MINING DIESEL
mdec
EMISSIONS COUNCIL

12th ANNUAL MDEC CONFERENCE

Sheraton Parkway, Toronto North, Canada

October 10 – 13, 2006

MDEC SHORT COURSE ON DIESEL TECHNOLOGY

ORGANISED BY:
Mahe Gangal, Natural Resources Canada (NRCan)

OCTOBER 10, 2006

MINING DIESEL mdec EMISSIONS COUNCIL

Diesel Workshop

MDEC Short Course on Diesel Technology

Sheraton Parkway, Toronto North
www.sheratonparkway.com

Markham Room

Tuesday, October 10, 2006

08:00 – 08:30	Welcome and Gathering (Coffee available)
08:30 – 10:30	Regulations • Off-road diesel engines (Addy Majewski – ECOpoint) • US u/g mine regulations (George Saseen – MSHA) • Canadian u/g mine regulations (Mahe Gangal – NRCan) • Surface mine regulations (Sara Barss – Senes Consultants)
10:30 – 10:45	Coffee Break
10:45 – 12:15	Emission Control Technologies • Advanced technologies for new engines (Joe Kubsh, MECA) • Retrofit systems (Kevin Brown, ECS)
12:15 – 13:00	Lunch
13:00 – 14:00	Engine Technology • Introduction (Manfred Duering – Cummins Diesel, Germany) • Technical summary (Todd Mysak – Cummins USA)
14:00 – 14:45	Diesel Fuel Properties (Hannu Jääskeläinen – University of Toronto)
14:45 – 15:00	Coffee Break
15:00 – 16:15	Diesel Equipment • Development (John Botelho, MacLean Engineering) • Maintenance (Sereno Vorano, Cummins Eastern Canada)
16:15 – 16:30	Open Discussion and Conclusion (Mahe Gangal, NRCan)

Notes: Course notes, coffee and lunch will be provided.

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Diesel Workshop

MDEC Short Course on Diesel Technology

CONTENTS

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Emission Regulations for Off-Road Diesel Engines

W. Addy Majewski
Ecopoint Inc.

MDEC Short Course on Diesel Technology
October 10, 2006
Richmond Hill, ON

www.DieselNet.com

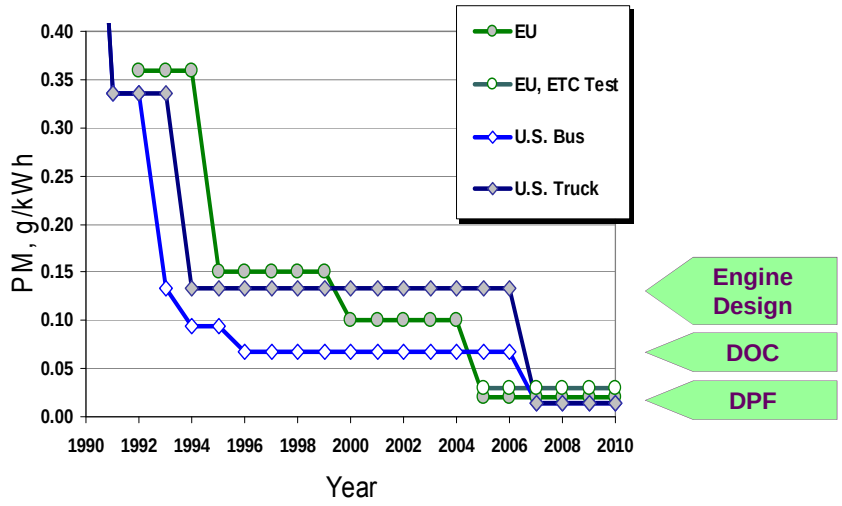
Types of Diesel Emission Regulations

- Tailpipe emission standards for new engines and vehicles
- In-use engine programs (e.g., I&M, idling, …)
- Retrofit programs for existing vehicle fleets
- Occupational health regulations (e.g., underground mining)

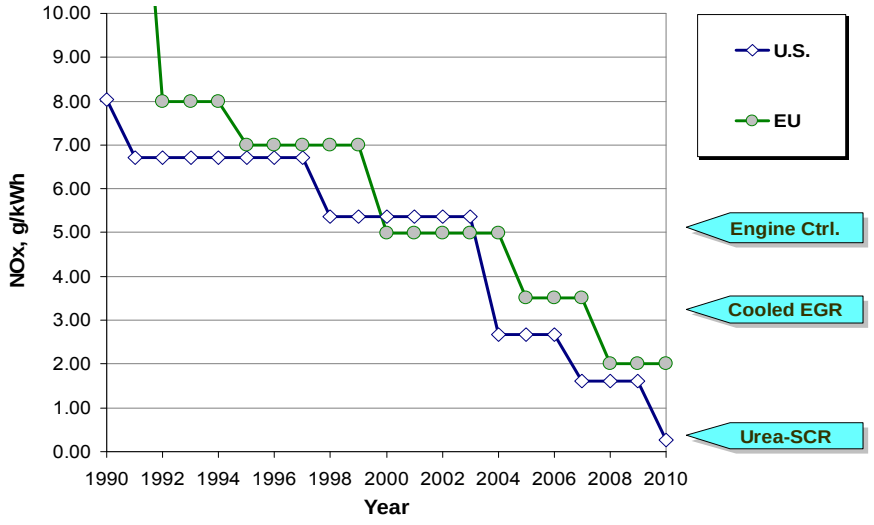
Tailpipe Emission Standards for New Diesel Engines

- Established and enforced by environmental protection authorities (e.g., the U.S. EPA)
- Set emission limits for engines / vehicles
- Specify emission test cycles to measure emissions
- Enforced through engine certification programs
- Duty to comply on engine / vehicle manufacturer

HD Diesel Truck & Bus PM Emission Standards



HD Diesel Truck & Bus NOx Emission Standards



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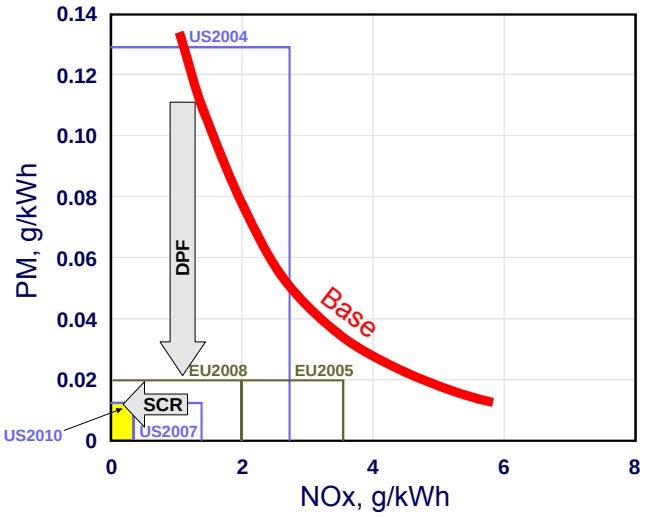
NOx and PM Control Strategies



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CAT ACERT Engine w/ Fuel Burner DPF System

US Tier 1-3 Nonroad Diesel Engine Emission Standards

- **Tier 1 standards**
  - Adopted in 1994
  - Phased-in 1996 – 2000
- **Tier 2 - 3 standards**
  - Adopted in 1998
  - Phased-in 2000 – 2008
- **Emissions measured over a steady-state test equivalent to ISO 8178**
- **Compliance achieved through engine technology (EGR in some, but not all, Tier 3 engines) without exhaust aftertreatment**

ISO 8178

Weighting Factors of Selected B-Type ISO 8178 Test Cycles

Mode number	1	2	3	4	5	6	7	8	9	10	11
Torque, %	100	75	50	25	10	100	75	50	25	10	0
Speed	Rated speed					Intermediate speed					Low idle
Off-road vehicles											
Type C1	0.15	0.15	0.15	-	0.10	0.10	0.10	0.10	-	-	0.15
Type C2	-	-	-	0.06	-	0.02	0.05	0.32	0.30	0.10	0.15
Constant speed											
Type D1	0.30	0.50	0.20	-	-	-	-	-	-	-	-
Type D2	0.05	0.25	0.30	0.30	0.10	-	-	-	-	-	-
Locomotives											
Type F	0.25	-	-	-	-	-	-	0.15	-	-	0.60
Utility, lawn and garden											
Type G1	-	-	-	-	-	0.09	0.20	0.29	0.30	0.07	0.05
Type G2	0.09	0.20	0.29	0.30	0.07	-	-	-	-	-	0.05
Type G3	0.90	-	-	-	-	-	-	-	-	-	0.10
Marine application											
Type E1	0.08	0.11	-	-	-	-	0.19	0.32	-	-	0.30
Type E2	0.20	0.50	0.15	0.15	-	-	-	-	-	-	-

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Tier 1 – 3 Nonroad Emission Standards (1)

g/kWh (g/bhp·hr)

Test cycle: ISO 8178 C1 (D2, G2, E3)

Engine Power	Tier	Model Year	NOx	HC	NMHC + NOx	CO	PM
kW < 8 (hp < 11)	Tier 1	2000	-	-	10.5 (7.8)	8.0 (6.0)	1.0 (0.75)
	Tier 2	2005	-	-	7.5 (5.6)	8.0 (6.0)	0.80 (0.60)
8 <= kW < 19 (11 <= hp < 25)	Tier 1	2000	-	-	9.5 (7.1)	6.6 (4.9)	0.80 (0.60)
	Tier 2	2005	-	-	7.5 (5.6)	6.6 (4.9)	0.80 (0.60)
19<= kW < 37 (25 <= hp < 50)	Tier 1	1999	-	-	9.5 (7.1)	5.5 (4.1)	0.80 (0.60)
	Tier 2	2004	-	-	7.5 (5.6)	5.5 (4.1)	0.60 (0.45)
37 <= kW < 75 (50 <= hp < 100)	Tier 1	1998	9.2 (6.9)	-	-	-	-
	Tier 2	2004	-	-	7.5 (5.6)	5.0 (3.7)	0.40 (0.30)
	Tier 3	2008	-	-	4.7 (3.5)	5.0 (3.7)	-*
75 <= kW < 130 (100 <= hp < 175)	Tier 1	1997	9.2 (6.9)	-	-	-	-
	Tier 2	2003	-	-	6.6 (4.9)	5.0 (3.7)	0.30 (0.22)
	Tier 3	2007	-	-	4.0 (3.0)	5.0 (3.7)	-*

* - Tier 3 PM standard were never adopted; engines must meet Tier 2 PM standard

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Tier 1 – 3 Nonroad Emission Standards (2)

g/kWh (g/bhp·hr)

Test cycle: ISO 8178 C1 (D2, G2, E3)

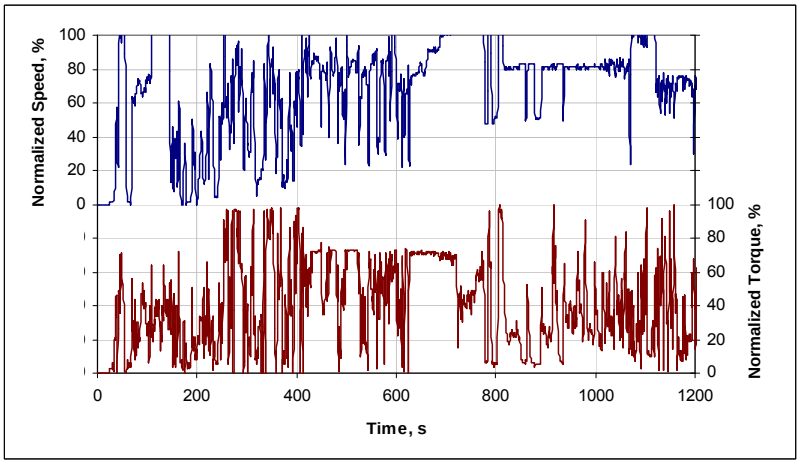
Engine Power	Tier	Model Year	NOx	HC	NMHC + NOx	CO	PM
130 <= kW < 225 (175 <= hp < 300)	Tier 1	1996	9.2 (6.9)	1.3 (1.0)	-	11.4 (8.5)	0.54 (0.40)
	Tier 2	2003	-	-	6.6 (4.9)	3.5 (2.6)	0.20 (0.15)
	Tier 3	2006	-	-	4.0 (3.0)	3.5 (2.6)	-*
225 <= kW < 450 (300 <= hp < 600)	Tier 1	1996	9.2 (6.9)	1.3 (1.0)	-	11.4 (8.5)	0.54 (0.40)
	Tier 2	2001	-	-	6.4 (4.8)	3.5 (2.6)	0.20 (0.15)
	Tier 3	2006	-	-	4.0 (3.0)	3.5 (2.6)	-*
450 <= kW < 560 (600 <= hp < 750)	Tier 1	1996	9.2 (6.9)	1.3 (1.0)	-	11.4 (8.5)	0.54 (0.40)
	Tier 2	2002	-	-	6.4 (4.8)	3.5 (2.6)	0.20 (0.15)
	Tier 3	2006	-	-	4.0 (3.0)	3.5 (2.6)	-*
kW >= 560 (hp >= 750)	Tier 1	2000	9.2 (6.9)	1.3 (1.0)	-	11.4 (8.5)	0.54 (0.40)
	Tier 2	2006	-	-	6.4 (4.8)	3.5 (2.6)	0.20 (0.15)

* - Tier 3 PM standard were never adopted; engines must meet Tier 2 PM standard

US Tier 4 Nonroad Emission Standards

- Adopted in 2004
- To be phased-in 2008 – 2015
- Emissions measured over a steady-state test equivalent to ISO 8178 and a new nonroad transient cycle (NRTC)
- Compliance achieved through engine technology and exhaust aftertreatment
  - Particulate filters for engines > 19 kW
  - NOx aftertreatment for engines > 56 kW

NRTC Test



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Tier 4 Nonroad Emission Standards

g/kWh (g/bhp·hr)

Shaded areas indicate aftertreatment

Engine Power	Model Year	CO	MNHC	NMHC + NOx	NOx	PM
kW < 8 (hp < 11)	2008	8.0 (6.0)	-	7.5 (5.6)	-	0.4 (0.3)
8 <= kW < 19 (11 <= hp < 25)	2008	6.6 (4.9)	-	7.5 (5.6)	-	0.4 (0.3)
19<= kW < 37 (25 <= hp < 50)	2008	5.5 (4.1)	-	7.5 (5.6)	-	0.3 (0.22)
	2013	5.5 (4.1)	-	4.7 (3.5)	-	0.03 (0.022)
37 <= kW < 56 (50 <= hp < 75)	2008	5.0 (3.7)	-	4.7 (3.5)	-	0.3 (0.22)
	2013	5.0 (3.7)	-	4.7 (3.5)	-	0.03 (0.022)
56 <= kW < 130 (75 <= hp < 175)	2012 – 2014[a]	5.0 (3.7)	0.19 (0.14)	-	0.40 (0.30)	0.02 (0.015)
130 <= kW < 560 (175 <= hp < 750)	2011-2014[b]	3.5 (2.6)	0.19 (0.14)	-	0.40 (0.30)	0.02 (0.015)

a - full PM compliance from 2012; NOx phase-in through 2014

b – full PM compliance from 2011 ; NOx phase-in through 2014

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DPF technology on new diesel engines

- **Highway engines: 2007**
- **Nonroad engines:**
  - 25 – 75 hp: 2013
  - 75 – 175 hp: 2012
  - 175 –750 hp: 2011

MSHA's Underground Mining Regulations for Diesel Engines

MDEC 2006

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Outline

- Diesel Engine Approval Requirements
- Diesel Particulate Matter Requirements for Underground Coal Mines
- Diesel Particulate Matter Requirements for Underground Metal/NonMetal Mines

MSHA Approved Diesel Engine

- Diesel Engines are approved under Part 7, subpart E
- Engine Manufacturer specifies horsepower ratings and engine configuration
- Category A engine in permissible machines
- Category B engine in nonpermissible machines
- Each engine has an Approval Plate
  - Approval No.
  - Rated Power, Rated Speed, High Idle Speed
  - Gaseous Ventilation Rate
  - Maximum Altitude Before Deration
  - Engine Model No.

MSHA Approval No.s

- Permissible Engines:
  7E-A001 or 07-EPA030001

- Non-permissible Engines
  7E-B001 or 07-ENA030001

TECHNICAL REQUIREMENTS
SECTION 7.84

- FUEL INJECTION ADJUSTMENTS - LOCKS AND SEALS
- MAXIMUM FUEL:AIR RATIO - LIMITS ON GASES
- GASEOUS EMISSIONS VENTILATION RATE
- FUEL DERATION FOR ALTITUDE
  - Based on 3% per 1000 feet beginning at either 1000 feet or 3000 feet above sea level.
- PARTICULATE INDEX

Laboratory Test
Gaseous and Particulate Emissions

- Use the 8 mode, steady state test
- Measure Carbon Monoxide, Carbon Dioxide, Nitric Oxide, and Nitrogen Dioxide
- Determine Gaseous Ventilation Rate in cubic feet per minute (cfm) of dilution air based on highest contaminant
- Measure Whole Diesel Particulate Matter (dpm) on a weighted average, gr/hr
- Determine Particulate Index, amount of dilution air in cfm to dilute dpm to 1mg/m^3

MSHA Approved Diesel Engines

Approval Number	Engine Manufacturer	Model	HP @ RPM at 1000ft Elevation	Particulate Index, CFM	DPM grams/hr weighted	DPM grams/-hp-hr weighted	Gaseous Vent Rate, CFM
07-ENA040001	CUMMINS	QSB-155C	155 @ 2500	5500	8.87	0.11	9000
07-ENA040018	DEUTZ	F6L 914	117 @ 2300	3500	5.73	0.09	6000
07-ENA050001	MITSUBISHI	S4S-DT	77 @ 2500	4500	6.91	0.18	3500
7E-B001	DEUTZ	MWM 916	94 @ 2300	11500	19.54	0.42	4000
7E-B003	CATERPILLAR	3306 PCNA	150 @2200	23000	39.08	0.49	7500
7E-B035	DEUTZ	F8L 413FW	182 @ 2300	9500	16.14	0.16	10500
7E-B098	Mercedes	OM904 LA	174 @ 2200	5000	8.5	0.09	7500

Internet Listing of
MSHA Approved engines

https://lakegovprod1.msha.gov/ReportView.aspx?ReportCategory=EngineAppNumbers

or

www.msha.gov
Approved products (Right Side of Page)
Part 7, Diesel Engines (Permissible and Non-Permissible)

Diesel Particulate Matter Requirements for Underground Coal Mines
Part 72, Title 30, CFR

Emission Limits: Permissible Equipment Section 72.500

- Each piece within the mine must emit no more than 2.5 grams per hour of DPM

  Effective Date: *As of July 19, 2002*

Permissible Equipment Standard - 2.5 gr/hr

- Cannot be measured in the field
- All permissible machines to date must use paper filters
- Correct paper/synthetic filter that can be installed is listed on the homepage by filter model:

  http://www.msha.gov/01-995/Coal/DPM-FilterEfflist.pdf

Emission Limits: Nonpermissible Heavy Duty Equipment, Generators, & Compressors: Section 72.501

Each piece within the mine must emit no more than 2.5 grams per hour of DPM

Effective date: *As of January 19, 2005*

Heavy Duty Equipment Generators, Air Compressors Standard - 2.5 gr/hr

- Define Heavy Duty equipment per CFR 75.1908
  - Cuts or moves rock or coal
  - performs drilling or bolting functions
  - moves longwall components
  - self-propelled fuel and lube transportation units
  - machines used to transport portable fuel and lube units

Information Needed For Compliance Determination

- Engine model and serial number per 72.520
- Emission of Engine in gr/hr per 72.520
- Minimum efficiency of filter needed to meet 2.5 gr/hr (1/19/05)
- Filter Efficiency listed on web at:

http://www.msha.gov/01-995/Coal/DPM-FilterEfflist.pdf

MSHA Approved Diesel Engines

Approval Number	Engine Manufacturer	Model	HP @ RPM at 1000ft Elevation	Particulate Index, CFM	DPM grams/hr weighted	DPM grams/-hp-hr weighted	Filter Eff to meet 2.5gr/hr
07-ENA040001	CUMMINS	QSB-155C	155 @ 2500	5500	8.87	0.11	72
07-ENA040018	DEUTZ	F6L 914	117 @ 2300	3500	5.73	0.09	56
07-ENA050001	MITSUBISHI	S4S-DT	77 @ 2500	4500	6.91	0.18	64
7E-B001	DEUTZ	MWM 916	94 @ 2300	11500	19.54	0.42	87
7E-B003	CATERPILLAR	3306 PCNA	150 @2200	23000	39.08	0.49	94
7E-B035	DEUTZ	F8L 413FW	182 @ 2300	9500	16.14	0.16	85
7E-B098	Mercedes	OM904 LA	174 @ 2200	5000	8.5	0.09	71

Emission Limits: Nonpermissible Light Duty Equipment Section 72.502

- Each piece introduced into the mine must emit no more than 5.0 grams per hour of DPM

or

Meet the EPA dpm standards listed in Table 72.502-1, part 7, Title 30, CFR

- *Effective date*: *After May 21, 2001*

MSHA Approved Diesel Engines

Approval Number	Engine Manufacturer	Model	HP @ RPM at 1000ft Elevation	Particulate Index, CFM	DPM grams/hr weighted	DPM grams/-hp-hr weighted	EPA Compliant per Table 72.502-1
07-ENA040001	CUMMINS	QSB-155C	155 @ 2500	5500	8.87	0.11	Yes
07-ENA040018	DEUTZ	F6L 914	117 @ 2300	3500	5.73	0.09	Yes
07-ENA050001	MITSUBISHI	S4S-DT	77 @ 2500	4500	6.91	0.18	Yes
7E-B001	DEUTZ	MWM 916	94 @ 2300	11500	19.54	0.42	No
7E-B003	CATERPILLAR	3306 PCNA	150 @2200	23000	39.08	0.49	No
7E-B035	DEUTZ	F8L 413FW	182 @ 2300	9500	16.14	0.16	No
7E-B098	Mercedes	OM904LA	174 @ 2200	5000	8.5	0.09	Yes

Diesel Particulate Matter Requirements for Underground Metal/NonMetal Mines Part 57, Title 30, CFR

- Personal Exposure Limit to diesel particulate matter not to exceed an average eight (8) hour equivalent full shift airborne concentration.
- Compliance using a single sample
- Respirable dust sampler equipped with a submicron impactor and analyzed using the method described in NIOSH Analytical Method 5040 for elemental carbon

May 18, 2006 Final Rule

- Phases in final DPM PELs over two years
  - – 308_{EC} µg/m^3 - effective May 20, 2006
  - – 350_{TC} µg/m^3 - effective January 20, 2007
  - – 160_{TC} µg/m^3 - effective May 20, 2008
- 1st step, 308_{EC} µg/m^3, is an EC limit
  - – In 2005, we converted the 400_{TC} µg/m^3 total carbon limit to 308_{EC} µg/m^3 elemental carbon.
  - – 308_{EC} x error factor (1.12) = 345_{EC}

2nd & 3rd steps are TC limits

- **For the 350_{TC}, treat like interim 400_{TC} limit under Settlement Agreement:**
  - **TC = EC + OC**
  - **TC = EC x 1.3**
  - **Compliance based on *lower* of [EC + OC] or [EC x 1.3]**
- **must develop appropriate error factor**
- ***For the 160, to be determined in a separate rulemaking***

- Mine Operator must install, use, and maintain feasible engineering and administrative controls to reduce miners' exposure to dpm
- If unable to limit exposure, respiratory protection required while working towards engineering and administrative solutions
- If unable to wear respirator, medical transfer is required
- Rotation of miners is not permitted to minimize dpm exposure

EXTENSION OF TIME TO MEET THE FINAL CONCENTRATION LIMIT §57.5060(c)

Mine operators may apply to District Manager for additional time to come into compliance with the final DPM limit

- **technological OR economic constraints**
- must demonstrate that there is no cost-effective solution to reducing a miner's exposure to DPM.

Feasible Control Strategies

- Clean Engines
- Ventilation
- Environmental Cabs
- Work Practices
- Alternative Fuels
- DPM Exhaust Filters

Additional Requirements

- Fueling Practices – Low sulfur fuel
- Maintenance Standards, Tagging
- Introduction of Cleaner Engines
  - MSHA approved engines
  - minimum EPA tier 1 or 2 based on engine horsepower
  - on-highway from 1994
- Miner Training
- Exposure Monitoring

QUESTIONS ???

CANMET Mining and Mineral Sciences Laboratories

Canadian Underground Mining Regulations for Diesel Engines

12th Annual MDEC Conference

MDEC Short Course on Diesel Technology

October 10, 2006

Richmond Hill, Ontario

Mahe Gangal, NRCan

MMSL 06-133(OP)

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CANMET Mining and Mineral Sciences Laboratories

Outline

- Regulations
  - Diesel engines
  - 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)

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U/G Mine Regulations in Canada

- Provinces & Territories jurisdiction
  - 9 Provinces (PEI does not have a mine)
  - 3 Territories
- Exemption
  - Crown Corporations and uranium mines are under the jurisdiction of Federal Government

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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
- Flameproof Non-Rail-Bound Diesel-Powered Machines for Use in Gassy Underground Coal Mines, CAN/CSA-M424.1-88
- Prepared by the Technical Committee on Underground Diesel Equipment
  - Chief inspectors, Labour, Mine operators, Manufacturers, NRCan

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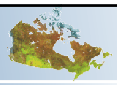

CANMET Mining and Mineral Sciences Laboratories

Diesel Equipment Standard for Non-Gassy U/G Mines

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

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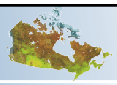

CANMET Mining and Mineral Sciences Laboratories

Diesel Engine Approval Requirements for Non-Gassy U/G Mines

- 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 for Non-Gassy U/G Mines

- Exhaust treatment systems may result in reduced ventilation assessments, provided
  - treatment does not deteriorate with use
  - suitable procedures maintain the device(s)
  - dynamometer treatment evaluation is performed
- Ventilation requirement is based on a dilution ration 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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CANMET Mining and Mineral Sciences Laboratories

Dynamometer Laboratory Engine Testing

- Confirmation of engine power and fuel rate as per manufacturer specification
- Setting of engine intake vacuum and back-pressure as per engine specification
- Quick measurement of CO and NO_X within engine operating range to determine Pass/Fail condition
- Steady state testing at about 20 mode points, including ISO 8178-C1, 8-mode points
- Measure engine parameters, CO, CO_2, NO, NO_2, O_2, DPM
- Calculate SO_2, EQI, and ventilation rate at all mode points
- The highest calculated ventilation rate is the minimum ventilation rate for engine approval

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CANMET Mining and Mineral Sciences Laboratories

Diesel Engine Approval Requirements for Non-Gassy U/G Mines

- Diesel fuel conforms to CGSB 3.16 standard
- Ventilation rate pertains to worst conditions from an emissions toxicity point of view
- Ventilation rate may be changed if permitted by regulatory authority for
  - ventilation system efficiency,
  - machine loading,
  - fuel sulphur content,
  - altitude, etc.

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CANMET Mining and Mineral Sciences Laboratories

Vent Rate for a CANMET Approved Engine

Engine Manufacturer: **Caterpillar**
Engine Model: **C18 (for use in truck AD45B)**
(composite Drawing # 2737263)
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
1183	589 HP @ 2000 RPM, 209.6 lb/hr	0.05	35,500	1,005.2
		0.10	38,500	1,092.2
		0.20	44,500	1,260.1
		0.25	47,500	1,345.0
		0.50	62,500 72,000+	1,769.8 2,038.8+

*These CSA ventilation rates are suitable for low sulphur fuel if permitted by the appropriate regulatory authority.
+ These ventilation rates are recommended by CANMET-MMSL where some of the gases govern ventilation rates rather than the EQI criterion

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Engine Approval Plate Requirements

- Certification mark
- Engine approval number
- Engine model number
- Rated power and speed
- Securely attached to the engine
- Obtained from NRCan or made by the manufacturer

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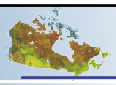

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Province/ Territory	Engine Certification CSA	MSHA	Ventilation/Notes
British Columbia	Yes	--	Ventilation as per CSA standard. Minimum of 0.06 m^3/kWs.
Alberta	Yes	--	Ventilation as per CSA standard. Minimum velocity of 1.9 m3/s at active headings.
Saskatchewan	(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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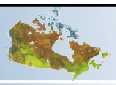

CANMET Mining and Mineral Sciences Laboratories

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 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 0.06 m^3/kWs.

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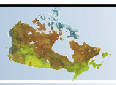

CANMET Mining and Mineral Sciences Laboratories

Canadian CGSB Fuel Specifications for Flash Point and Sulphur Content

Fuel Standards	Maximum Sulphur, %	Minimum Flash Point, °C
*3.16-M86/M88, Regular	0.50	40
Special	0.25	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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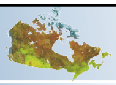

CANMET Mining and Mineral Sciences Laboratories

Diesel Fuel Requirements

Province/ Territory	Sulphur, % Maximum	Flash point, °C Minimum
British Columbia	CAN/CGSB-3.16-M86, Mining Diesel Fuel-Special Type	
Alberta	CAN/CGSB-3.16-M86, Mining Diesel Fuel	
Saskatchewan	0.5	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-3.517-2000 (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-CP-6 or latest version of CGSB fuel standard Mining Diesel Fuel	
Northwest Territories and Nunavut	0.25	43
Yukon	0.25	52 (and CAN/CGSB 3.16-99 or other acceptable)

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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
- CSA ventilation rate increases by 30% if the fuel sulphur increases from 0.05 % to 0.25%

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Diesel Particulate Matter (DPM) Exposure Limits in mg/m^3

British Columbia	1.5
Alberta	--
Saskatchewan	--
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

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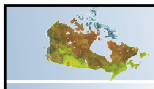

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Time Weighted Average Gaseous Exposure Limits in ppm

	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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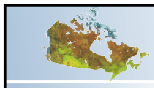

CANMET Mining and Mineral Sciences Laboratories

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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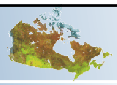

CANMET Mining and Mineral Sciences Laboratories

Engine Approval Procedures

Definitions:

- **Applicant - Manufacturer of an engine or machine**
- **Certification Officer – NRCan, issues approval**
- **Approval Plate - Installed on an engine or machine**
- **Rejection Letter - Indicates that engine is not suitable for use in underground mines**

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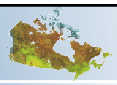

CANMET Mining and Mineral Sciences Laboratories

Engine Approval Procedures

- **Manufacturer makes an application to NRCan/CANMET-MMSL for engine approval**
- **NRCan provides an agreement letter with approval details and requirements**
- **Applicant sends an engine to the test laboratory with required documents**
- **Engine should be ready for testing**
- **Testing proceeds as per the required standard**
- **The test results are sent to the client**

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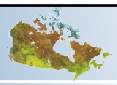

CANMET Mining and Mineral Sciences Laboratories

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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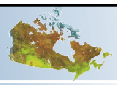

CANMET Mining and Mineral Sciences Laboratories

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
  - Approval plates can be installed on the engine
  - Laboratory testing for CSA, MSHA and other standards can be done at the same time. The manufacturer should discuss the requirements prior to any testing

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CANMET Mining and Mineral Sciences Laboratories
Diesel Engine Approval Procedure and Listing of Approved Engines
• Visit the following websites, and click on a desired topic on the left hand side of the page
• English version:
http://www.diesel.NRCan.gc.ca
• French version:
http://www.diesel.RNCan.gc.ca
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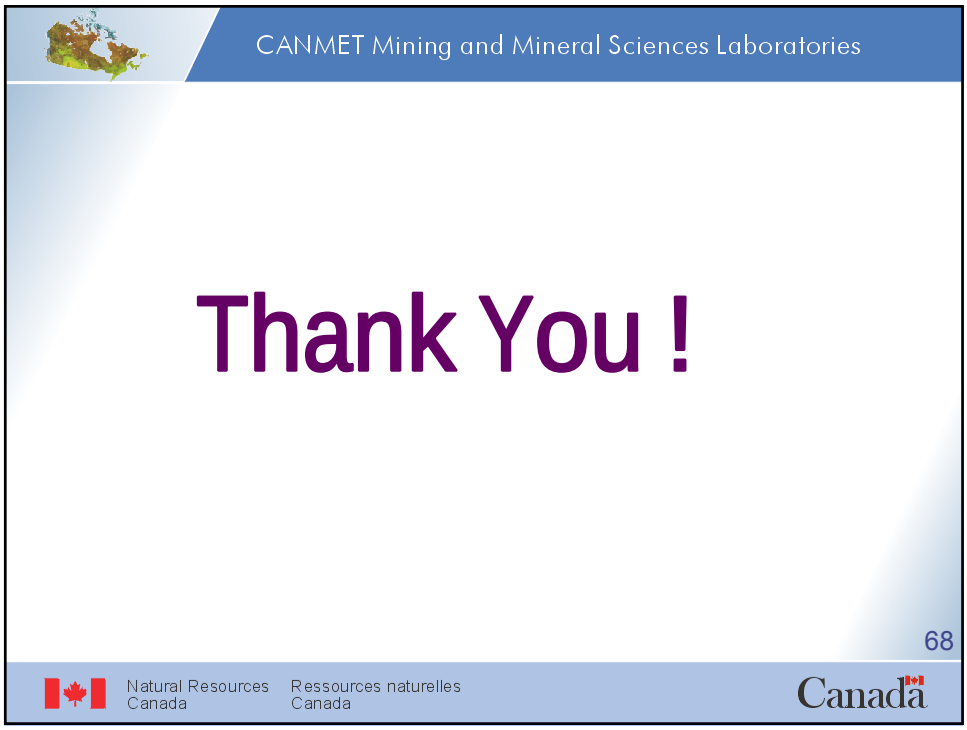
Natural Resources Canada
Ressources naturelles Canada
Canada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Thank You !
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Surface Mine Regulations

Presented at : Diesel Workshop
Mining Diesel Emissions Council (MDEC)
Richmond Hill
October 10, 2006
Presented by: **Sara Barss, B.Eng.**
SENES Consultants Ltd.

Purpose of Presentation

To review air regulations applicable to the use of diesel-powered equipment[1] in the Ontario surface mining sector

[1] Includes: mobile equipment, diesel generators/pumps, portable crushers, emergency generators, etc.

Topics of Discussion

1. Ontario Regulation 419/05 (O. Reg. 419/05)
   a. Certificates of Approval (Air & Noise)
      i. Updated Standards
      ii. Dispersion Models
      iii. Fugitive Emissions
2. Environmental Assessment Act
3. Sulphur in Diesel Fuel Regulations
4. Aggregate Resources Act

Ontario Regulation 419/05[1]

Air Pollution – Local Air Quality

- **Air quality standards** apply to discharges of contaminants into the environment
- Approved dispersion models
  - Demonstrate compliance with standards
- Reporting to the Ministry of the Environment
  - Emission Summary and Dispersion Modeling (ESDM) Report

[1] Regulation under Environmental Protection Act

Certificates of Approval (CofA)

Contaminants:

- chemical substances
- particulate matter
- noise/vibration
- odours

CofA (cont'd)

A CofA (Air) must be issued by the MOE to:

➔Construct, alter, extend or replace any plant, structure, equipment, apparatus, mechanism or thing that may discharge a *contaminant* into the environment (other than water)

➔Alter the process, production rate, or manner of discharge to the natural environment (other than water)

Sources Requiring CofAs

Examples of Diesel Equipment Requiring a CofA (Air):

- Diesel-powered generators / motors
- Fixed & portable crushers / screeners

Potential Negligible[1] Sources

Diesel Equipment Not Requiring a CofA (Air)[2] :

- **Emergency generators** used for emergency duty only with periodic testing
- On-site storage tanks and facilities used for fueling on-site vehicles
- Low temperature handling of compounds with a vapour pressure less than 1 kiloPascal (i.e., diesel fuel)

[1]Only negligible if source is not only source of emission onsite
[2]Table B-3 of MOE ESDM Guideline

Emission Summary & Dispersion Modeling (ESDM) Report

ESDM reports include:

- Process & Facility Description
- Source & Contaminant Identification
- Assessment of Significance of Contaminants & Sources
- Operating Conditions, **Emission Estimates**, and Data Quality
- **Source Summary Table** & Site Plan(s)
- **Dispersion Modelling**
- **Emission Summary Table** & Conclusions

Air Quality Standards

➔Updated standards from Reg. 346

➔Phase in of Schedules 1, 2 & 3 between present and 2020

- existing or new facility
- Industry Sector

➔Schedules of standards correspond with dispersion model requirements

- Varying averaging times

Dispersion Models

➔Schedule 1 & 2 Standards:
- Reg. 346 dispersion model applicable

➔Schedule 3 Standards:
- Refined models: SCREEN3, ISCST3, ISC-PRIME, AERMOD

Compliance with Schedule 3 Standards

➔New facilities: immediately

➔Schedule 4: Target Sectors for 2010
- NAICS Code 2122: Metal Ore Mining

➔Schedule 5: Target Sectors for 2013

➔All other facilities: 2020
- NAICS Code 2123: Non-Metallic Mineral Mining & Quarrying

Typical Emission Sources

- Processing plant:
  - crushers, screeners, etc.
- Material handling:
  - transfer points, conveyors
- Fugitive emissions:
  - storage piles, roads
- Combustion equipment:
  - diesel engines, comfort heating units

Diesel Emissions

- Contaminants to consider in modelling emissions from diesel-fired equipment
  - Sulphur dioxide
  - Particulate matter
  - NO_x

Fugitive Emissions: Particulate

MOE Document "*Procedure for Preparing an Emission Summary and Dispersion Modelling Report*"

➔ **Table 6-1:** Sectors that Should List Roadways as a Source of Air Emissions, includes:

- NAICS Code 2122: Metal Ore Mining
- NAICS Code 2123: Non-Metallic Mineral Mining & Quarrying

➔ **Table 7-3:** Sectors Where Fugitive Particulate Must be Included in an ESDM Report Unless an Effective Best Management Practices Plan (BMP) for Fugitive Particulate is Implemented, includes:

- NAICS Code 2123: Non-Metallic Mineral Mining & Quarrying

➔ **Metal Ore Mining must quantify particulate fugitive emissions**

Fugitive Emissions: Metals

➔ **Table 7-2**: List of Sectors Where Metal Content within Fugitive Particulate May be of Concern

- NAICS Code 2122: Metal Ore Mining

Therefore: Must assess metal content within fugitive particulate arising from roadways and storage piles

- Exception: have BMP and
  - Combined maximum POI concentration, from all sources, less than 90% of the MOE POI Limit; and
  - The total contribution, of insignificant sources, Is less than 10% of the MOE POI Limit

Canadian Environmental Assessment Act

Federal Environmental Assessment (EA) Triggers :

- Federal funding
- Federal lands (typically native Canadian)
- Federal Regulations (ex. Fisheries & Oceans)
- Inclusion List

Mining facilities do not fall under the triggers for a provincial (Ontario) EA

Environmental Assessment Act

Examples of differences between CofA and EA Process

Subject	CofA	EA
Main Focus	max. conc. off property	Protection of human & biological receptors
time frames assessed	1 or 24 hr (usually)	all
Background Concentration	Not included	Included, and results compared to background
Exceedances	Not allowed (generally)	More room for discussion: Analysis of significance, discussion of mitigation

Sulphur in Diesel Fuel Regulations (SOR/2002-254)

Limits sulphur content in diesel fuel used and sold

- **SOR/2006-163: Limits for on-road use**
  The concentrations of diesel fuel sold for use in on-road vehicles shall not exceed:
  - 22 mg/kg of from Sept. 1, 2006 – Oct. 15, 2006
  - 15 mg/kg after Oct. 15, 2006
- **SOR/2005-305: Limits for off-road engines**
  The concentration of sulphur in diesel fuel sold for use in off-road engines shall not exceed:
  - 500 mg/kg from Oct. 1, 2007 until Sept. 30, 2010
  - 15 mg/kg after Sept. 30, 2010

Sulphur in Diesel Fuel Regulations (SOR/2002-254)[1]

Fuel	Sulphur Limit (mg/kg)	Date		
		Producer / Importer	Point of Sale	Northern Supply Area Point of Sale
On-road diesel	500	1997	January 1998	-
	22	-	Sept. 1, 2006	-
	15	June 1, 2006	Oct. 15, 2006	Sept. 1, 2007
Off-road diesel	500	June 1, 2007	Oct. 1, 2007	Dec. 1, 2008
	15	June 1, 2010	Oct. 1, 2010	Dec. 1,2011

[1] Amended by SOR/2006-163 and SOR/2005-305

Aggregate Resources Act

The Act and the regulations do not apply where:

- material is not defined as “aggregate” under the Act;
- material is excluded from the definition of “rock” under the Act; or
- material is being extracted through underground mining (i.e. not open pit).

➔ The term ‘**aggregate**’ is defined by the Act as: gravel, sand, clay, earth, shale, stone, limestone, dolostone, sandstone, marble, granite, and rock .

➔ ‘**Rock**’ does not include metallic ores, andalusite, asbestos, barite, coal, diamond, graphite, gypsum, kaolin, kyanite, lepidolite, magnesite, mica, nepheline syenite, petalite, phosphate rock, salt, sillimanite, spodumene, talc, or wollastonite.

Compliance with Aggregate Resources Act

Pit & Quarry Operations:

- ➔ Site Plan
- ➔ Operational Standards
- ➔ License or Permit Conditions
- ➔ Annual Compliance Reporting

Site Plans

Primary Tool that controls operation and rehabilitation of all pits and quarries

The site plan includes information on:

- How extraction of aggregate will occur
- How progressive rehabilitation will be carried out
- what the final rehabilitation of the site will involve
- any required monitoring programs

Operational Standards

The **Aggregate Resources of Ontario Provincial Standards (Provincial Standards)** contains a set of Operational Standards

Some examples of Operational Standards are:

- Fencing and gate requirements
- topsoil stripping requirements
- minimum extraction setback distances
- scrap removal requirements

License or Permit Conditions

Prescribed Conditions can cover such topics as:

- Dust suppression
- fuel storage
- spills contingency plans
- approval under Ontario Water Resources Act (eg. Permit to Take Water), if required

Questions?

Diesel Engine Emission Control Technology

MDEC Workshop

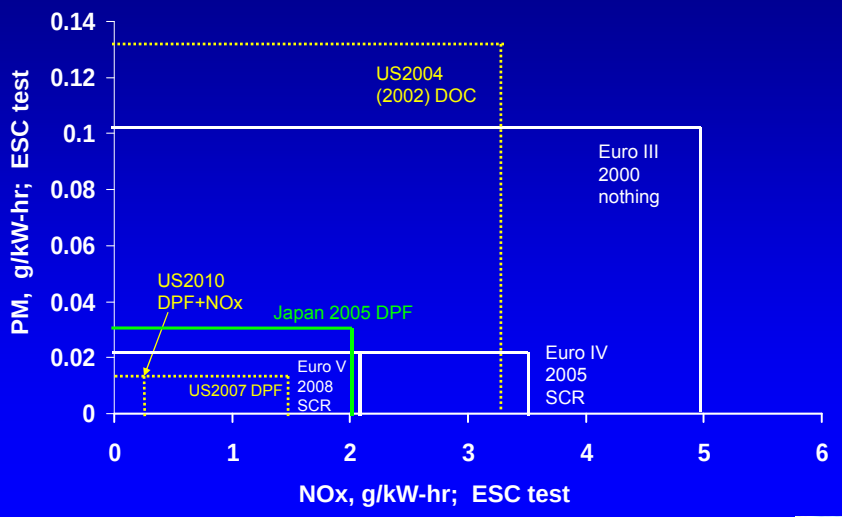
October 10, 2006

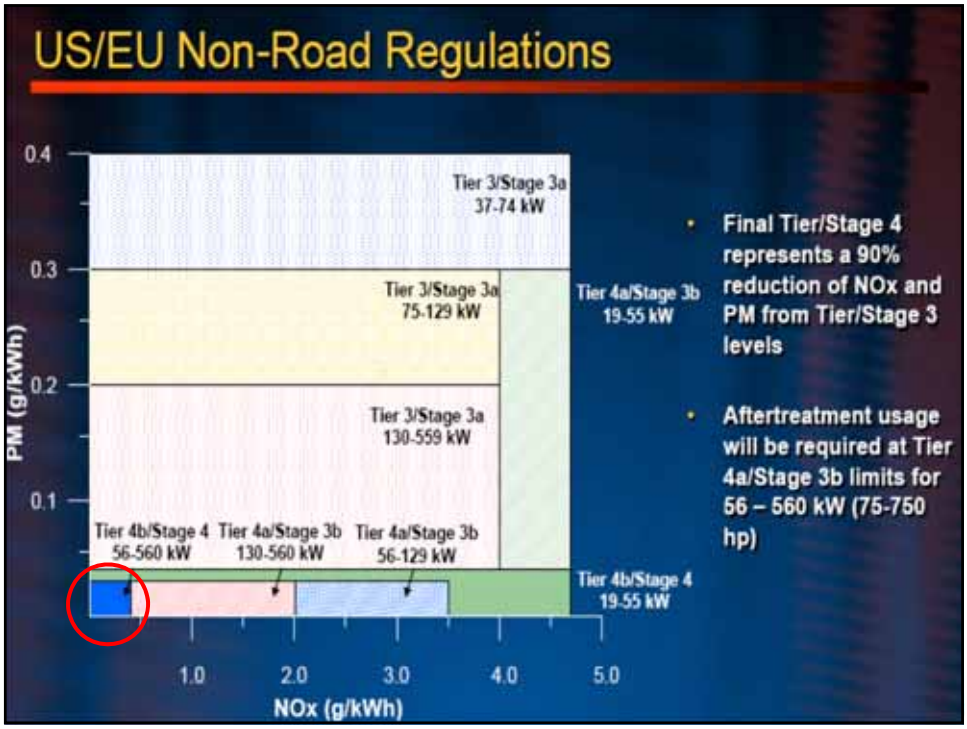
Dr. Joe Kubsh

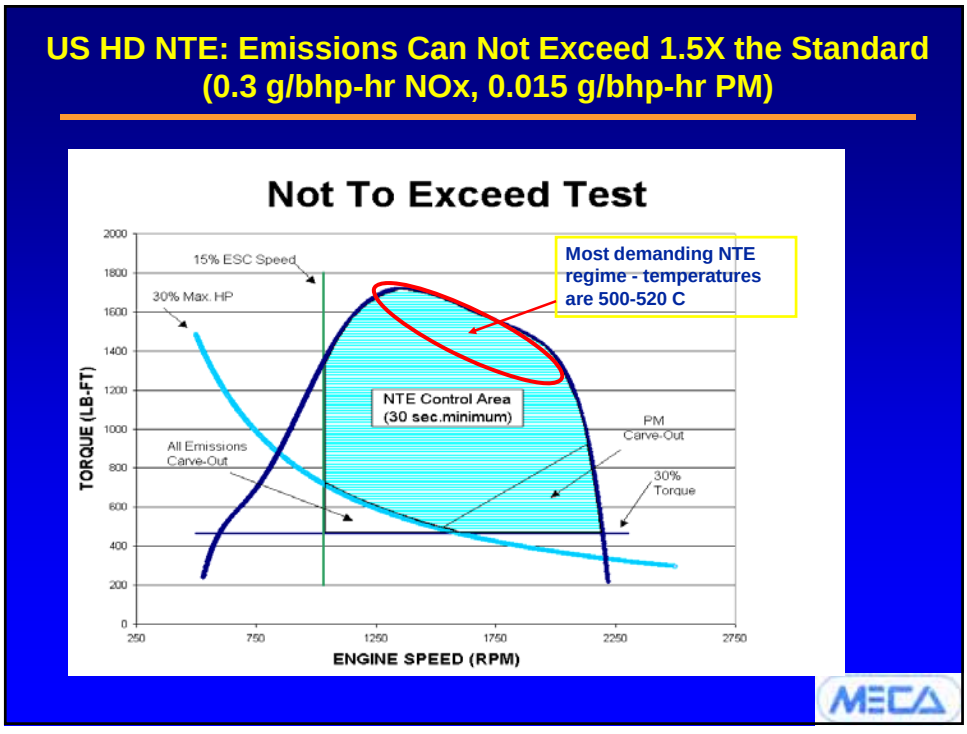
Manufacturers of Emission Controls Association

www.meca.org

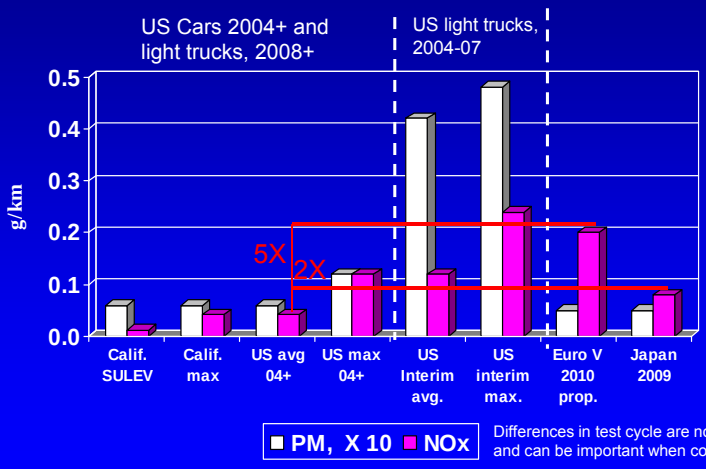
Heavy-duty Diesel Regulations are Progressively Tightening This Decade in all Major World Markets




US/EU Non-Road Regulations
PM (g/kWh)
0.4
0.3
0.2
0.1
Tier 3/Stage 3a
37-74 kW
Tier 3/Stage 3a
75-129 kW
Tier 3/Stage 3a
130-559 kW
Tier 4b/Stage 4
56-560 kW
Tier 4a/Stage 3b
130-560 kW
Tier 4a/Stage 3b
56-129 kW
Tier 4a/Stage 3b
19-55 kW
Tier 4b/Stage 4
19-55 kW
1.0
2.0
3.0
4.0
5.0
NOx (g/kWh)
Final Tier/Stage 4 represents a 90% reduction of NOx and PM from Tier/Stage 3 levels
Aftertreatment usage will be required at Tier 4a/Stage 3b limits for 56 – 560 kW (75-750 hp)


US HD NTE: Emissions Can Not Exceed 1.5X the Standard
(0.3 g/bhp-hr NOx, 0.015 g/bhp-hr PM)
Not To Exceed Test
15% ESC Speed
30% Max. HP
Most demanding NTE regime - temperatures are 500-520 C
NTE Control Area
(30 sec.minimum)
All Emissions
Carve-Out
PM
Carve-Out
30%
Torque
TORQUE (LB-FT)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
250
750
1250
1750
2250
2750
ENGINE SPEED (RPM)
MECA

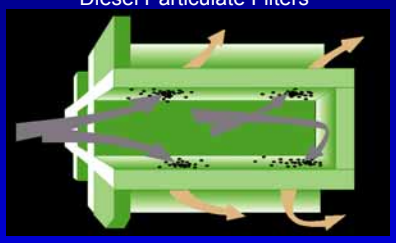
NOx for US Tier 2 Bin 5 (ARB max.) is 20% of Euro V (prop.) and 50% of Japan 2009 - Unique US Solutions are Required



Differences in test cycle are not included, and can be important when comparing regs.

DOCs and DPFs Form the Technology Base for Reducing PM Emissions from New and In-use Diesel Engines

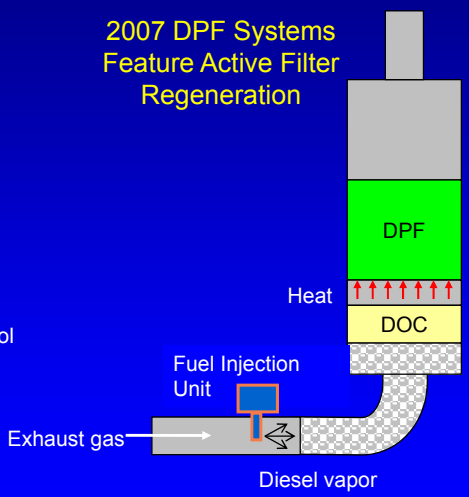
Diesel Particulate Filters



- Significant experience base with LDD in Europe (> 3 M) & HDD retrofits (> 200 K)

Crankcase Filters Provide Additional PM Control

2007 DPF Systems Feature Active Filter Regeneration

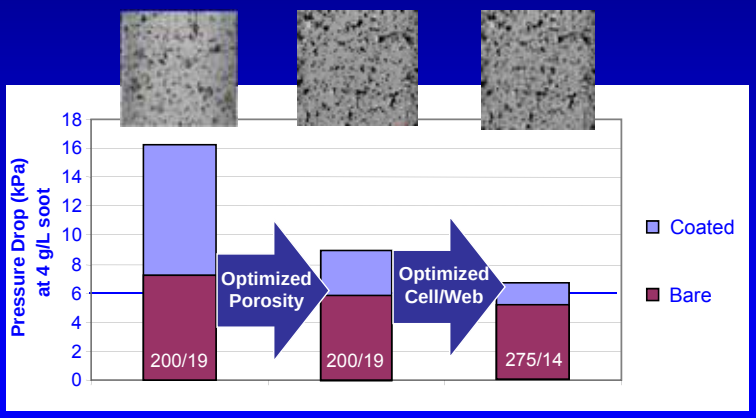


Active Retrofit DPFs Experience Expanding with Diesel Locomotives in Switzerland

- Burner regeneration at 5g/liter soot
- Extruded SiC DPF SVR = 5 to maintain <30 mbar ΔP
- Easily adapted to SCR

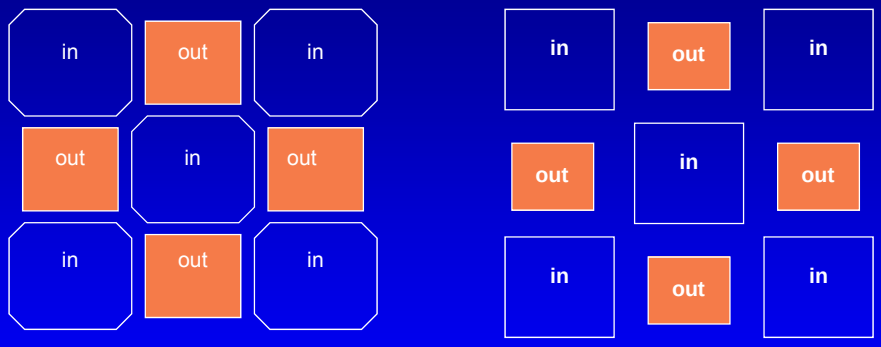
DPF Substrate Design Optimization Includes Minimizing System Backpressure

Example: Cordierite DPF Substrate Designs



Reference: 2004 SAE Commercial Vehicle Congress; Highway Diesel Panel

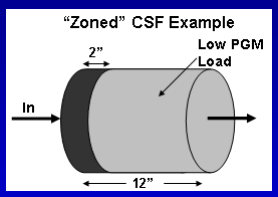
New Filter Cell Configurations Increase Ash Storage Capacity



Reference: SAE 2004-01-0949

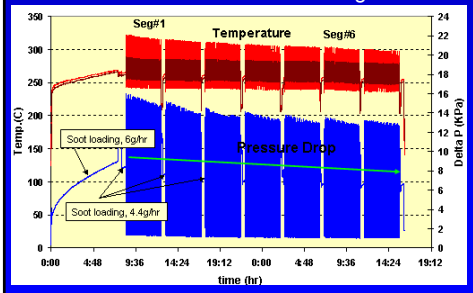
Reference: SAE 2004-01-0948

Zone-Coated DPFs Can Be Used to Optimize Precious Metal Content and Limit NO_2 Emissions

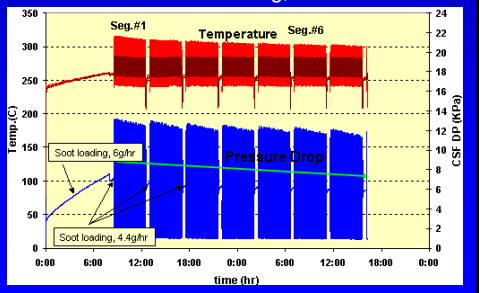


NO_2 emissions cut by more than 50% with zone coating

CDPF with normal coating

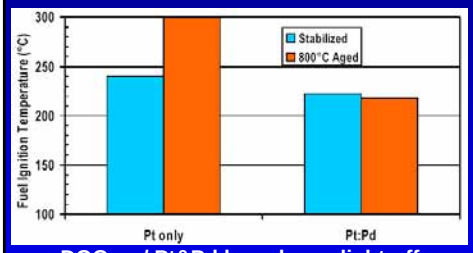


CDPF with zone coating, **65% less PGM**

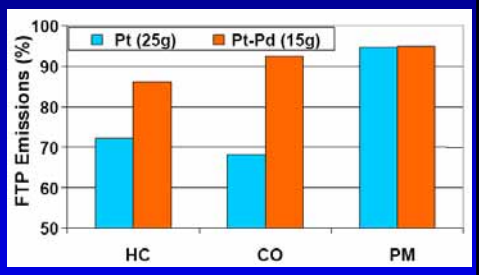


SAE Paper No. 2006-01-1091

DOC + CSF Systems are Lighting Off at Lower Temps with Pt-Pd Catalyst Formulations



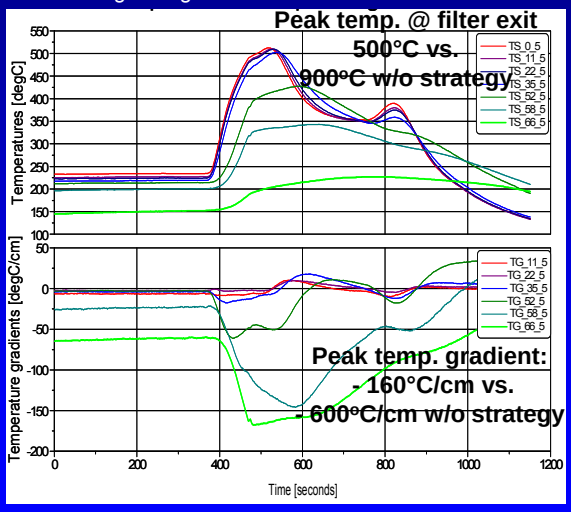
DOCs w/ Pt&Pd have lower light-off temperature and better durability than with Pt only.



CSF with Pt-Pd has 50% lower HC and 75% lower CO emissions than Pt CSF, despite lower PGM loadings.

Engine Control Strategies Are Being Developed to Avoid Run-Away Filter Regenerations

Soot loading = 14 g/liter



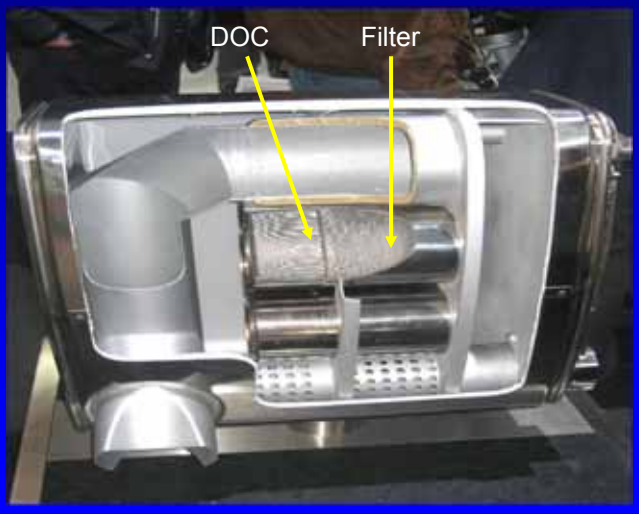
Development of a strategy to avoid uncontrolled filter regeneration during engine deceleration to an idle condition

Implementation of additional regeneration control measures:

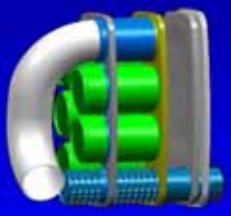
- Control of the amount of post injection
- Temperature compensation to fine tune the filter inlet temperature
- Adjustment of the mass flow
- Torque compensation

Reference: SAE 2004-01-2657

EGR, DOC+Flow-Thru Filter Selected for Heavy-Duty Euro 4 Diesel Application



5 DOC/Filter Elements

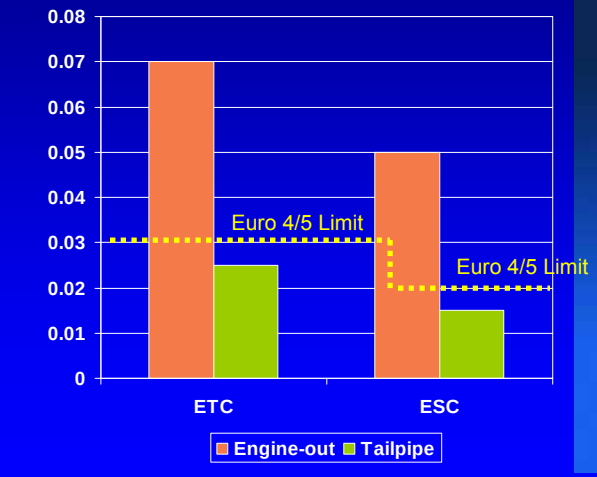


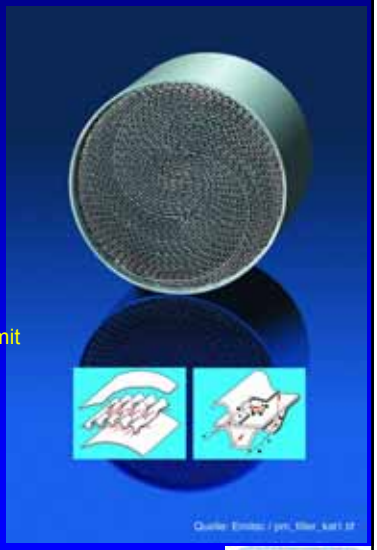
Exhaust Inlet

60-70% PM Reduction Reported in Transient & Steady-State Tests

Reference: MAN

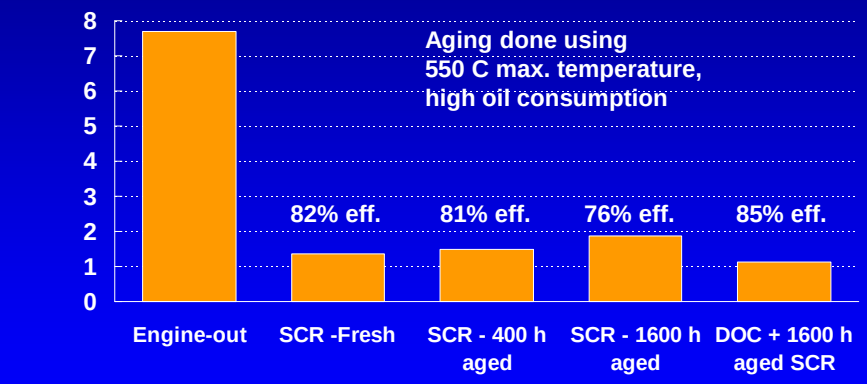
Euro 4 Application with Flow-Thru Filter Demonstrates 60-70% PM Reduction





Source: MAN

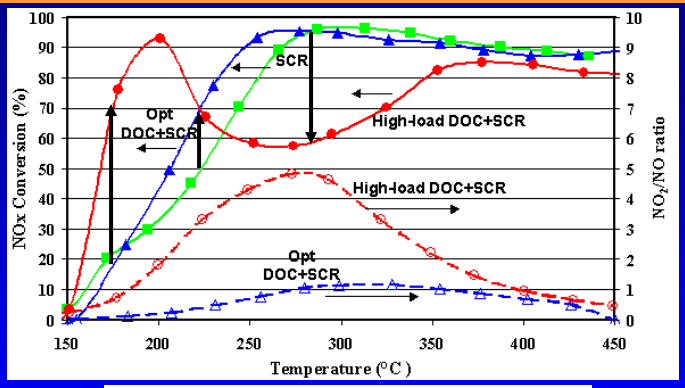
SCR Applications for 2005 Euro IV/V Heavy-Duty Standards: High Performance & Durability



8.5 liter SCR catalyst evaluated on a 10 liter engine;
Aging estimated to be equivalent of 1.2 million km

Reference: SAE 2004-01-1791

NO_2/NO Ratio Is Important in Achieving Good Low Temperature SCR Performance



fast
slow

$4\ NH_3 + 4\ NO + O_2 \rightarrow 4\ N_2 + 6\ H_2O$ (1)

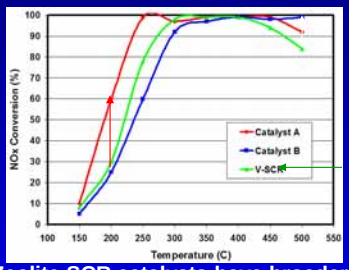
$2\ NH_3 + NO + NO_2 \rightarrow 2\ N_2 + 3\ H_2O$ (2)

$8\ NH_3 + 6\ NO_2 \rightarrow 7\ N_2 + 12\ H_2O$ (3)

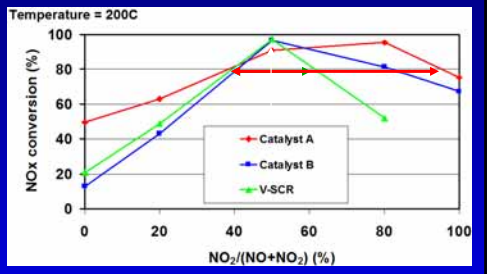
- Reaction 1 is fast, Reaction 2 is very fast, Reaction 3 is very slow
  - low temperature SCR is strongly promoted by NO_2
  - but too much NO_2 can cause problems

Reference: SAE 2004-01-1289

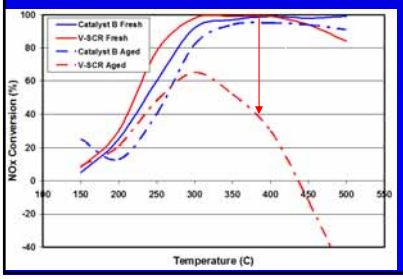
Zeolite SCR Catalysts Provide Performance Advantages vs. Vanadia SCR Catalysts



Zeolite SCR catalysts have broader temperature range



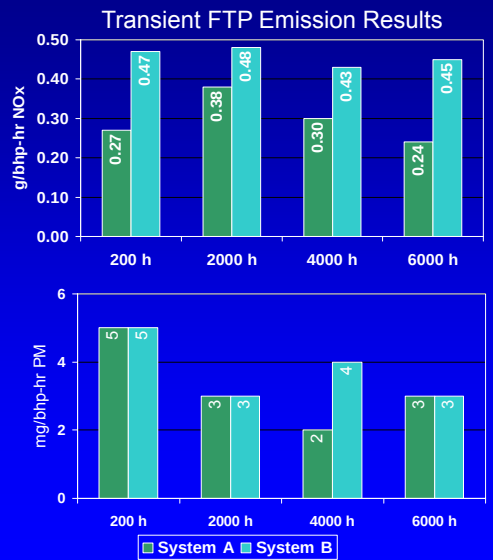
Zeolite SCR catalysts are more tolerant of excess NO_2 than vanadia systems.

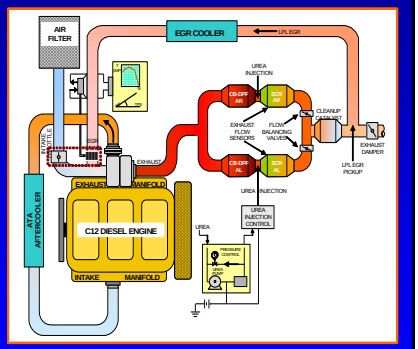


Zeolite SCR catalysts have better HT durability than vanadia catalysts.
Aged 50 hours at 700C.

Source: SAE Gothenburg, 9/05

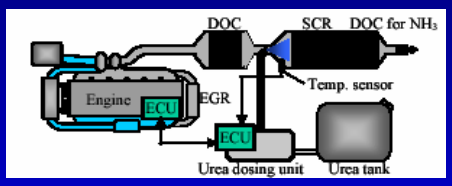
DPF/SCR Systems Maintain High Efficiencies after 6000 Hours of Aging

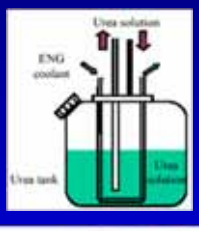


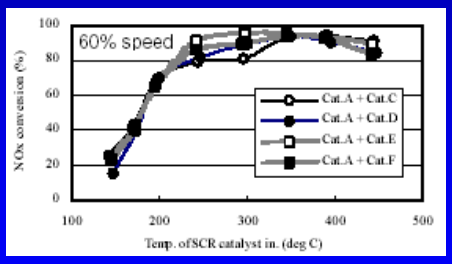


Reference: DEER 2005

Complete HD SCR System Descriptions Available







Zeolite catalysts are preferred due to higher efficiency over the temperature range, and due to smaller size.

Reference: SAE Paper No. 2005-01-1860

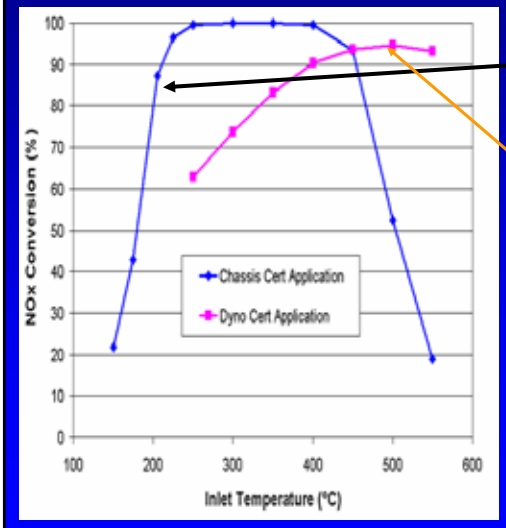
NOx Sensors in Production – Active Development Focused on Diesel Applications

12V version (1st gen. sensor) in serial production since mid 2002

2nd gen. sensor introduced in mid 2005

- NOx sensors recently completed 6000 h durability evaluation on heavy-duty diesel engine as a part of DOE's APBF-DEC program
- Work underway on low NOx range/high accuracy sensor

LNTs are Being Designed for LD and HD Applications

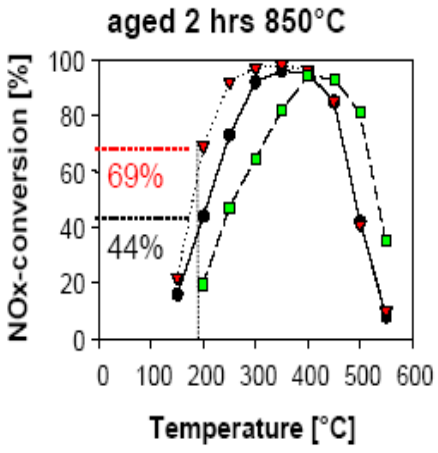


For chassis cert, the issue is cold start and LT NOx efficiency.

For engine (dyno) cert, the issue is HT efficiency at 500C and under high flow rate and NOx flux.

SAE Symposium – Gothenburg Sept. 2005

NOx Adsorber Catalyst Development Continues to Show Progress: Example – Low Temperature NOx Performance

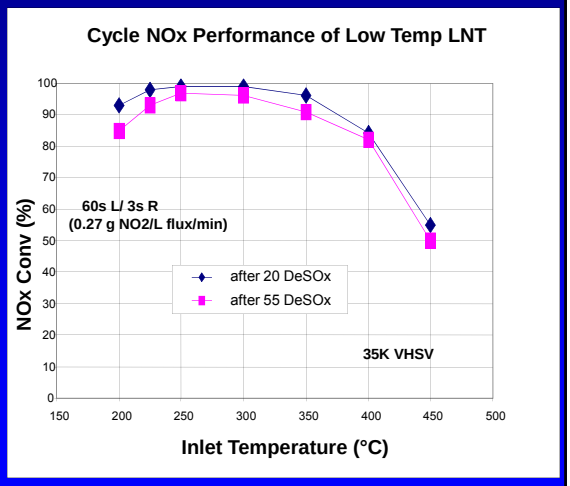


Note: first baseline LNT and advanced LNT are Ba-based; Second baseline LNT is K-based

Reference: SAE Paper No. 2006-01-1369

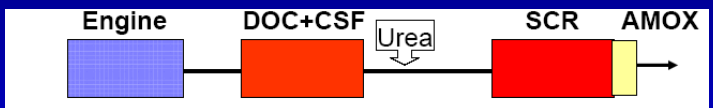
NOx Adsorber Performance Window Stable after Multiple Sulfation and Desulfation Cycles

- Low Temperature system has excellent activity window at low SV
- NOx efficiency maintained through end-of-life simulation
- Mercedes late 2006 launch of E320 diesel with NOx adsorber/DPF system



Reference: AVECC 2004

Favored Design Approach in Most Sectors is to Put NOx System After the Filter System



Advantage

- Filter acts as a thermal reservoir for the SCR bed. The SCR stays closer to isothermal
- The filter can take advantage of higher transient temperatures
- Particulate, SOF and ash are removed prior to the SCR bed.
- NO_2 formation on the CSF will lead to higher SCR activity.

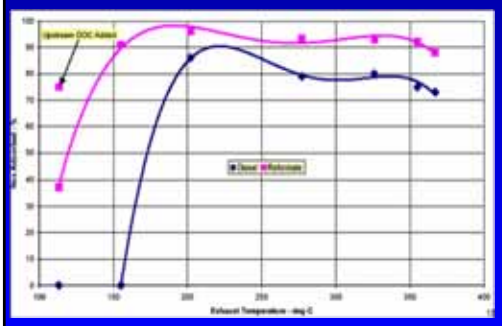
Disadvantage

- Cold start NOx control will be difficult due to thermal mass of the filter
- An exotherm from the CSF may damage the SCR catalyst

SAE HDD Symposium - Gothenburg, Sept. 2005

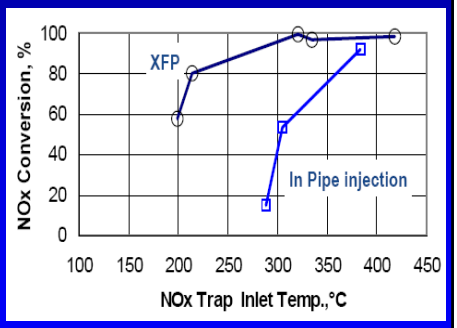
Hydrogen/CO Reformate Significantly Improves LNT Regen. & Desulfation Performance

Plasma reformer uses 250W to form 9% H_2 and 14% CO from 35 kW of fuel; w/ DOC: 20% H_2



Reference: SAE 2004-01-0582

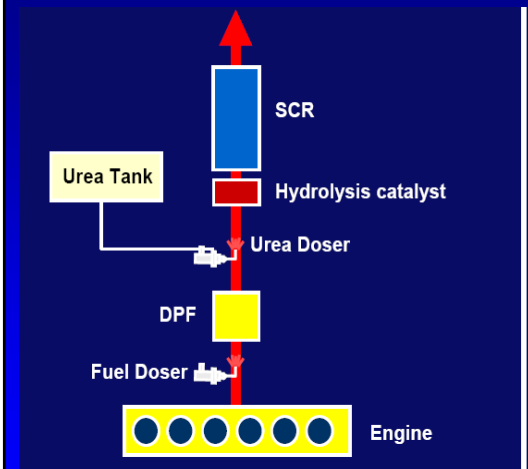
Catalytic reformer operates as low as 200 C to produce pulsed CO/H_2 reformate



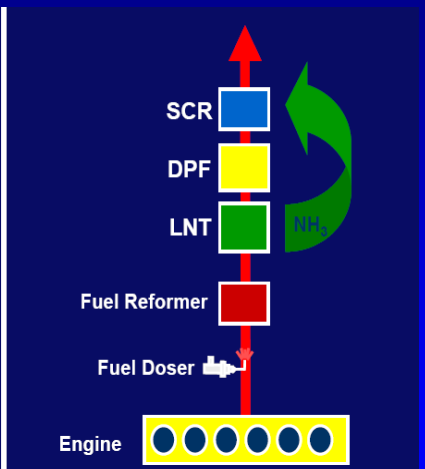
Reference: DEER 2004

CO/H2 also shown to significantly lower LNT desulfation temperatures (up to 100 C)

Advanced System Designs Emerging that Combine LNTs and SCR Catalysts



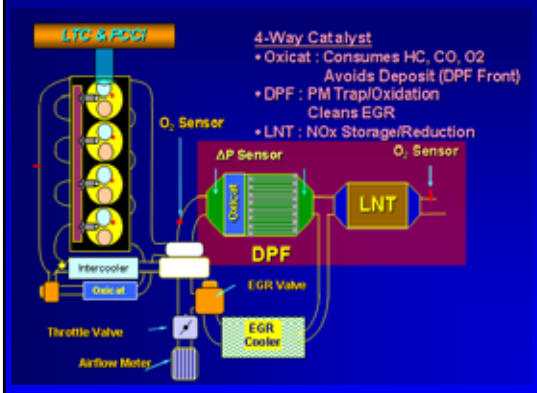
"Conventional" HDD DPF/SCR Design

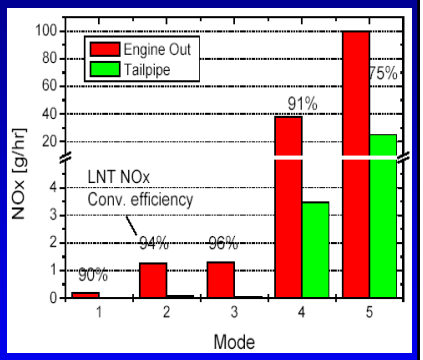


Advanced HDD LNT+ SCR Design (no urea addition)

Reference: DEER 2006

Future Diesel Engines Will Include High Performance Emission Systems Integrated with Advanced Engine Combustion Technologies





- Dual loop EGR is used to stabilize low load lean combustion
- Highly-premixed rich combustion is used for LNT regen
- Tier 2, Bin 3 potential (0.035 g/mi NOx estimate for FTP)

SAE Paper No. 2005-01-1091

Conclusions

- All Major Markets Moving to Tight PM and NOx Emission Standards for Diesel Engines
- A Variety of Technologies Are Available and Emerging for PM, NOx, and Toxic HC Emission Control for Both Diesel Light-Duty and Heavy-Duty Vehicles
- On-Road Diesel Technologies Will Migrate into Nonroad Diesel Applications
- The Ultimate Solution to Reducing Emissions from Diesel Engines Requires a Systems Approach Utilizing Advanced Engine Designs, Advanced Integrated Emission Control Technology, and Low Sulfur Diesel Fuel

Engine Control Systems

Retrofit 101: Options for Compliance

MDEC Workshop 2006

Kevin F. Brown

Retrofit Technology Options

PM Control

- Oxidation Catalysts
- Flo-thru Filters
- Particulate Filters
- Fuel Choice
  - Reduce Fuel Sulfur
    - ULSD
  - Bio-Diesel
  - Fuel Emulsion

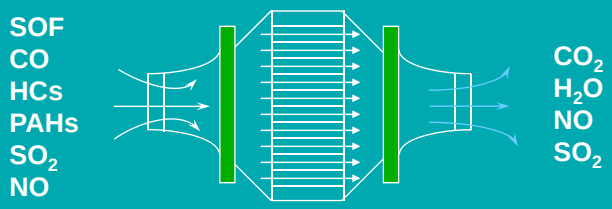
Commercial

NOx Control

- Fuel Emulsions
- Lean NOx catalysts
- Selective Catalytic Reduction Systems (SCR)

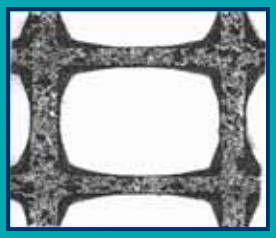
Earlier commercial stages

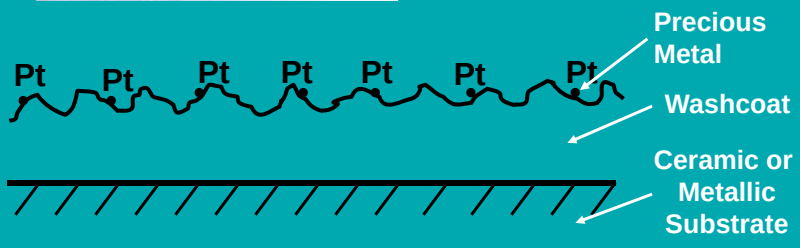
Diesel Oxidation Catalysts



- 25-50+% PM Reduction
  - reduction depends upon amount of SOF/OC in the DPM
- Formulated for Heavy Duty applications
- All Reduce Toxics
- Nearly Universal Application with > 1 Million Retrofits Worldwide
- Tens of Millions of OE Applications

DOC Composition





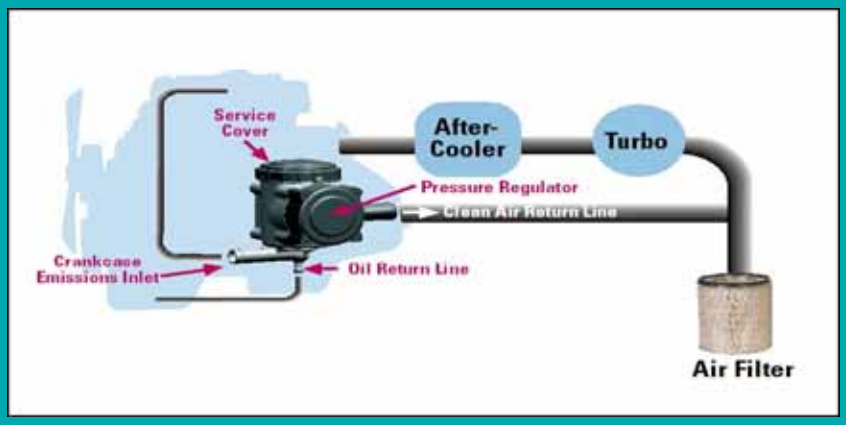
Flexible DOC Design for Non-road

- generic converter or muffler, modular design or integrated, or direct fit converter muffler
- need to deal with vibration
- need to deal with aspirator / venturi tubes, insulated muffler skins, spark arrestors
- prevent water entry into exhaust (i.e. raincaps)

DOC Advantages

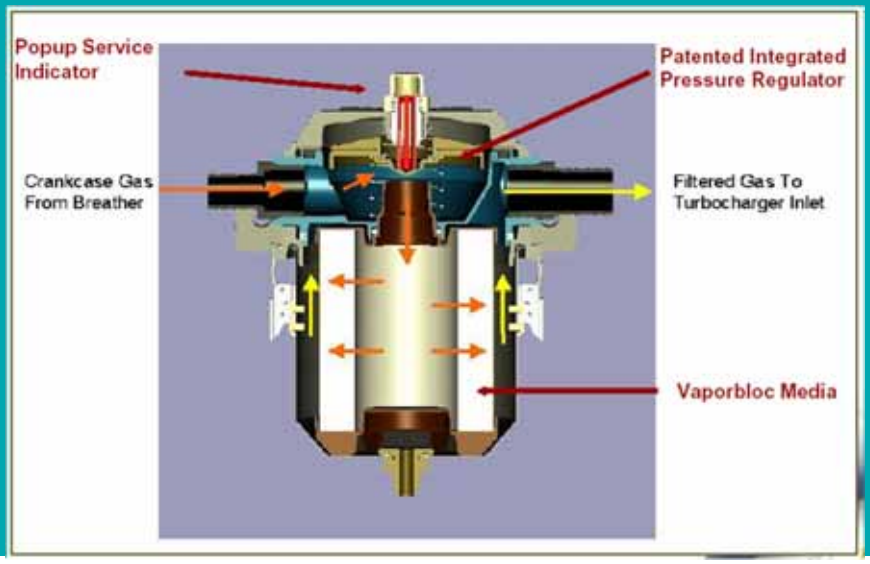
- Cost effective
- Fuel Sulfur tolerant
- Compatible with an array of traditional and alternate diesel fuels (i.e. biodiesel, e-diesel, emulsions)
- Flexible design attributes
- Easiest Installation
- Durable

Closed Crankcase Filtration



- only closed systems resolve health concerns
- can be used separately or in combination with DOC's and DPF's
- cartridges replaced at specified oil change intervals
- should have service indicators

Closed Crankcase Filtration



Closed Crankcase Filtration

Specifications

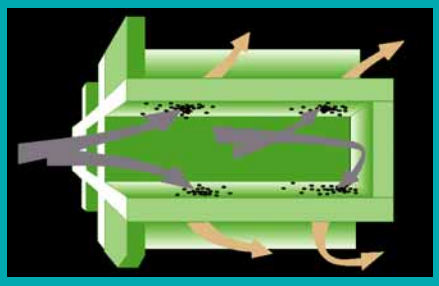
	CCV1500	CCV3500	CCV4500	CCV6000	CCV8000
Height	5.1" / 130 mm	7.0" / 178 mm	9.25" / 235.0 mm	12.00" / 304.8 mm	13.87" / 352.6 mm
Maximum Opening With (incl. clamps & bracket)	8.7" / 221 mm	8.7" / 221 mm	7.50" / 190.5 mm	11.25" / 285.8 mm	13.25" / 336.6 mm
Depth	5.0" / 127 mm	6.3" / 160 mm	5.60" / 142.2 mm	7.30" / 185.4 mm	9.30" / 236.2 mm
Weight	1.5 lbs / .68 kg	2.3 lbs / 1.0 kg	3.26 lbs / 1.48 kg	5.01 lbs / 2.29 kg	8.72 lbs / 3.96 kg
Filter Removal Clearance	6.0" / 152 mm	6.0" / 152 mm	2.25" / 57.2 mm	4.00" / 101.6 mm	5.00" / 127.0 mm
Replacement Element / Media Density/Medium	CCV 55365-04	CCV 55365-06	CCV 55248-06	CCV 55274-06	CCV 55222-06
Replacement Element / Media Density/High	N/A	CCV 55365-08	CCV 55248-08	CCV 55274-08	CCV 55222-08
Housing Material	Glass-filled nylon and black powder epoxy coated steel bracket	Glass-filled nylon components	Die cast head, glass-filled nylon and black powder epoxy coated steel bowl.	Die cast head, glass-filled nylon and black powder epoxy coated steel bowl.	Die cast head, glass-filled nylon and black powder epoxy coated steel bowl
Inlet & Outlet Thread Size	3/4" hose	3/4" hose	1 3/16" - 12 SAE	1 5/8" - 12 SAE	1 7/8" - 12 SAE
Max. Cubic Feet per Minute	1" cfm / 30 lpm	3.0" cfm / 84 lpm	10 cfm / 283 lpm	20 cfm / 566 lpm	40 cfm / 1132 lpm
Crankcase Pressure Regulator	N/A	Integral	Integral	Integral	Integral
Bypass/Change Indicator	N/A	Integral	Integral or Remote	Integral or Remote	Integral or Remote
Engine Block Check Valve Return Fitting	N/A	1/4" NPT	1/4" NPT	1/4" NPT	3/8" NPT
Swivel Fitting (Qty.)	N/A	# 6 JIC (2pcs.)	# 6 JIC (2pcs.)	# 6 JIC (2pcs.)	# 8 JIC (2pcs.)
Oil drain hose I.D.	N/A	.375"	.375"	.375"	.5"

"Flow-Through" or "Partial" Filter Technologies Emerging for Diesel Retrofits

- FTF technologies are emerging which afford >50 to 65% PM reduction
- Are less cost effective than DOC's
- These systems still have duty cycle requirements similar or identical to DPF's
- Duty cycles below minimum requirements, afford at best, DOC performance and increased risk of plugging or required maintenance
- All FTF's operate under higher exhaust backpressures
- FTF's employ NO2 to oxidize elemental carbon
  - As such, they require ULSD and increase NO_2
  - They can be severely affected by higher sulfur fuels

Diesel Particulate Filters

Wall Flow Monolith



- 85+% PM Reduction
- 95+% Particle Number Reduction
- Large Reduction in Toxics
- > 200,000 Retrofits Worldwide
- > 1 Million OE Applications

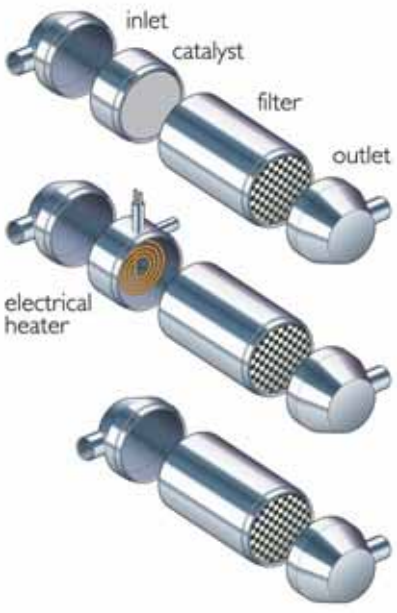
Other claimed DPF types

- Sintered Metal
- Foam
- Wire Mesh
- etc.

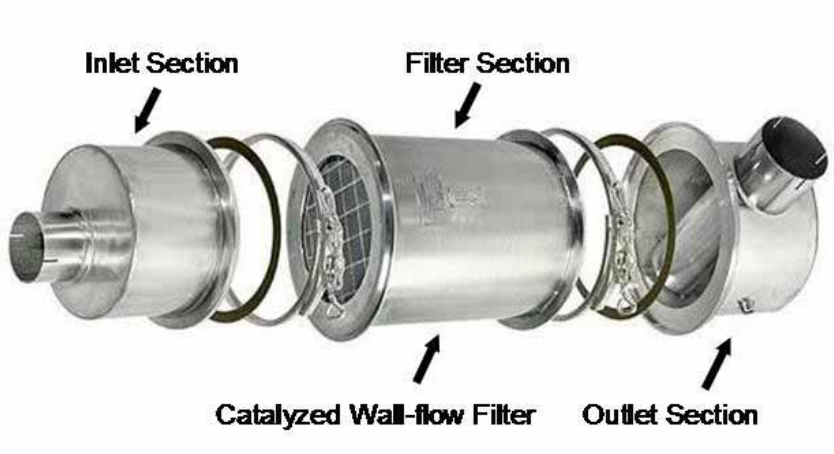
DPF Technology Types

Modular design allows a variety of configurations:

- DOC / DPF
- Active DPF
- DPF



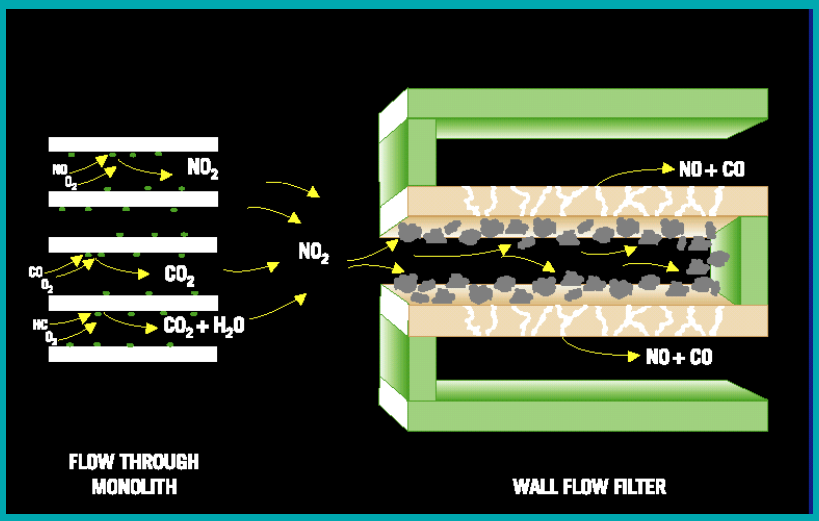
Diesel Particulate Filters



DPF Regeneration Types

Filter	Precious Metal Passive	Base Metal Passive	Active Electric
Fuel Required	ULSD	<500ppm	any
Regeneration Temperature	280 – 320 C or lower	380 – 420 C	Not Required
Regeneration Catalyst	Precious & Base Metal Coating	Base Metal Coating	Electrical Connection
Regeneration Downtime	None	None	60 minutes to 8 hours
Regeneration Method	Passive Filter Regeneration	Passive Filter Regeneration	Active Filter Regeneration

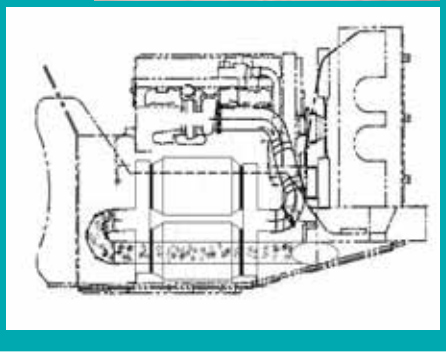
Precious Metal Catalyst Mechanism



Issues with Precious Metal Catalyzed Traps or FTF's

- These systems are designed for low temperature regeneration and typically employ high Pt loadings
  - Significantly higher than most HD DOC's
- As temperatures increase there is a significant increase in NO2 slip
- Check MSHA list to verify potential for NO2 slip

Base Metal DPF's in Mining



Canadian DEEP Trials of Cattrap

Wagner ST8-B Loader; DDC S60 325 hp

- **4053 hrs total accumulation**
- **>25% above 380 ºC**
- **21.9% time at idle (887 hrs)**
- **One mine cave-in**
- **Now over 10,000 engine hours**

Source: SAE 2004-01-0077

DEEP Trials- Brunswick Mine

Fe additive fiber filter 2898 hrs / 32% idle

Base metal catalyzed Cordierite filter 4053 hrs / 22% idle

Pt catalyzed with Electric Regen. SiC filter 4261 hrs / 23% idle

Comparison of BM-DPF & PM-DPF from DEEP Program with <500 ppm Fuel Sulfur

	DEEP Series 60 Testing	
	PM Mass Reduction	
Mode / Exh. Temp	Base Metal DPF	Precious Metal DPF
1 / (371°C)	83%	67%
3 / (321°C)	85%	86%
5 / (464°C)	41%	-146%
7 / (376°C)	60%	11%

Source: Gangal et. al., MDEC Conference, 2002

Electrical Regeneration

Active DPF's in Mining

DEEP Trials:
Stobie Mine
(report available at www.deep.org)

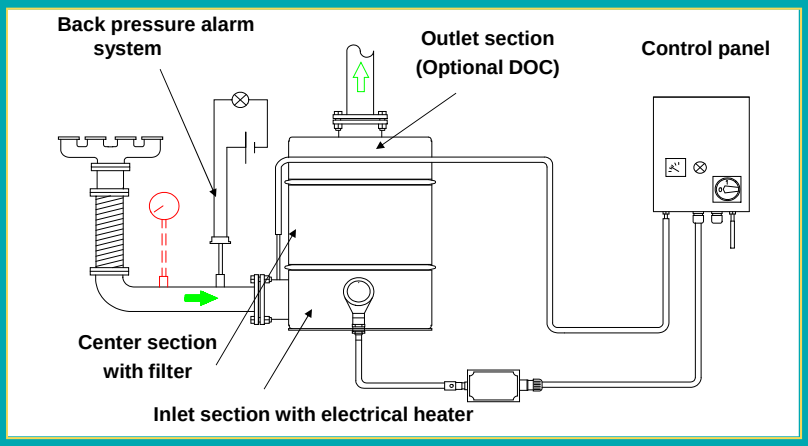
Wagner ST-8 Loader
DDC Series 60
with Combifilter
Model 2xS18

- regenerated daily

Active DPF's in Mining

Electrical Regeneration in Construction

On-board regeneration



Off-Board Regeneration

- Allows all filters to be exchanged and regenerated off-board
- Reduces worker exposure to fine particles
- can be used to service passive filters

DPFs Require Regular Preventative Cleaning

Ash captured in the filter . . .

collected in filter bag using recommended cleaning practices. . .

sealed in containers . . .

and sent to the appropriate waste facility

DPF Regeneration and Maintenance

Increasing number of machines in the marketplace

Can be used to remove ash and hard carbon deposits from un-catalyzed and catalyzed filters

DPF Maintenance Site implementation

Croton Project, NYC

Key Considerations for Successful Retrofit Programs

- Application
  - Selecting the right technology
- Installation
- On-vehicle monitors
- Maintenance

➢ **Successful Retrofits Require a Team Effort Between Fleet Owners, Operators, and Technology Providers**

Addressing Installation Issues

Dealing with Aspirator / Venturi tubes

• incorporate into design downstream of emission control components

• incorporate into tailpipe

Horizontal vs. Vertical Installation

Dealing with Vibration

Backpressure Monitors

- DPF systems should be used with a backpressure monitor
- Backpressure should be specified by customer
- Can be purchased separately or as part of DPF system
- vital to determine when maintenance is needed and prevent premature DPF failure

Backpressure Alarms

- Peak measurement with 30 seconds time delay
- Multi-light
- mounted in engine compartment
- Provision for remote dash mounted display

Backpressure Alarm Kit #	DC Voltage	Pressure Setting
A56 – 0013	12 V	27″ H_2O
A56 – 0014	12 V	42″ H_2O
A56 – 0015	24 V	27″H_2O
A56 – 0016	24 V	42″ H_2O
A56 – 0017	12 V	60″ H_20
A56 – 0018	24 V	60″ H_20

Backpressure Monitor / Loggers

- New 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

NY City Croton Demonstration




New York DOT – Asphalt Roller


Problems encountered to date

- Basic problems
  - Lack of accurate engine information
  - Buying on price alone without considering support, warranty and backpressure
  - Mis-fueling
  - Lack of preventative maintenance
    - especially air filters, injectors and turbochargers
    - basic inspection and maintenance of installations
- Underestimating vibration
  - Vibration requiring extensive use of high grade vibration isolators especially in track drive equipment
- Interference with installation process
  - taking short cuts to get machine done now
  - Owners demanding things done their way

MDEC Workshop 2006

Combustion Controlled Emission Technology

Manfred Duering and Todd Mysak

"The Right Technology Matters"

Interest in Emissions?

Today
Interest in Emissions?

Tier 4?

EGR?

ACERT?

ULSF?

Urea?

DOC?

DPF?

Pre-Buy?

$$$$

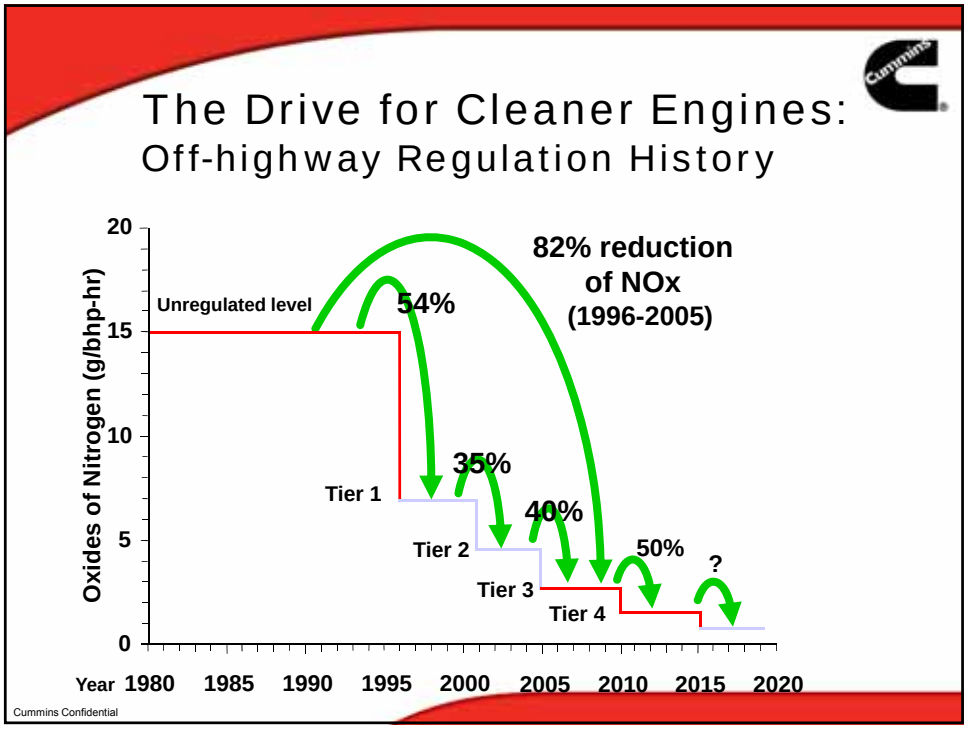
Regulated Emissions: Combustion Chemistry

Particulate Matter (PM)

$$C_x H_y S_z + O_2 + N_2 \rightarrow CO_2 + H_2O + N_2 + O_2 + NO_x + HC + CO + SO_x + C$$

Diesel fuel | **Air** | **Major exhaust constituents** | **Exhaust components found in trace concentrations**

EPA diesel regulated emissions indicated in red


The Drive for Cleaner Engines:
Off-highway Regulation History
Oxides of Nitrogen (g/bhp-hr)
20
15
10
5
0
Unregulated level
54%
82% reduction of NOx (1996-2005)
Tier 1
35%
Tier 2
40%
Tier 3
50%
Tier 4
?
Year 1980 1985 1990 1995 2000 2005 2010 2015 2020
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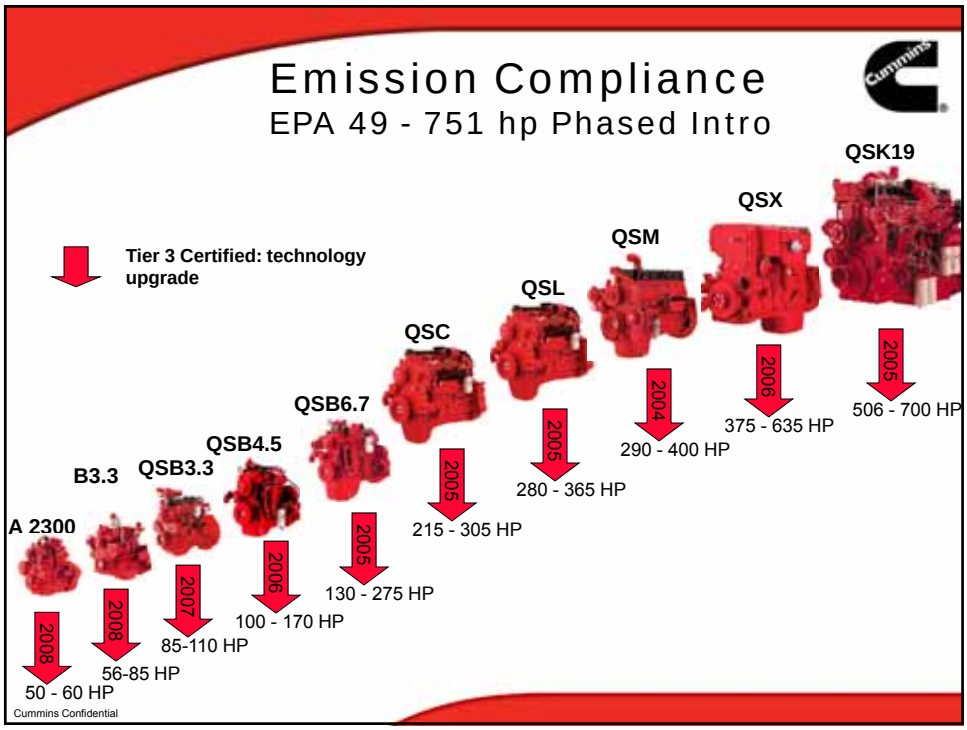
Emission Compliance
EPA 49 - 751 hp Phased Intro
Tier 3 Certified: technology upgrade
A 2300
B3.3
QSB3.3
QSB4.5
QSB6.7
QSC
QSL
QSM
QSX
QSK19
2008
50 - 60 HP
2008
56-85 HP
2007
85-110 HP
2006
100 - 170 HP
2005
130 - 275 HP
2005
215 - 305 HP
2005
280 - 365 HP
2004
290 - 400 HP
2006
375 - 635 HP
2005
506 - 700 HP
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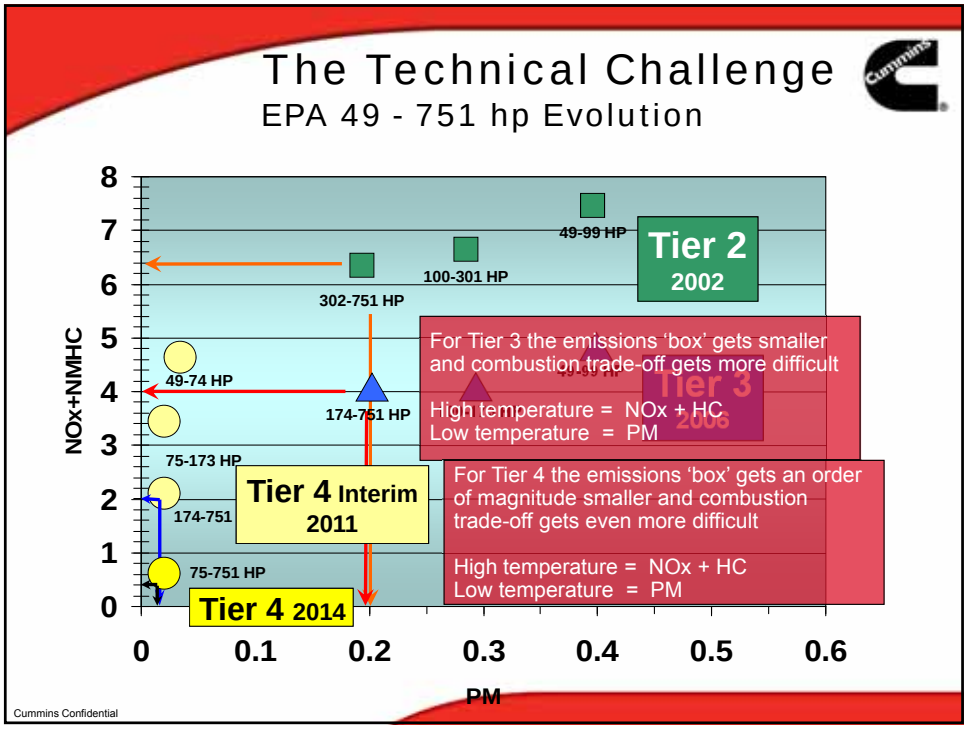
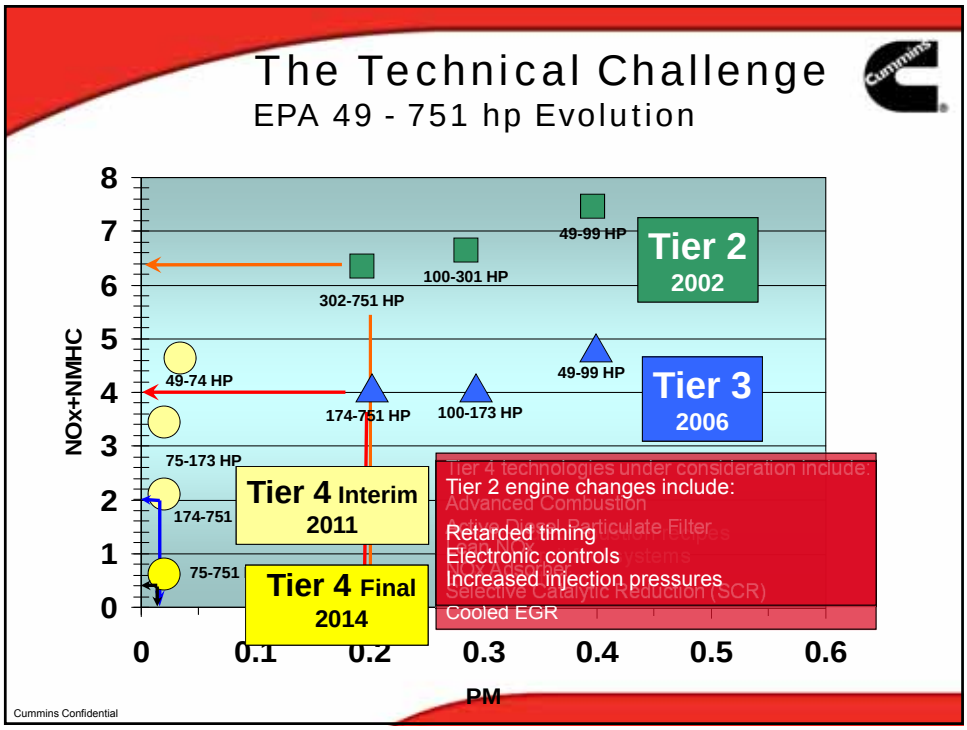

The Technical Challenge
EPA 49 - 751 hp Evolution
NOx+NMHC
PM
0
1
2
3
4
5
6
7
8
0
0.1
0.2
0.3
0.4
0.5
0.6
49-99 HP
100-301 HP
302-751 HP
Tier 2
2002
For Tier 3 the emissions 'box' gets smaller and combustion trade-off gets more difficult
High temperature = NOx + HC
Low temperature = PM
Tier 3
2006
49-74 HP
174-751 HP
75-173 HP
Tier 4 Interim
2011
174-751
75-751 HP
Tier 4 2014
For Tier 4 the emissions 'box' gets an order of magnitude smaller and combustion trade-off gets even more difficult
High temperature = NOx + HC
Low temperature = PM
Cummins Confidential


The Technical Challenge
EPA 49 - 751 hp Evolution
NOx+NMHC
PM
0
1
2
3
4
5
6
7
8
0
0.1
0.2
0.3
0.4
0.5
0.6
49-99 HP
100-301 HP
302-751 HP
Tier 2
2002
49-99 HP
100-173 HP
Tier 3
2006
49-74 HP
174-751 HP
75-173 HP
Tier 4 Interim
2011
174-751
75-751
Tier 4 Final
2014
Tier 2 engine changes include:
Retarded timing
Electronic controls
Increased injection pressures
Cooled EGR
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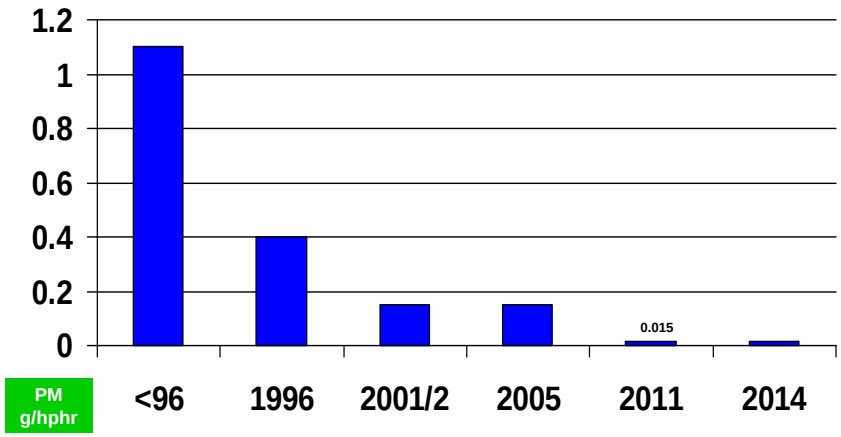
PM Emissions
Reduced 99% 302 - 751hp



EPA Mobile Off Highway Regulations

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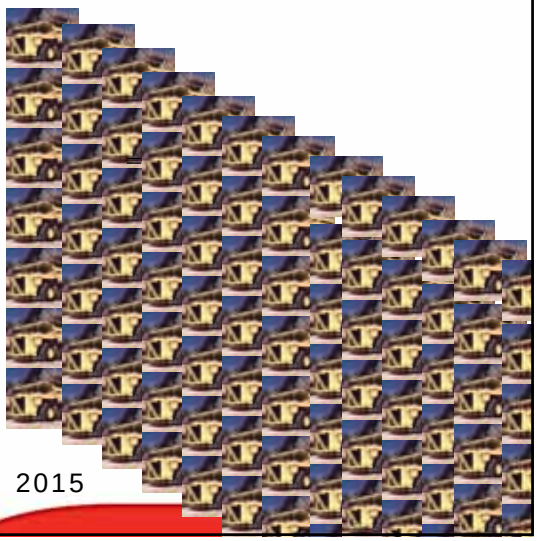
1 Truck in 1995 =
85 Trucks in 2015

1995

=



2015

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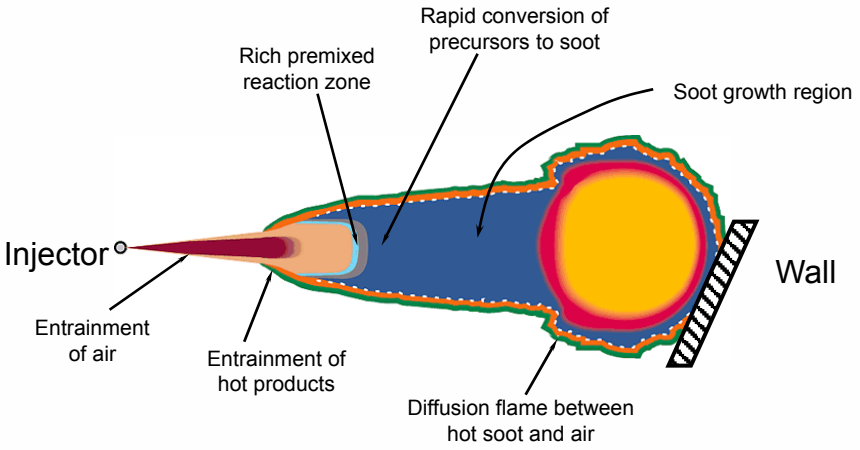
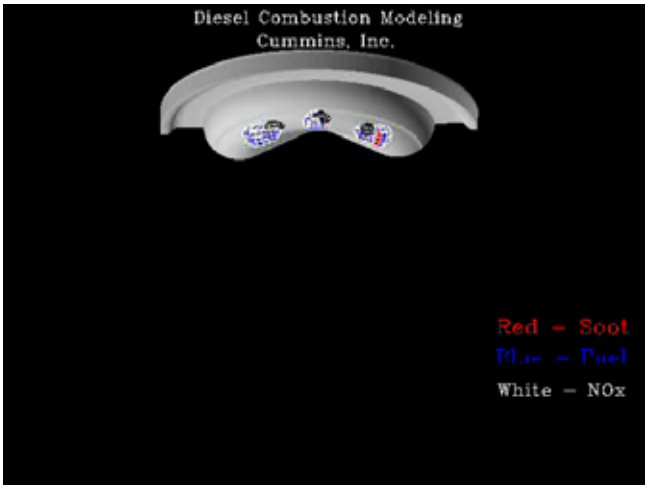
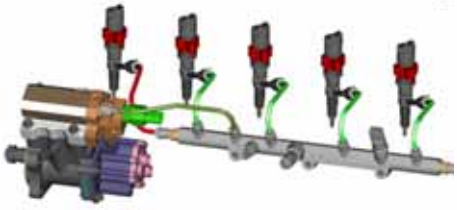
Combustion Processes Modeled in CFD Code



Combustion Processes Modeled in CFD Code



The Right Technology Matters ... in Emissions Control



– Fuel systems
– Electronic controls

... to deliver best customer value at low emissions

Tier 3 Design Philosophy
Beyond Meeting Emissions

Starting Point: EPA Tier 3 Regulations

OEM

Minimal installation impact

Engine platform stability to Tier 4

Robust for toughest duty cycles & high altitude

Operator

Mature reliability at launch

Maintain power density

Lowest possible operating cost

Technology

Advanced In-cylinder combustion as key emissions solution

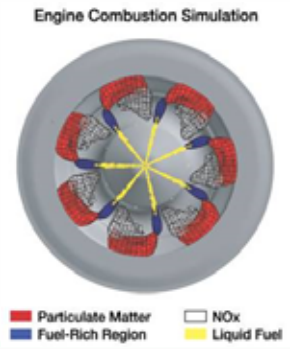
Enhance performance with common rail, electronics & power cylinder

Utilize proven engine platforms

Technology Enabler:
Advanced In-Cylinder Combustion

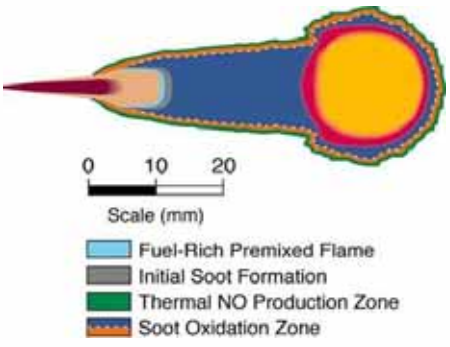
Proprietary in-cylinder combustion technology path for meeting EPA Tier 3 January 2005 and beyond

- Most effective solution - but only achievable through advanced combustion technology
- Reduces NOx by 40% and PM by 60% to meet Tier 3
- Utilizes proven engine platforms with no displacement or base engine changes
- Avoids complicated engineering such as EGR or major changes to turbocharging or cooling
- Tolerates high sulfur fuel



Technology Enabler
In-Cylinder Advanced Combustion

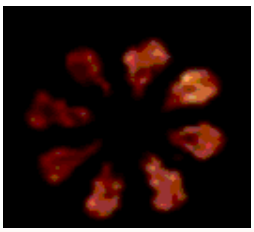
- Multiple injection events
- Precisely controlled pre, main and post charges
- Low swirl
- Combustion bowl geometry
- Directed piston cooling
- Lower piston temperatures & cylinder pressures reduce mechanical stress



Technology Enabler
Design-Led Analysis

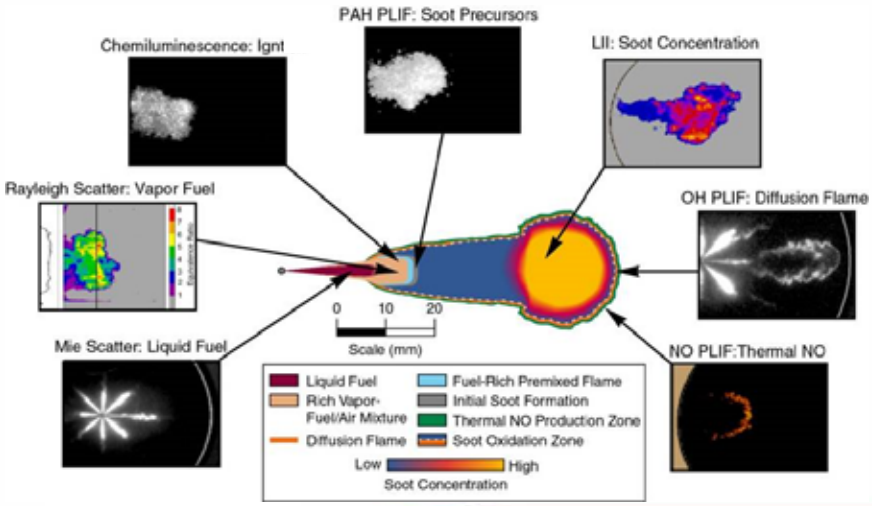
Cummins has the best capability in the industry to accurately analyze thousands of combustion formulas before committing to a design

- Analysis-Led Design computer modelling
  - combustion analysis reduced from 12 to 5 months
  - combustion design evaluations increased from 10 to 1,000
- Can predict the combustion process anywhere in the cylinder and influence reactions by fine tuning every variable
- Based on joint research with leading universities and US National Laboratories - Sandia, Oak Ridge etc
- Close working relationships with leading component suppliers such as Bosch and Motorola



Technology Enabler
Combustion Model Validation

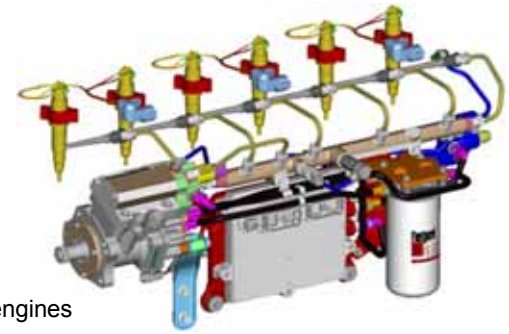
Based on multiple laser/Imaging Diagnostics



Images Courtesy of Sandia National Lab

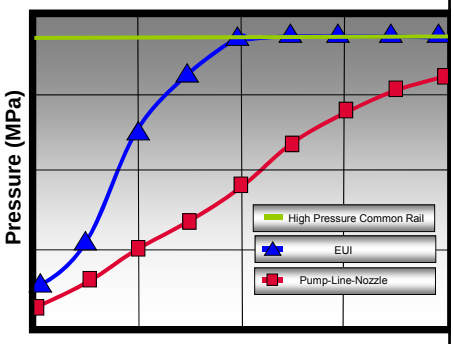
Technology Enabler:
High Pressure Common Rail

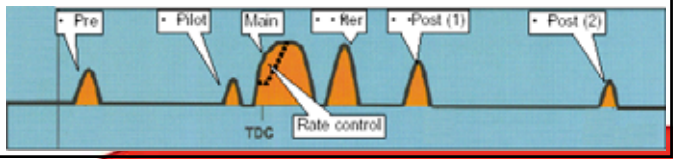
- Purpose-designed for Cummins industrial engines
- Enhances engine performance:
  - – Reduced noise & smoke
  - – Improved idle stability
  - – Improved cold start
  - – Faster response
  - – Low-end torque improvement
  - – Cleaner combustion
- Available on QSB, QSC, QSL engines



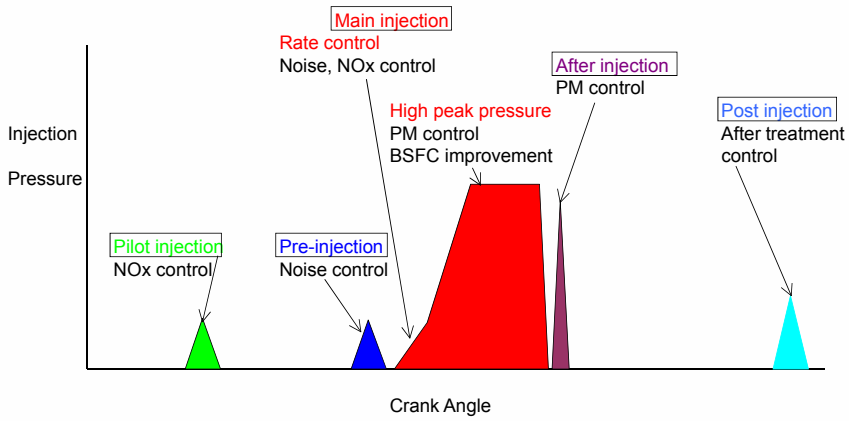
Technology Enabler:
High Pressure Common Rail z

- Constant high injection pressure across the rpm band – does not depend on engine speed or load conditions
- Multiple injection events with precision control of rates & timing
- No injector camshaft or overhead rocker levers
- Fuel injection pressure of up to 23,000 psi





Future Fuel Systems Must Provide Multiple Injection Events

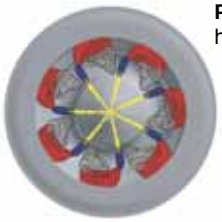


For multiple injection events the injection is not controlled by mechanical Cams but by Engine Electronic Control Module

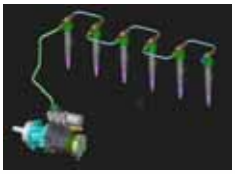
Cummins Confidential

Meeting Tier 2:
Proven Technology Enablers

Combustion
'Advanced In-Cylinder Combustion" formula proven on Tier 3 engines



Power cylinder proven high durability FCD piston



Fuel System
New Modular Common Rail provides improved power delivery

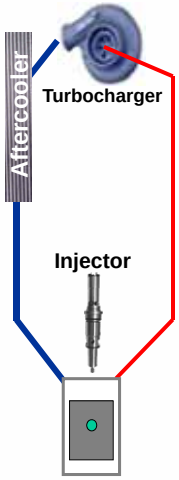
Common rail proven on high volume engines

Controls
Proven ECMs with x 3 faster processing power & upgraded sensors

Cummins Confidential

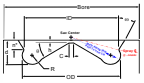
Tier 4 Building Blocks

Cummins Tier 3 Engine



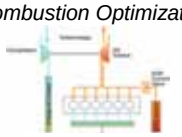
Possible Tier 4 Building Blocks

Flexible Fuel Systems



Combustion Optimization

Air Handling



Cooled EGR

Advanced Controls = ECM

Particulate Filter

NOx Adsorber

SCR

Technology Enabler:
Aftertreatment – Tier 4

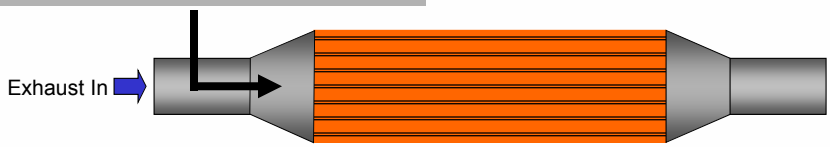
- Stringent Tier 4 emissions (2011 onward) will require exhaust aftertreatment together with the use of ULSD
- Cummins has a unique in-house capability to meet these requirements:
  - Cummins Emissions Solutions aftertreatment expertise
  - system integration with a single control system driven by the engine ECM
- Tier 3 platforms enabled to move forward to Tier 4

Emission Solutions

NOx Aftertreatment
1. Lean NOx Catalysts

- **Simple System:**
  - **Requires continous injection of fuel upstream**
  - **But only reduces NOx 10-25%**
  - **Not enough for Tier 4**

Continuous fuel injection



Lean NOx Catalyst

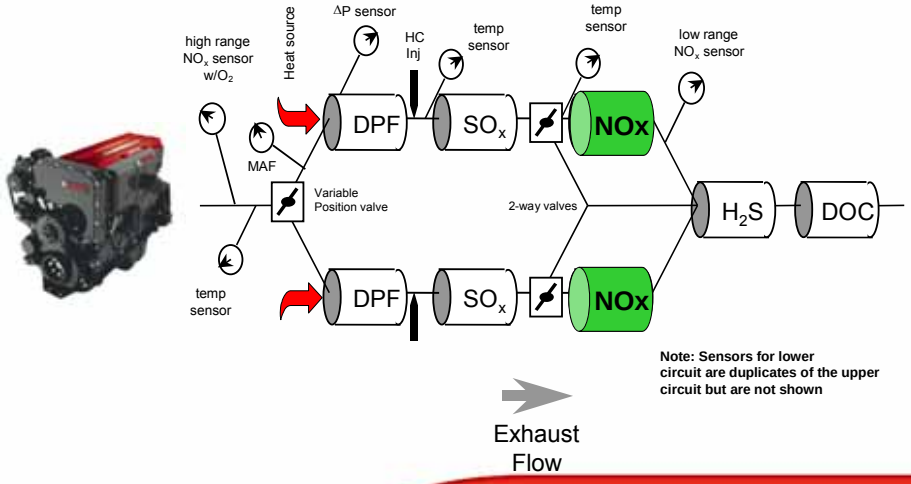
NOx Aftertreatment
2. NOx Adsorbers

- **Very effective - reduces NOx 95%**
- **To regenerate, only require periodic injection of fuel**
- **BUT, catalyst cannot tolerate any sulphur**
- **AND, system can get pretty complex**

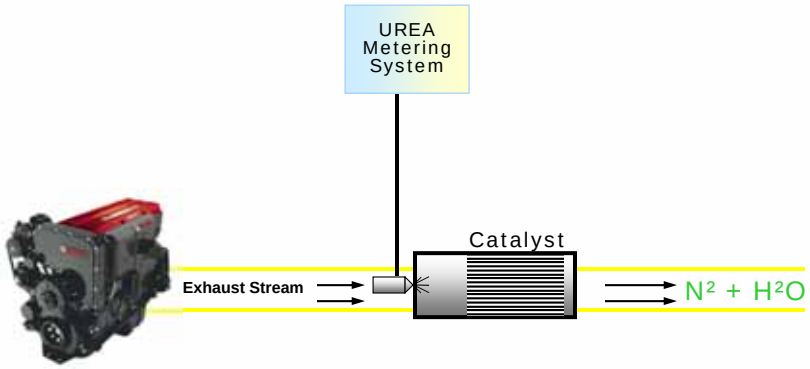
Periodic fuel injection

NOx Adsorber Catalyst

Tier 4 Engine System?
NOx Adsorber + DPF + DOC



NOx Aftertreatment
3. SCR - Selective Catalyst Reduction



Basic Principle - Spraying Urea into the exhaust stream to promote NOx reducing catalyst activity.

Emission Compliance

EPA Tier 3 Certified 2005

QSL

Tier 3
Advanced in-cylinder combustion
Common rail

305-365HP

QSM

Tier 3
Advanced in-cylinder combustion
CELECT

290-400 HP

QSX

Tier 3
Advanced in-cylinder combustion
HPI

375-630 HP

QSK19

Tier 3
Advanced in-cylinder combustion
Modular common rail

506-700 HP

Proven in-service technology since EPA effect date 01/01/2005

Emission Compliance

EPA Tier 3 Certified 2006 & 2007

QSB4.5

2007

Tier 3
Advanced in-cylinder combustion
High Pressure Common Rail

110 - 170 HP

QSB6.7

2006

Tier 3
Advanced in-cylinder combustion
High Pressure Common Rail

130 - 275 HP

QSC

2006

Tier 3
Advanced in-cylinder combustion
High Pressure Common Rail

215 - 305 HP

MINE OPTIONS TO OFFSET COSTS

PROVEN TECHNOLOGY → DEVELOPMENT

Option 1	Option 2	Option 3	Option 4
Generate & Use Electricity Using Gas in Mine Fields	Collect Gas and Transport for Commercial Use	Blending other fuels with Diesel (like Bio-Diesel)	New Technology engines for Mining

Generate Electricity using Natural Gas found in Mine Fields.

Compression enables a well to produce higher volumes of gas and increases gas pressure for introduction into downstream transmission lines.

Applications:
Wellhead (< 500 hp)
Gathering (< 1000 hp)
Pipeline (> 1000 hp)

With increased interest in emissions & reducing use of petroleum distillate based fuels, many regulating bodies encourage bio-diesel fuels.

Bio-diesel fuels must be considered experimental at this time

Cummins continues to participate with partners to develop and test innovative technologies.

Thank You for your attendance.

Diesel Fuel Properties

Hannu Jääskeläinen
University of Toronto

MDEC Workshop 2006

Combustion
Emissions
Fuels

Why are fuel properties important?

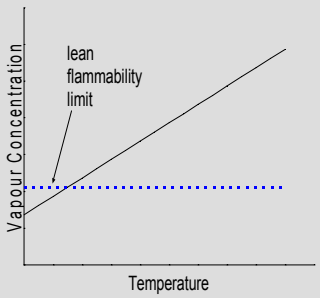
- environment
- safety
- equipment operation
- equipment reliability

Some important fuel properties

- Flash point
- Cold flow properties
- Cetane
- Lubricity
- Sulfur

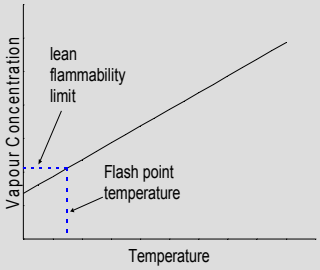
Flash Point

- Heating a liquid fuel sample increases the concentration of fuel vapour above it.
  - *lean flammability limit – minimum concentration of fuel vapour in air in which a flame will propagate.*



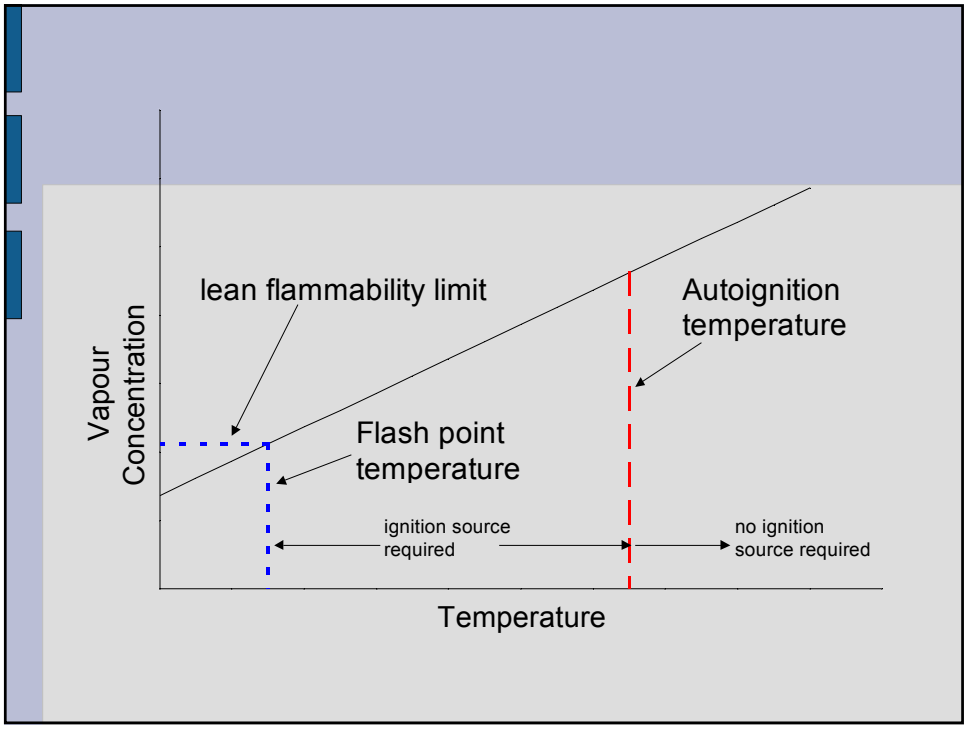
Flash Point

- the lowest temperature at atmospheric pressure at which the application of an ignition source causes the vapor above a liquid fuel sample to ignite under the specified test conditions.
  - measure of the temperature at which a combustible mixture (at or above the lean flammability limit) of fuel vapor will form in air.



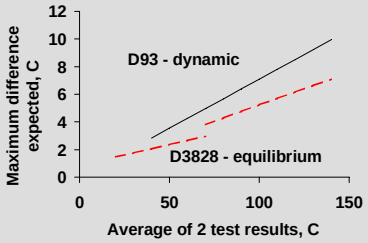
Autoignition temperature

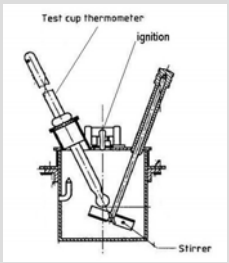
- minimum temperature at which a combustible mixture of a sample will ignite without an external ignition source.



Flash Point measurement

- Closed cup tester
  - dynamic method
    - vapour & liquid may not be at same temperature
    - results dependent on rate of heating
    - quick and low cost
  - equilibrium method
    - vapor & liquid at same temperature
    - slower and more expensive





Flash Point

- Most diesel fuels > 37.8 ^{o}C
  - between 37.8 to 93.9^{o}C - combustible liquids
  - < 37.8 ^{o}C – flammable liquid
    - ASTM D975 – 38 ^{o}C No.1; 52 ^{o}C No. 2
    - CAN/CGSB 3.517 – 40 ^{o}C for types A & B
    - CAN/CGSB 3.16 – 52 ^{o}C mining diesel
    - EN 590 – 55 ^{o}C
    - ASTM D6751 – 130 ^{o}C for biodiesel; flash point test used to limit methanol content

Cold flow properties

- Important to prevent operational problems such as filter plugging at low temperatures
  - Cloud point
  - Pour point
  - Low Temperature Flow Test (LTFT)
  - Cold Filter Plugging Point (CFPP)

Cold flow properties

- Cloud point - temperature at which a cloud or a haze of wax crystals starts to appear in the fuel under the test conditions.
  - applicable to clear fuels
- Wax appearance point is similar for dark coloured fuels.
- Very safe estimate of low temperature operability.

Cold flow properties

- Pour point - lowest temperature at which a product is fluid.
- Not appropriate for low temperature operability
- Actual low temperature operability limit will usually fall between cloud point and pour point – especially if cold flow improvers are used.

Cold flow properties

- LTFT - estimates the filterability of diesel fuels at low temperatures.
- introduced in the early 1980s
- designed to correlate with one of the most common fuel delivery systems used in North American heavy duty trucks at the time
- indicates the minimum temperature at which a fresh 200 ml sample can flow through a 17 µm filter in less than 60 seconds

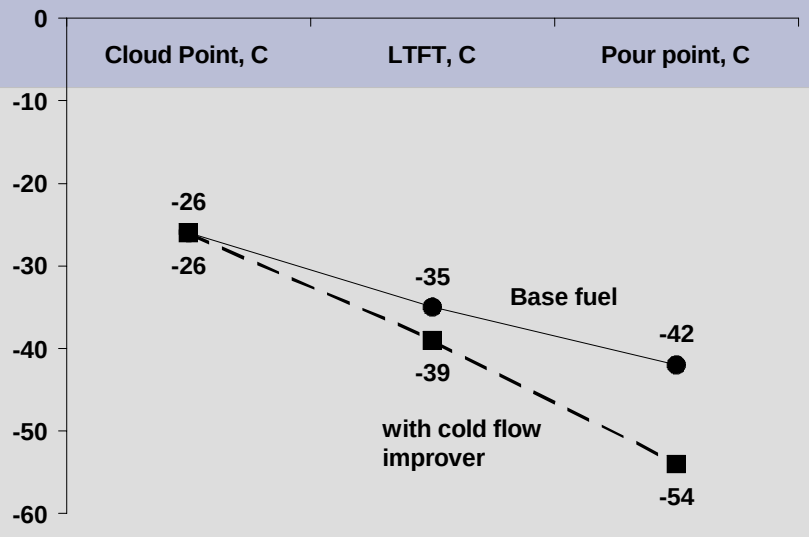
Cold flow properties

- CFPP - correlates well with European light duty trucks except when the fuel system contains an exposed paper filter or if the CFPP temperature is more than 12°C lower than the cloud point.

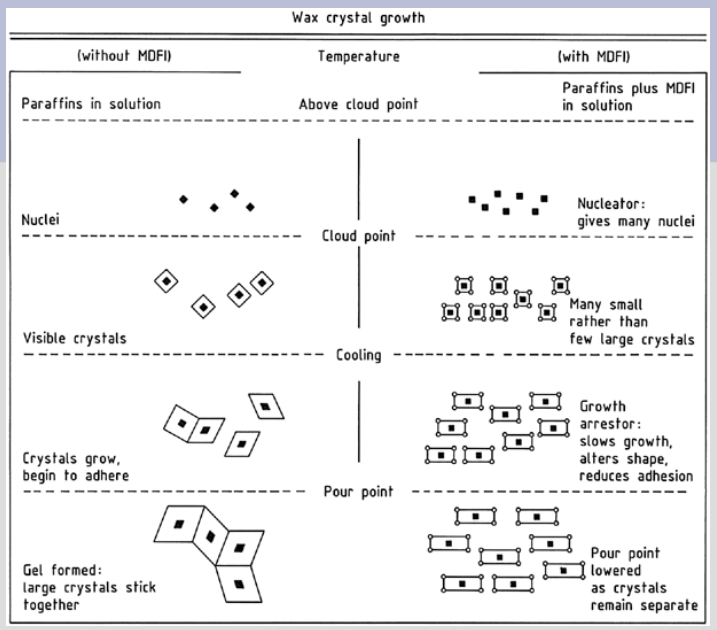
Cold flow properties

- a cooled 20 ml sample is drawn through a 45 µm screen and then allowed to flow back for further cooling. Testing continues until the amount of wax crystals that have separated out of solution are sufficient to prevent the fuel from flowing through the screen in under 60 seconds.

Cold flow properties can be improved with additives



No. 1 Diesel
Chui, 2004. Biomass & Bioenergy, 27(485-491)



Source: Ullmann's Encyclopedia of Industrial Chemistry

Cold flow properties

- Based on a 1981 CRC study:
  - cloud point and LTFT predicted the performance of base fuels well
  - LTFT was better able to predict the low temperature operability of fuels with flow improvers.
  - CFPP over predicted cold weather operability of North American vehicles tested in the CRC study.

Cold flow properties

- With the major changes to diesel engines, do the results of the 1981 CRC study apply to new diesel engine designs?
- This is currently being addressed by CRC

Ignition Quality

- Ignition Quality is characterized by the ignition delay time, the time between the start of injection and the start of combustion.
- Shorter ignition delay times = higher ignition quality.
  - improved cold starting
  - reduced white smoke on cold start
  - reduced noise
  - reduced NOx and PM

Ignition quality characterization

- A number of different tests have evolved for the quantification of ignition quality:
- Cetane number is determined with a standard single cylinder variable compression ratio diesel engine.
- Cetane index is a calculated value, which is derived from relatively easily measured fuel properties.
- Ignition delay is measured using a constant volume combustion chamber method.

Ignition quality characterization

- Cetane number - fuel is tested in a standard single cylinder variable compression ratio engine CFR (Cooperative Fuel Research) engine and compared with reference fuels.

Source: Dresser Inc.

Ignition quality characterization

- Cetane number scale is defined by blends of two pure hydrocarbon fuels.
  - Cetane (n-hexadecane), high ignition quality, cetane number of 100.
  - heptamethylnonane, very low ignition quality, cetane number of 15.
- CN = % n-cetane + 0.15 × (% HMN)

Ignition quality characterization

- Cetane number (ASTM D613) remains the industry standard for the measuring ignition quality of diesel fuels, its relatively poor precision, high cost, operator skill requirements and other drawbacks has continued to motivate the search for alternative procedures.

Ignition quality characterization

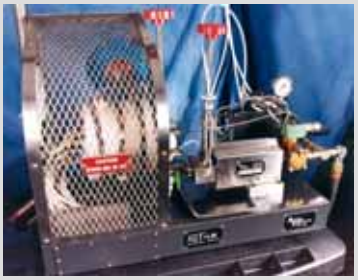
- Cetane Index
  - To avoid the expense of experimental determination of the cetane number, correlations have been developed for predicting ignition quality based on the physical properties of diesel fuels.
  - calculated from density and/or distillation characteristics
  - not reliable for fuels with cetane improver additives or with fuels whose properties differ significantly from those used to develop the correlation

Ignition quality characterization

- Cetane indices rely on an extensive database of cetane number measurements that must be updated as fuel properties change with time
- alternatives must respond to cetane improving additives
- must be able to predict cetane number well
  - cetane number is entrenched in standards and regulations worldwide.

Ignition quality characterization

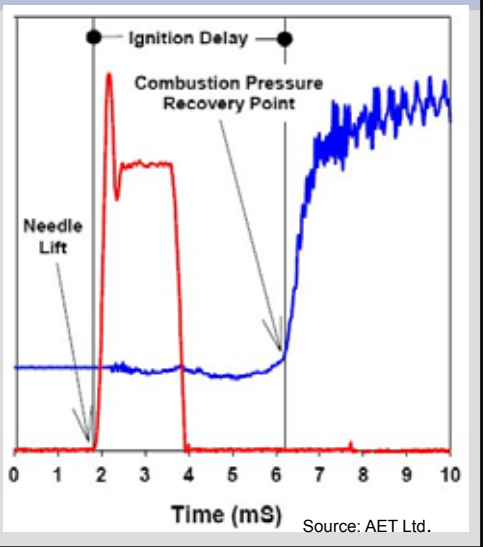
- One alternative that has emerged is a combustion-based analytical method that was originally developed at Southwest Research Institute.
- Constant Volume Combustion Apparatus (CVCA)



Source SwRI

Ignition quality characterization

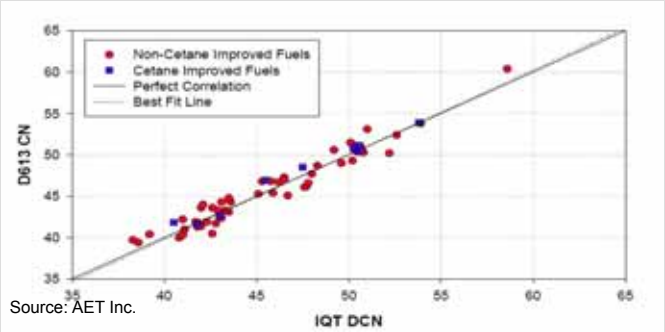
- Small specimen of diesel fuel is injected into the heated, temperature controlled constant volume chamber which has previously been charged with compressed air.
- Ignition delay time is measured.



Source: AET Ltd.

Ignition quality characterization

- Correlation of ignition delay times with cetane number data from CFR engines allows the calculation of a “derived cetane number” (DCN)

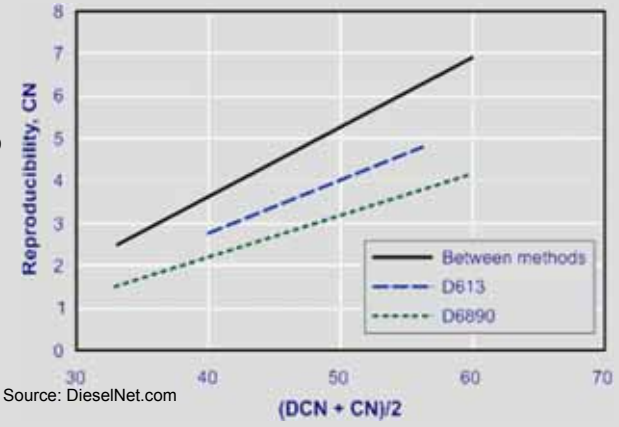


Source: AET Inc.

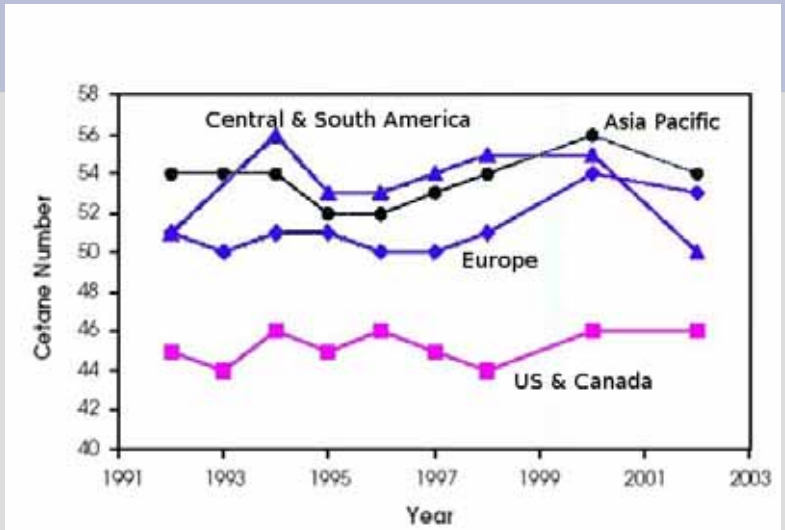
Ignition quality characterization

- ability of alternative method to precisely predict CN is important.

D613 = CFR
D6890 = CVCA
Reproducibility = maximum expected difference between two measurements of the same fuel



Source: DieselNet.com



Source: Infineum Worldwide Winter Diesel Fuel Survey 2002

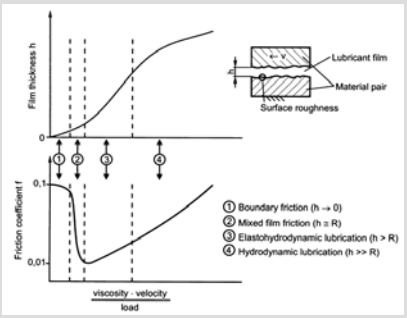
Lubricity

- All fuel injection equipment relies either wholly or partially on the fuel to provide adequate lubrication
- factors critical to ensure the long term durability and trouble free performance of fuel systems:
  - design: clearances, surface finishes and material properties
  - fuel: clean, low levels of contaminants, viscosity, lubricity

Lubricity

- Surfaces in relative motion under load:
  - Hydrodynamic lubrication: viscosity
  - Boundary or mixed: surface active compounds

Stribeck diagram



Source: Ullmann's Encyclopedia of Industrial Chemistry

Lubricity

- Lubricity is the ability of a lubricant (fuel in this case) to minimize friction between and damage to surfaces in relative motion under load
- Boundary lubricating properties of a fluid
  - Viscosity is not sufficient
- Compounds naturally occurring in diesel fuel that provide good lubricity:
  - O and N compounds improve lubricity
  - S compounds decrease lubricity

Lubricity

- Processing used to lower sulfur in diesel fuel also removes O and N containing compounds.
- Since early 1990's, additives used to restore lubricity.

Lubricity

- Testing required to ensure that levels of additive are sufficient.
- Numerous possible wear and failure mechanisms in fuel injection equipment.
  - improper hydrodynamic film formation, oxidation, adhesive wear, scuffing, abrasive wear, fatigue, corrosion, fretting and erosion
- Some of these wear mechanisms can be addressed through
  - proper equipment design,
  - proper fuel viscosity limits and
  - clean and contaminant free fuel

Lubricity

- Preventing wear associated with boundary lubrication is more challenging.
  - oxidation, adhesive wear, scuffing and fretting
- A simple test method that could test a fuel for all of these possibilities has not been developed.

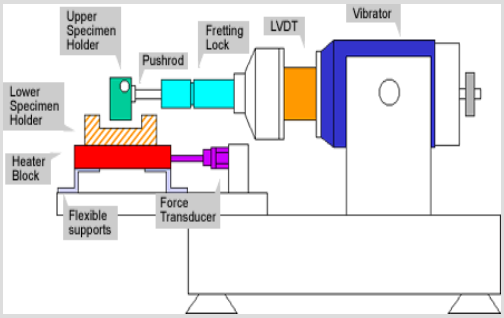
Lubricity

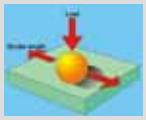
- Test options:
  - Field trials
    - Reproduce all possible failure mechanisms.
    - Time consuming and very expensive.
    - Difficult to test large number of combinations.
  - Pump rig tests
    - Reproduce most failure mechanisms.
    - Time consuming and expensive.
    - Limited number combinations can be tested.
  - Bench top tests
    - Limited number of failure mechanisms simulated
    - Quick and low cost
    - Large number of combinations can be tested quickly
    - Careful interpretation required.

Lubricity – HFRR Bench Test

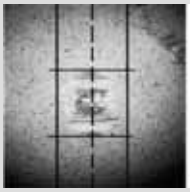
HFRR – High Frequency Reciprocating Rig

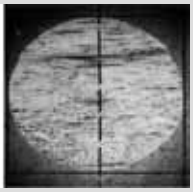
Source: SwRI





Source: Bosch



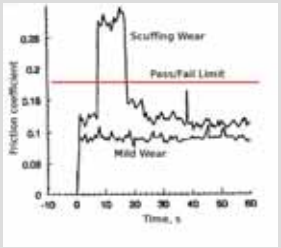


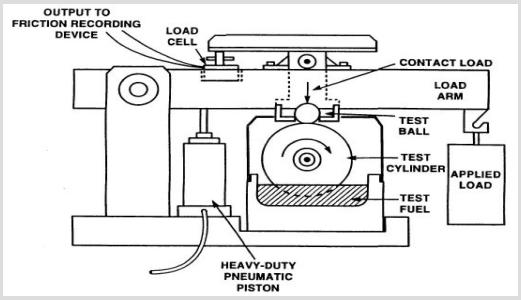
Source: PCS Instruments

Lubricity – SLBOCLE Bench Test

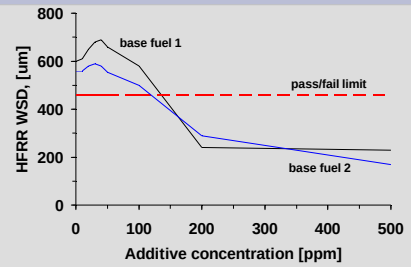
SLBOCLE – Scuffing Load Ball-On-Cylinder Lubricity Evaluator

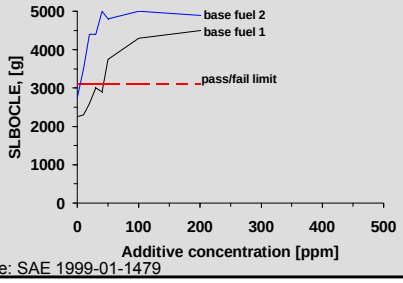
Source: Octel-Starreon LLC





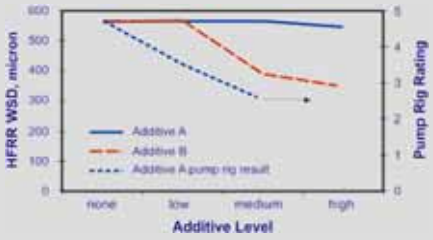
Lubricity





Source: SAE 1999-01-1479

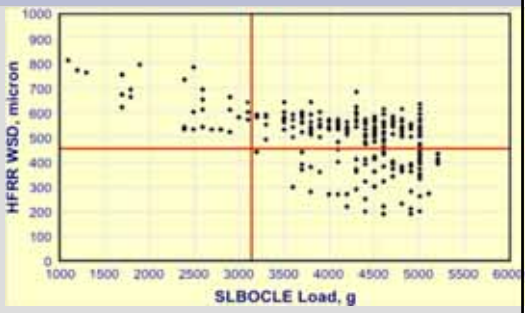
- Different bench tests can respond very differently because of different wear mechanisms and severities.



Source: DieselNet.com

Lubricity

- For SLBOCLE > 3100g, HFRR can still be > 460 µm.
- For HFRR < 460 µm, SLBOCLE will be > 3100 g.



Source: DieselNet.com
SAE paper 1999-01-1479

Sulphur

- Sulphur can effect:
  - Emissions
    - SO2
    - Sulphate increases particulate emissions
  - Corrosion and wear
  - Exhaust aftertreatment devices
    - catalysts can increase the conversion of SO2 into sulphate and cause large increases in particulate emissions
    - poisoning of catalysts and decreasing their effectiveness.

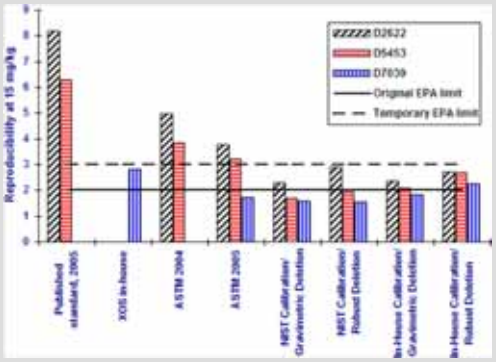
Sulphur

Sulphur in on-road diesel fuels

Source: DieselNet.com

Sulphur

- Measuring sulphur precisely at ultra low levels is a big challenge.



Source: DieselNet.com

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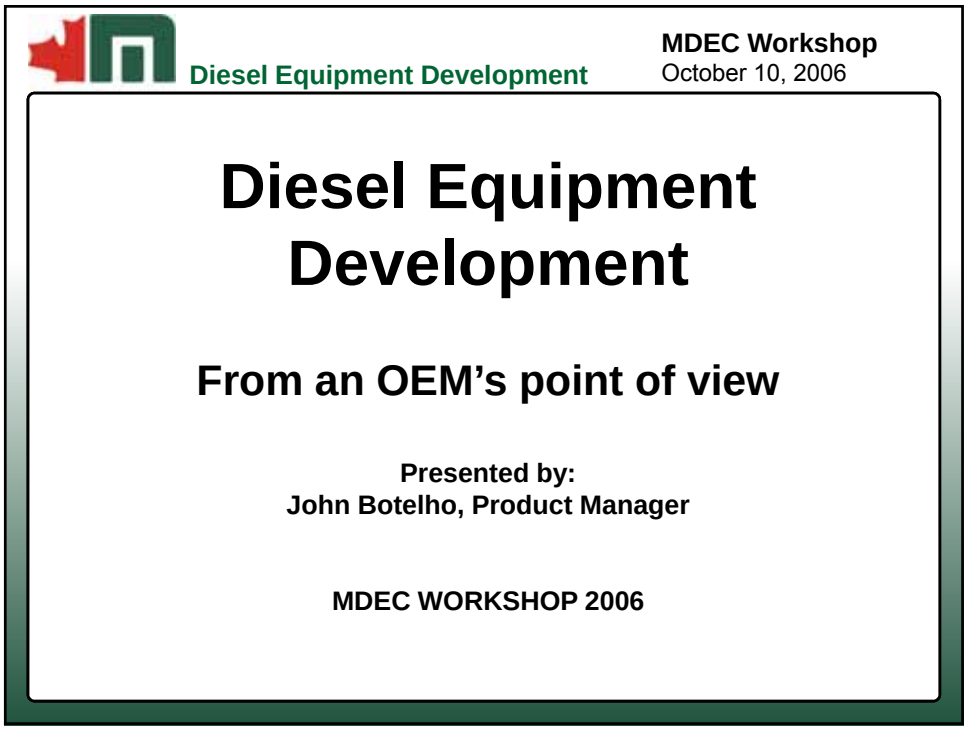
Combustion
Emissions
Fuels


MacLean Engineering
& Marketing Co. Limited
Collingwood, Ontario
CANADA


Diesel Equipment Development
MDEC Workshop
October 10, 2006
Diesel Equipment Development
From an OEM's point of view
Presented by:
John Botelho, Product Manager
MDEC WORKSHOP 2006

Diesel Equipment Development

MDEC Workshop
October 10, 2006

Dedicated U/G Mining Vehicles

- Hard rock mining
- Articulated, rubber tire, 4wd
- UTV class - Scissor Lifts etc.
- 30,000 – 55,000 lbs GVW

Diesel Equipment Development

MDEC Workshop
October 10, 2006

Diesel Equipment Development

MDEC Workshop
October 10, 2006

Diesel Engine Options

- Deutz, Mercedes & Caterpillar
- Power ratings: 147-220 hp
- Mechanical and electronic governed
- Coupled to powershift transmissions
- MSHA, CANMET, EPA certifications

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CANMET Certification

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Engine Manufacturers Concentrate on Surface Regulations and Standards

- U/G requirements do not play into engine designs
- U/G market too small for specific model

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OEM Challenges

- EPA does not have any jurisdiction U/G
- MSHA pre-approve Tier II engines but do not provide vent rates
- Customers now specifying EPA Tier III
- MSHA will not certify engines for OEMs
- Some provinces penalize vent rates for non CANMET or MSHA engines
- Engine manufactures discontinue older models

OEM Challenges

- High demand on cooling system - CAC
- 125 degrees Fahrenheit ambient rating
- Hood line – visibility, access to cleaning coolers
- Large air cleaners and exhaust components
- EGR to add to cooling requirements

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OEM Challenges

- Engine manufactures fear changes related to fuel management systems
- Barometric sensors go out of range after minus 2,000 ft BSL
- Data logging after emergency shut-down
- Automotive standards for wiring and connectors

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Reducing Potential Fires

- #1 concern from end users and OEM
- HTI coating on exhaust manifold and turbo
- Exhaust shielding and wraps
- Over-crank starter protection
- Remote mounted filters
- Hot side – cold side design

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Exhaust Shield / Wrap

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Fire Prevention – “Hot side – Cold side”

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Noise Emissions

- More requests for enclosed cabs
- Better sound suppressing mufflers
- Quieter engines
- Larger, slower cooling fans
- Noise level benchmarking

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OEM Wish List

- Single engine certification body
- Standardization of vent rates and rules
- Design changes related to U/G parameters
- Design changes related to reducing fires
- More flexibility in the electronics
- Quieter engines

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2 Years Warranty

Engine Pictured with Optional Equipment


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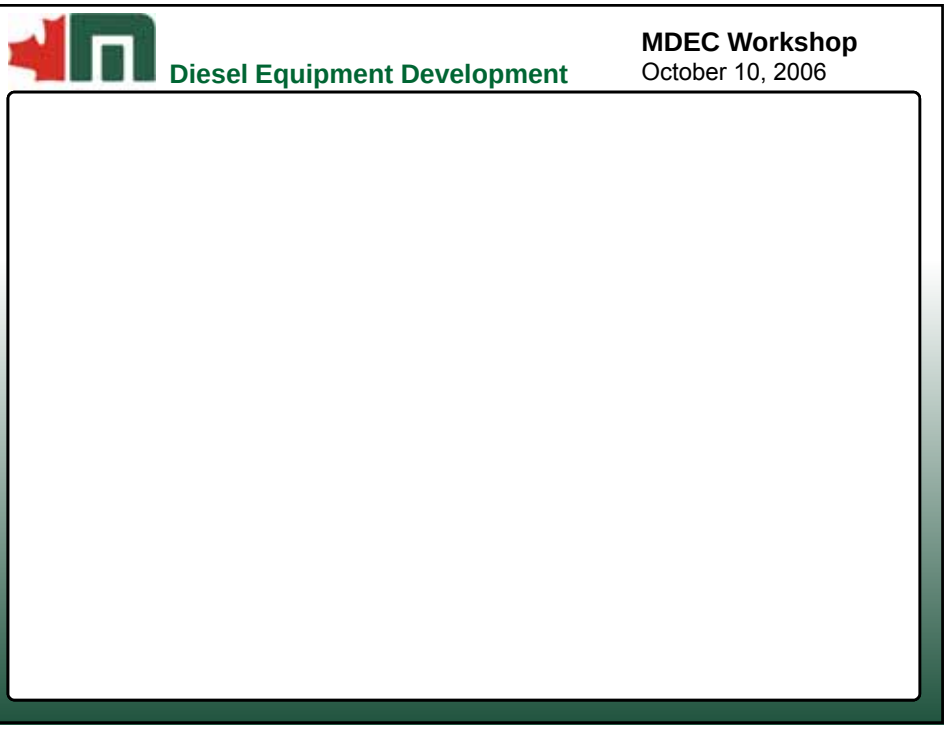
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MAINTENANCE TIPS, UNDERGROUND MINING ENGINES

SERENO VORANO
TERRITORY MANAGER
INDUSTRIAL/MINING,
NORTHERN ONTARIO

CUMMINS EASTERN CANADA LP

Don't Throw Away a Good Filter Just Because it Might Look "Dirty"

Although this air filter may look "dirty" – It can go plenty more miles. Installation of a restriction indicator can save you money and time.

260

Two of the most common air cleaner servicing problems are:

1. Over-servicing: the least efficient time in the life of the filter is when it is new. Filter elements increase in efficiency as dust builds up on the media.
2. Improper servicing: your engine is highly vulnerable to abrasive dust contaminants during the servicing process when the filter is removed from the housing. A leading cause of engine damage is due to careless servicing procedures.

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Why Service By Restriction?

Proper air cleaner servicing will result in maximum engine protection against the ravages of dust. Proper servicing can also save you time and money by increasing filter life and dust cleaning efficiency.

By using proper filter restriction measurement tools you will use the full life of the filter at maximum efficiency. DON'T BE FOOLED by filter appearance: it should look dirty.

262

The only way to determine when a filter is plugged or plugging is to measure the restriction on the system with the engine working at max airflow.

263

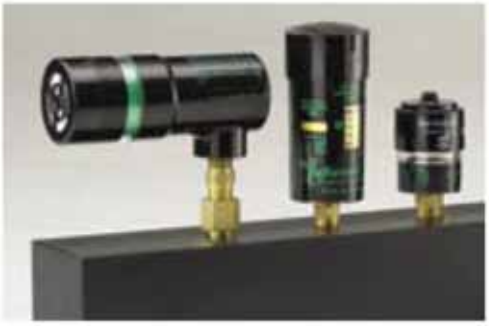
Use a Filter Service Indicator for Maximum Filter Life

Filter service indicators are easy to mount on the air cleaner, in the ducting or remotely. Over-servicing and excessive handling of the filter can lead to filter damage resulting in intake contamination from ambient dust, and/or increased service cost, time and material. In contrast, filter service based on restriction readings can enable you to obtain:

- The longest life possible from the filter
- The best engine protection.

264

Filter Service Indicators Reduce Air Filter Maintenance Costs



Replacing filters based on restriction readings can reduce your maintenance costs significantly. Visual inspection of air filters is not adequate and should not dictate service life.

265

What is the Purpose of a Safety Filter?

Safety filter…Secondary element…Inner filter… Spare filter? These filters go by many names…

266

A safety filter backs up the primary (main) filter and protects the engine while the primary filter is out of the housing during service. The engine should never be run with only a safety filter in place.

The safety is NOT a spare filter! Its purpose is to protect the engine if something goes wrong with the primary (main) filter. Until then, it quietly does its job.

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CLEANING OF HEAVY DUTY AIR FILTERS

FACTORS TO CONSIDER BEFORE YOU DECIDE IF CLEANING IS RIGHT FOR YOUR BUSINESS.

FLEETGUARD, AND MANY OTHER FILTER MANUFACTURERS DISCOURAGE THE PRACTICE OF CLEANING AIR FILTERS AND DO NOT WARRANT CLEANED AIR FILTERS.

NONETHELESS, SOME EQUIPMENT OWNERS AND MAINTENANCE SUPERVISORS BELIEVE THAT CLEANING AND RE USE OF HEAVY DUTY AIR FILTERS CAN LOWER OPERATING COSTS.

BEFORE YOU DECIDE TO CLEAN YOUR FILTERS, CONSIDER THE FOLLOWING FACTS.

268

Proper use of a quality air filter restriction gauge and adherence to OEM recommended air filter change guidelines will provide the maximum life out of the air filter element and the engine/equipment that the filter is protecting.

Cleaning your air filter will reduce the dust holding capacity compared to a new air filter. Dust capacity can drop up to 25% after the first cleaning, with additional capacity loss after each subsequent cleaning.

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BUT, if you decide to clean your air filters…..

Select a reputable commercial cleaning service that uses cleaning and handling practices proven to be effective for your filters and applications. It is recommended that this business offer a warranty for the cleaned filter, since FLEETGUARD and most other filter manufacturers will not warranty a cleaned filter. Before any type of cleaning, a visual inspection of the filter is needed. If there is any damage to the filter body, gaskets, or endplates, do not clean or re use. Discard the filter.

270

Loss of dust capacity shortens the useable service interval of the filter leading to more frequent service, which in turn adds additional risk of miss-service and/or accidental dust ingestion.

The air filter media can be weakened as a result of cleaning, which could cause ruptures. Even the smallest rupture will cause the filter to be less efficient and may allow enough dust into the engine to cause serious damage, downtime and rebuilds.

271

On highway air filters should not be cleaned since the contamination encountered over the road (fine particles and soot material) is very difficult to remove from the air filter media. On-highway filters that have been cleaned, generally display a dingy, dirty color due to the retained contaminant. Filters in this condition generally have marked reductions in dust capacity as compared to a new air filter. Cleaning to the point of yielding a “like new” appearance will most likely result in damage to the air filter media.

272

Safety air filters should NEVER be cleaned since the safety filter is the last barrier to contaminant before it reaches your engine.

The useful life of a safety air filter is equivalent to three changes of the primary air filter, or one year of continuous service, whichever occurs first!!

Extra handling of air filters could inadvertently cause damage. Proper inspection of cleaned elements is of vital importance for the proper operation of the air cleaner system.

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Generally, the commercial air filter cleaning businesses do not want to clean air filters that have been used to the OEM recommended change point (20-30 inches water) restriction. This fact encourages more frequent filter service and leads to the problem associated with too frequent opening and closing of the filtration system. Utilizing the maximum life of the air filter is your best practice for gaining the maximum, cost effective engine protection.

274

Lube Filter Installation Instructions

It is extremely important to follow the manufacturers' installation instructions when installing lube filters on heavy duty applications due to the pressures, vibrations and filter weights associated with the application. Both under-installation and over-installation torque can contribute to problems while the filter is in service. Any failures due to improper installation are not covered under the Fleetguard warranty.

Under-Installation

Insufficient installation torque can contribute to the filter backing off the head, allowing the sealing gasket to leak or blow-out of the retainer seat while in service, resulting in oil loss, and ultimately engine failure due to lack of lubrication.

Over-Installation

Excessive installation torque contributes to high removal torque requirements and removal problems. Also, excessive installation torque can damage the filter canister resulting in a stress point and shell failure. Cracking of the shell results in oil loss and engine failure due to lack of lubrication.

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Installation Using Number of Turns after Gasket Contact:

1. Remove old filter using a filter wrench.
2. Clean filter base, ensuring that all the old gasket material is completely removed.
3. Check the filter mounting spud for tightness. (**A loose mounting spud can result in the filter vibrating loose during service resulting in engine damage.)**
4. Apply a thin coat of clean engine oil to the gasket sealing surface of the new filter. Press the gasket firmly into the gasket retainer grove while lubricating the sealing gasket. (**Do Not Use Grease. The use of grease can result in oil leakage between the sealing gasket and the lube filter head.)**
5. Carefully read the installation instructions printed on the outside of the filter to determine the number of turns the filter must to be rotated past gasket contact for proper installation and gasket compression.

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6. Pre-fill the new filter with clean lube oil per OEM recommendations.
7. Spin on the new filter until the sealing gasket makes contact with the sealing surface on the lube filter head.
8. Mark a reference point on the filter and head to identify the point that the sealing gasket first makes contact with the sealing surface of the head.
9. Rotate the filter the number of turns past gasket contact indicated by the installation instructions printed on the side of the filter canister.
10. Start the engine and check for oil leakage around the sealing gasket and filter assembly.

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PROBLEMS ARISING WITH LOW SULPHUR FUEL (ALSO,JET A, KEROSENE)

LOW SULPHUR FUELS THAT ARE COMING INTO USE, WILL CONTRIBUTE TO MECHANICAL FUEL SYSTEMS (FUEL INJECTION PUMPS,FUEL TRANSFER PUMPS, INJECTORS) TO HAVE SHORTER OPERATIONAL LIFE.

TO HELP PREVENT THIS, FUEL LUBRICITY ADDITIVES WILL HAVE TO BE USED IN THE FUEL USED.

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Fleetguard
FS20000
Slow Release Lubricity-Enhancing Fuel System
Fleetguard FS 20000
The FS20000 Advantage
• Enhances Fuel Lubricity for Life of Filter
• Provides Lubricity Enhancing Additive with Patented Slow Release Technology
• Removes Both Free and Emulsified Water
• Protects Fuel System from Abrasive Wear Particles
• Unique Thread Size
Cummins
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What is Lubricity?
How does the FS20000 work?
FS20000 Applications
FLEETGUARD FAMILY OF BRANDS
Specifications
Service Parts
Cummins
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Why use FS20000?

Lower Operating Costs: Fuels with low lubricity such as Jet A can drastically reduce the pump life in certain fuel systems. The FS20000 can reduce operating costs by greatly enhancing fuel lubricity for improved fuel pump life, even when running on light fuels such as Jet A.

Increased Uptime: The assurance of having a lubricity enhancing additive consistently added to fuel, with no measuring and pouring required of mechanics or drivers, ensures increased uptime.

281

SUMMARY, AIR FILTERS

A COMMON PRACTICE STILL USED DURING MAINTENANCE INSPECTIONS, IS TO REMOVE THE AIR FILTER ELEMENT AND INSPECT IT.

THIS WILL EVENTUALLY LEAD TO ENGINE DAMAGE.

WHEN FILTER ELEMENT IS REMOVED, SOME DIRT FALLS OFF AND ENTERS THE OUTLET TO ENGINE INTAKE.

FOLLOW THESE STEPS WHEN CHANGING FILTERS WITHOUT A SAFETY FILTER.

1. REMOVE THE AIR INTAKE PIPE FROM THE AIR CLEANER, AND COVER THE PIPE TO PREVENT DIRT FROM ENTERING.
2. REMOVE THE ELEMENT, LOOK FOR SIGNS OF AIR LEAKAGE (DIRT) AT THE GASKETS. CLEAN THE HOUSING WITH A DAMP SHOP TOWEL AND MAKE SURE THERE IS NO LOOSE DIRT PRESENT.
3. INSTALL THE NEW FILTER MAKING SURE IT SEATS CORRECTLY.
4. RE-INSTALL THE AIR INTAKE PIPE AND TORQUE THE HOSE CLAMPS.
5. RE SET THE RESTRICTOR INDICATOR .

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SUMMARY, LUBE OIL FILTERS

ALWAYS!! FILL LUBE FILTER WITH CLEAN OIL, AS SPECIFIED BY THE ENGINE MANUFACTURER, BEFORE INSTALLING FILTER ON ENGINE.

IF YOU CANNOT FILL OIL FILTER, (ie, FILTER IS MOUNTED UPSIDE DOWN ETC.) BEFORE STARTING ENGINE, DISCONNECT THE FUEL SOLENOID OR SHUTDOWN SYSTEM,

CRANK ENGINE UNTIL OILPRESSURE IS SHOWN ON THE OIL GUAGE. RECONNECT SHUTOFF SYSTEM AND START ENGINE.

283

Valve and Injector adjustments

Proper clearances for valves (and injectors, if required) are essential for the engine to run correctly, and to keep the emission levels low from the engine.

Older engines required this adjustment every 250 hrs.

Newer Electronic Tier 2-3 engines only require this every 5000hrs!!!

284

Oil and Oil filter, Fuel Filter, Coolant Filter and SCA concentration change intervals

Many of the new Tier2-3 engines require servicing of the above components at 500 hrs.

If you are performing these services at less than the recommended time intervals, you are wasting money!!!

Supplemental Coolant Additives (SCA) are essential to prevent cylinder wet liners from pitting.

Test kits are the best way to check the SCA concentration.

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Final thoughts

ALWAYS, ALWAYS!!! Consult, and follow the engine manufacturer's Operation and maintenance manual, for the correct maintenance schedule for a particular model engine.

Engine designs change from time to time, so what you may have been doing two years ago in regard to maintenance may not be valid today on a newer similar engine.

Small steps can mean giant savings in the end, and lower operating costs.

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Information presented here is available from:

FLEETGUARD www.fleetguard.com.

DONALDSON www.donaldson.com.

Cummins Inc.. www.cummins.com.

THANK-YOU FOR YOUR TIME

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