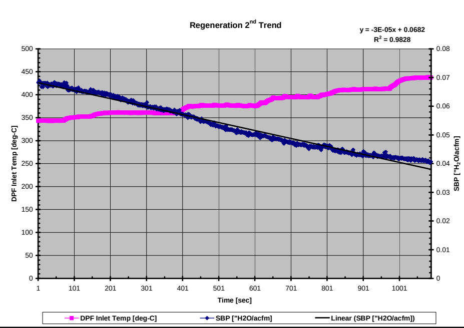
# Performance Monitoring - DPF



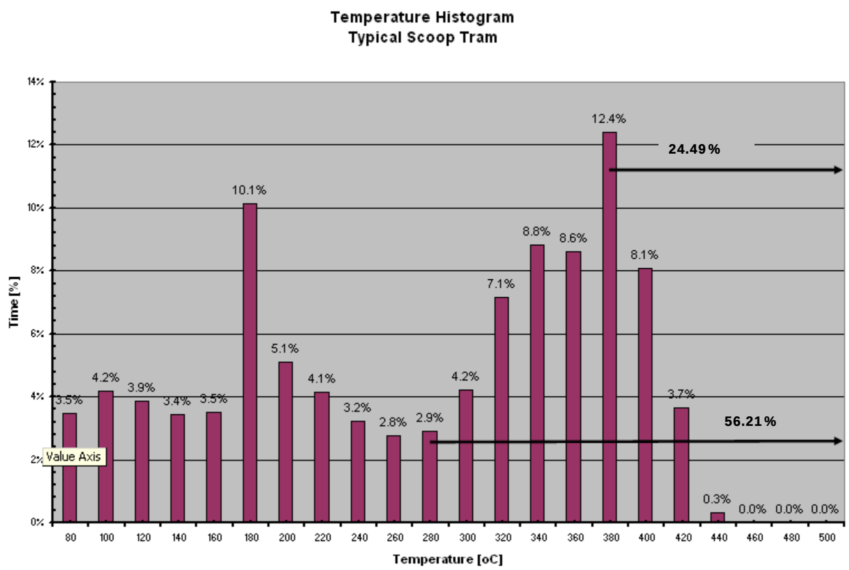

How the system supplier determine DPF passive performance requirements in relation to duty cycle?




Courtesy of ECS

## Performance Monitoring – DPF

**Create Histogram for logged data and compare to Supplier passive qualification**

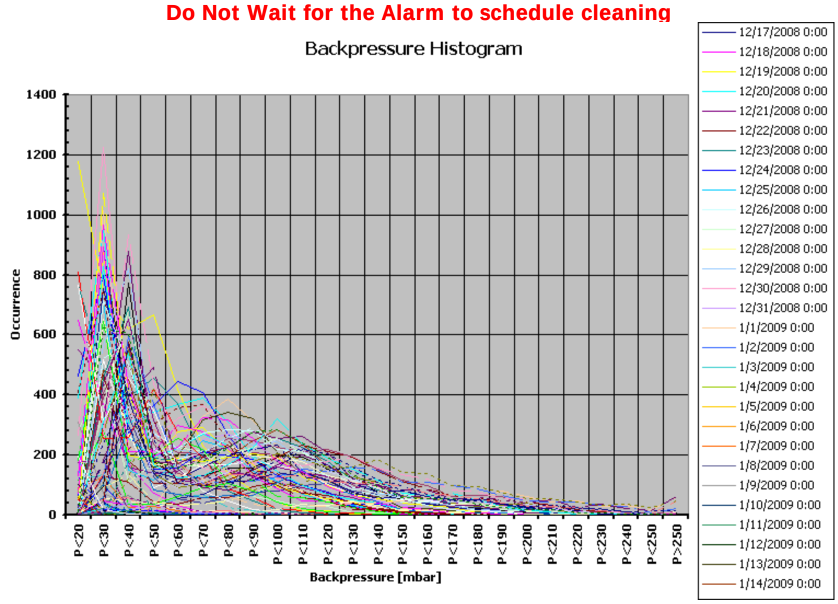



Courtesy of ECS

## Performance Monitoring – DPF

**Monitor Backpressure Trends**

**Do Not Wait for the Alarm to schedule cleaning**




Courtesy of ECS

**Thank you, questions?**