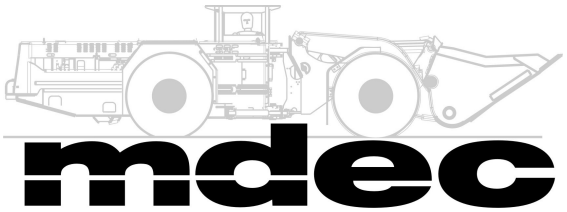
19th ANNUAL MDEC CONFERENCE
Toronto Airport Marriott Hotel, Canada
October 8 – 10, 2013

MDEC DIESEL WORKSHOP
Emissions Testing: Best Practices, Methods and Maintenance

PRESENTED BY: Brent Rubeli of NRCan
Sean McGinn of MKNIZD Factors Inc.

COORDINATED BY: Mahe Gangal & David Young of NRCan

OCTOBER 8, 2013



MDEC Diesel Workshop

Diesel Emissions Testing: Best Practices, Methods, and Maintenance

Toronto Airport Marriott Hotel
Ontario, Canada

Tuesday, October 8, 2013

07:30 – 08:30 Breakfast and Registration

08:30 – 10:15 Welcome and Introduction – Mahe Gangal, Co-chair MDEC Conference

- Fundamentals of engine emissions testing, Brent Rubeli, NRCan
- Practical emission-based maintenance, Sean McGinn, MKNIZD Factors Inc.

10:15 – 10:45 **Coffee Break**

10:45 – 12:00 Video Session: Several videos demonstrating in-use testing will be shown

12:00 – 13:00 **Lunch**

13:00 – 14:30 Hands-On Technical Sessions – Participants will be divided into two groups. Two concurrent sessions will be run with participants.

Group A - Gas analyser and emission measurement technology (Brent Rubeli)

Group B – Diesel engine technology and the six systems approach to emissions testing (Sean McGinn)

14:30 – 15:00 **Coffee Break**

15:00 – 16:30 **Group A and B**

Discussion and Conclusion, David Young, Secretary/Treasurer MDEC

Diesel Emissions Testing: Best Practices, Methods, and Maintenance

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Contents

2. Video Session

This will include several videos demonstrating emissions testing, test procedure development, baseline emissions testing and testing of aftertreatment devices including Tier 4 engines with selective catalytic reduction (SCR)

3. Hands-On Technical Sessions

Participants will be divided into two groups, A and B. Two concurrent sessions will be run.

Group A: Gas Analyzer and Emissions Measurement Technology (Rubeli). This session will demonstrate to participants the types of emissions measurement technology commercially available to the mining industry and provide them with an opportunity to learn how to start, warm-up, calibrate and use each type of analyzer system correctly. A series of videos will also be shown highlighting the different analyzers in use in vehicle testing.

Group B2: Diesel Engine Technology and the Six Systems Approach to Emissions Testing (McGinn). This session will familiarize participants with the basics of diesel engine operation and emissions-based maintenance through the Six Systems approach developed by the DEEP program. A series of videos will be shown highlighting the best practices for engine emissions testing and exhaust aftertreatment performance evaluation.

MDEC – 2013
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Natural Resources Canada | Ressources naturelles Canada

Field Emissions Testing of Engines and Aftertreatment: Best Practices, Methods and Maintenance

Brent Rubeli

Natural Resources Canada

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Diesels Underground

- New engines destined for underground use must pass minimum type certification:
  - US EPA
  - MSHA
  - CAN/CSA
- In-use engines ar
  underground for emissions.

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Certification Testing

- Pass fail criteria (CSA)
  - CO – 2500 ppm
  - NOx – 1500 ppm
  - DPM – 150 mg/m^3
- Prescribed ventilation recommendation based on multi-mode emissions test data.

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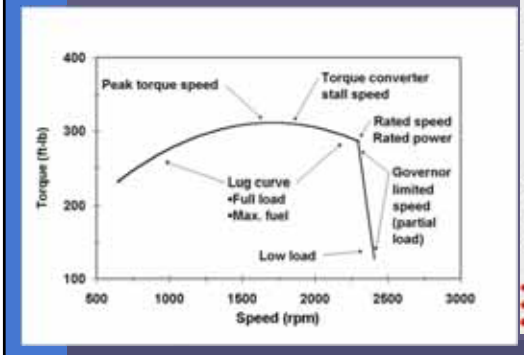
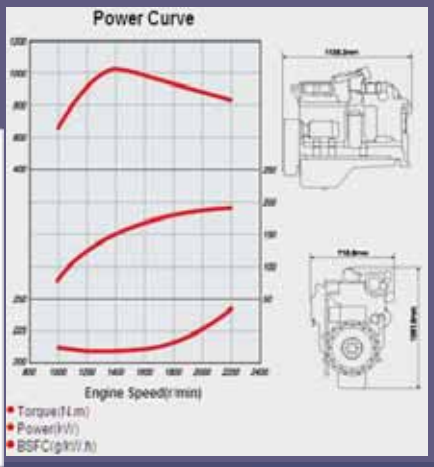
Where to test?

- Reflect "real world" engine performance.





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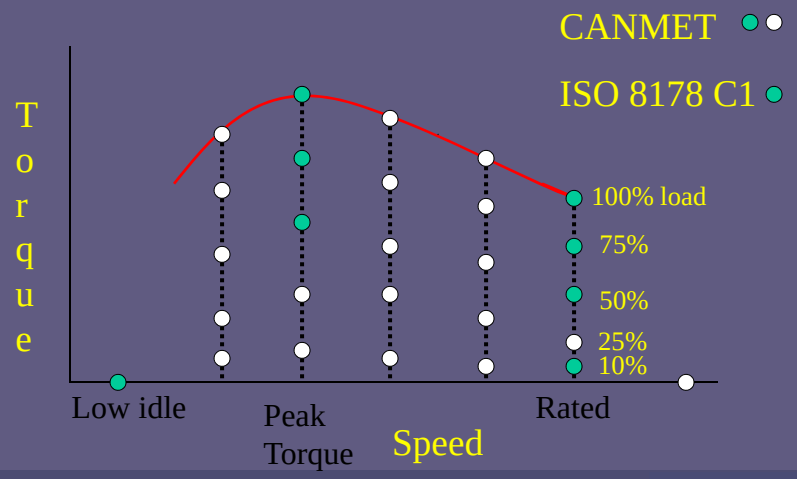
Certification Test



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Ventilation Certificate

Example of a CANMET Approved Engine Ventilation Rates

Engine Manufacturer: Detroit Diesel
Engine Model: DDEC 8V-2000TA, R0837K32
Governing Standard: CSA M424.2-90 (Non-coal mines)

Certificate Number	Engine Rating and Maximum Fuel Rate at Sea Level	Sulphur in Fuel - %wt.	CSA Ventilation Prescription *	
			CFM	m^3/min
1103	650 HP @ 2100 RPM fuel 213.5 lb/hr	0.05	37,000	1,047.7
			47,500+	1,345.0+
		0.10	41,000	1,161.0
			47,500+	1,345.0+
		0.20	48,900	1,384.7
		0.25	52,900	1,498.0
		0.50	72800	2,061.5
			79,500+	2,251.5+

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

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Vehicle Types

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Emissions Underground

- Mining is a confined space so poor engine emission quality can quickly become a serious safety hazard.
- Legislated in-use testing:
  - Catches defects or failures.
  - Verifies maintenance.
  - Confirms type certification emission levels are being maintained by the engine.

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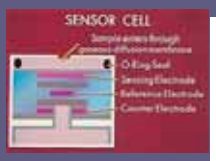
Underground In-use testing

- Over and above legislative requirements, some mines use in-use testing for predictive maintenance and proactive air quality.

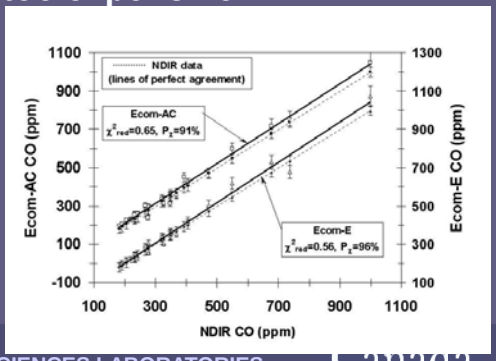
Test Equipment

- Stain tubes
- Electrochemical cells
- Smoke dot
- Opacity
- NDIR / PAS



Accuracy for Mining

- EC cells are very good provided they are calibrated properly and often.
- Stain tubes have too many interferences.
- NDIR, etc are often too expensive.



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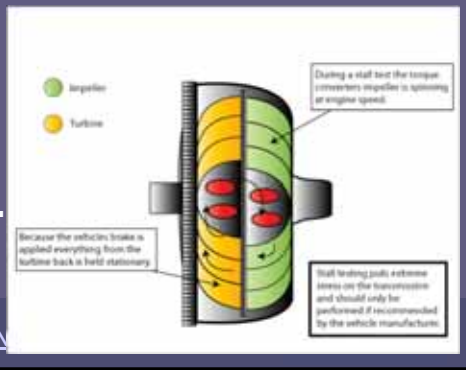
How to test - Loading

- Meaningful data is only obtained with engine under loaded conditions.
- Torque converter/hydraulic stall procedure.
- Idle does not have significant fuel delivery of temperature.
- Snap acceleration

test does achieve

full fuel but only briefly.



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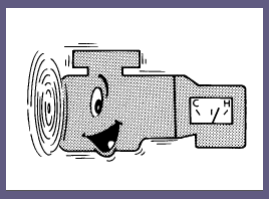
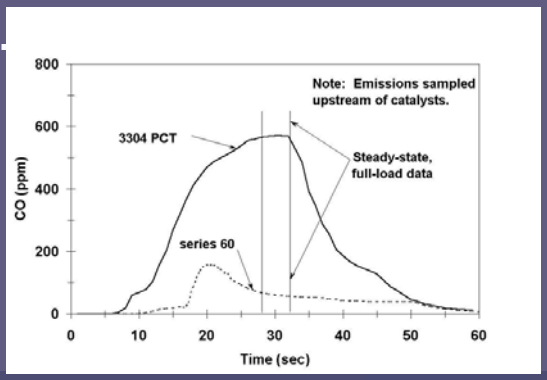
Stall testing

- This is not a trivial test!
- Safety audits, training, etc.
- Measure for target gases.
- Watch converter.





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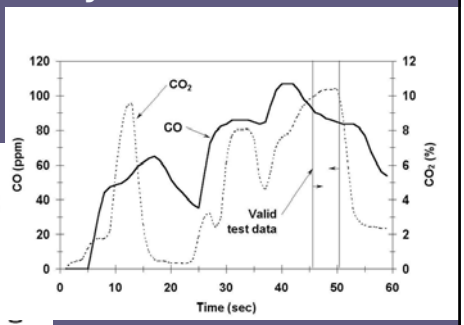
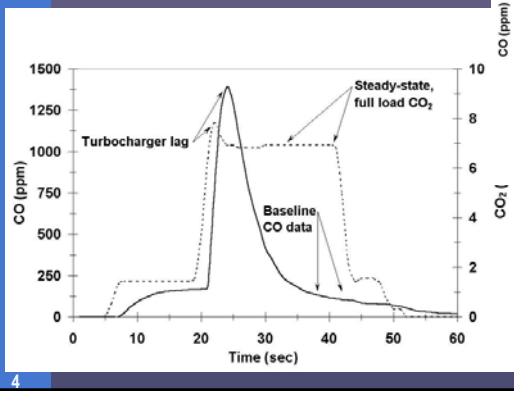
How to test - Interpretation

- Emissions must be at steady-state to be repeatable.
- Wait for CO peaks.





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NIOSH EAMP

- Emissions-assisted maintenance procedure.
- Support of emissions testing regulation.
- Defined a repeatable emissions test procedure.
- Tested field and laboratory grade instruments.
- Evaluated different engine types.
- http://www.cdc.gov/niosh/mining/topics/diesel/eamp/eamp.html

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So what will your standards be?

- Legislation first and foremost – you must comply with the test requirements in you jurisdiction.
- Why not develop your own internal guidelines for pass / fail.
- Ultimately try individual engine emissions tracking for the complete picture.

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Current Legislation

- **Example: Ontario Provincial Mining Regulation recently changed to reflect cleaner engine deployment.**
- **Undiluted tailpipe CO from 1500 to 600 ppm.**

(2) Subsections 182 (5) and (6) of the Regulation are revoked and the following substituted:

(5) An employer shall ensure that the undiluted exhaust emissions from diesel-powered equipment contain less than 600 parts per million by volume of carbon monoxide.

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Certification Engine Testing

- **MSHA has guidance.**
- **CO lug curve data.**
- **Certification tests.**

TORQUE CURVE TEST ALL TESTS AT FULL THROTTLE		
MSHA # :	7E-B090	
Engine:	Deutz F3L 1011F	
Engine Rating:	44 HP @ 3000 RPM	
Engine Speed, RPM	CO, ppm	CO2, %
3000	982	10.9
1800	1834	11.7

TORQUE CURVE TEST - ALL TESTS AT FULL THROTTLE		
MSHA # :	7E-B098-0	
Engine:	DaimlerChrysler OM 904LA	
Engine Rating:	174 HP @ 2200 RPM	
Engine Speed, RPM	CO, ppm	CO2, %
1200	1341	11.81
1400	318	10.32
1600	335	10.1
1800	299	10.09
2000	267	9.94
2200	222	9.58

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Build your own database!

Table 1. Emissions of New Equipment						
Engine	**Rated hp**	**CO2 %**	**CO ppm**	**NO ppm**	**NO2 ppm**	**Comments**
Series 60	375	6.9	139	586	31	Turbocharged, DI
Series 50	250	7.9	162	615	31	Turbocharged, DI
F8L413FW	180	9.7	91	605	15	Naturally aspirated, IDI
F8L413FW	180	7.9	95	708	23	Turbocharged, IDI
F6L912W	82	11.4	527	630	17	Naturally aspirated, IDI

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How to recognize faults

- In-use testing and diagnosis requires a knowledge base of how maintenance faults affect engine emissions.
- Effect of engine faults on mechanically-controlled engines is well known.
- Unclear how and when electronic engines would compensate for fault conditions.
- Emissions behavior could not be predicted.

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USBM

- 1985 study of simulated faults in engines.
- Combinations of faults more severe than individual faults applied separately.

PERCENT DEVIATION OF EXHAUST EMISSIONS FROM BASELINE CAUSED BY INDUCED FAULTS IN A DEUTZ F6L 912 W DIESEL ENGINE

TEST NO.	FAULT DESCRIPTION	DEGREE OF FAULT	HC	CO	NO_x	PARTICULATES* A	B	C
1-1	Intake Restriction (in - H_2O)	25	-28	+8	-15	+25	+31	+44
1-2	Intake Restriction (in - H_2O)	50	-36	+28	-12	+75	-11	+184
2-1	Exhaust Restriction (in - Hg)	3.0	+17	+1	+9	-15	+23	-6
2-2	Exhaust Restriction (in - Hg)	6.0	+2	+6	-3	-8	+16	-11
3-1	Timing Advance (from mfg. spec.)	-4°	+306	+53	-33	-4	+1037	-23

What about modern engines?

- Some uncertainty for newer engines:
  - Turbocharger / Intercooler system.
  - Electronic control system behavior.
  - Warm-up emissions.
- Test procedures for vehicles with manual transmissions and light hydrostatic drives.

CANMET-MMSL Tests

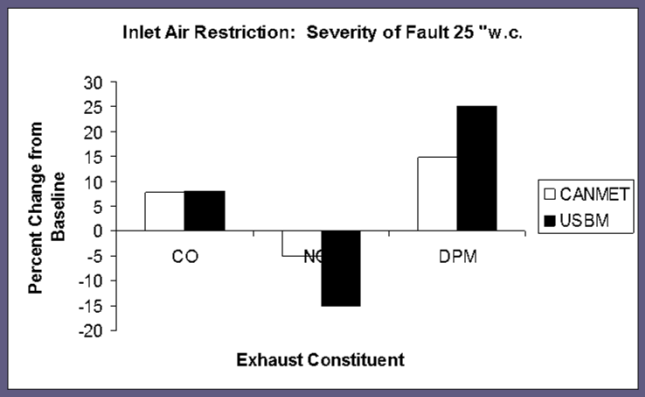
- Laboratory emissions testing.
- Deutz Engine:
  - Confirmation of some USBM work.
  - Air cooling system deficiencies.
- Detroit Engine:
  - General maintenance deficiencies.
  - Turbocharger / intercooler faults.
  - Sensor / electronics glitches.
  - Cold start and warm-up behavior.

Test Engines

- Deutz F4L912W
- Detroit 11.1L Series 60

Deutz Engine Tests (1)

- General agreement with USBM results.



Deutz Engine Tests (2)

- Air-cooled engine: cooling system faults

Operating Mode: 2300rpm & 100% load	Cooling System Fault (%)	Cooling System Fault & Restr. %
Intake Restriction	0	+60
Exhaust Restriction	0	+195
Cooling Air Outlet Temp	+8	+32
Exhaust Temperature	+11	+13
CO (% change)	+35	+56
NO_x (% change)	+2	-1
NO (% change)	+6	+3
NO_2 (% change)	-60	-77
HC (% change)	+66	+66
O_2 (% change)	0	-9
CO_2 (% change)	+1	+8
DPM (% change)	+57	+100

Detroit S60 Engine Tests (1)

- General maintenance deficiencies.
- Stable operation even with faults.
- Requires severe degree of fault.

Simulated Faults at Rated Power	Percent Change From Baseline				
Fault Description	Degree of Fault	HC	CO	NOx	DPM
Intake Restriction	+67	+8	+2	+2	+18
Exhaust Restriction	+100	+0	+19	+4	+33
Intake / Exhaust Restriction	+67 / +100	+13	+28	+8	+56
Severe Intake and Exhaust Restriction	+250 / +140	+0	+79	+15	+114
Manifold Inlet Air Temperature (Cold)	-38	+29	+0	+105	+5
Cold Inlet Air Temp (sensor disconnected)	no signal	-8	+19	-19	+58
Manifold Inlet Air Temperature (Hot)	+46	+0	-7	+21	-14
Hot Inlet Air Temp (sensor disconnected)	no signal	-8	-9	+29	-10
Fuel Temperature Sensor disconnected	no signal	-12	-5	+1	+2
Disconnect SRS sensor while running	no signal	+0	-2	+1	+0
Loss of Turbo Boost Pressure	-55	-71	+1190	-21	+867

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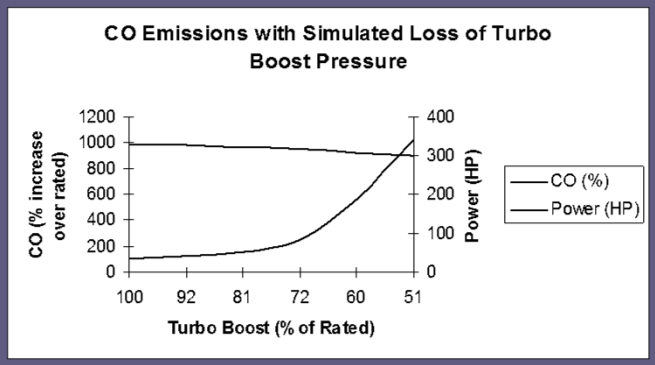
Detroit S60 Tests (2)

- Turbocharger / intercooler faults.



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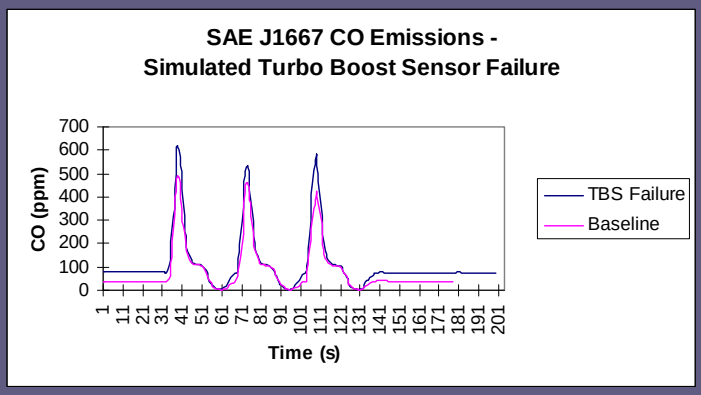
Detroit S60 Tests (3)

- Sensor / electronics glitches.



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Snap Acceleration Tests

- Some light-duty vehicles are difficult or impossible to test under load.
- 100% fuel delivery is often not achieved.
- SAE J1667 test procedure for snap acceleration based smoke emissions.
- Light extinction (opacity) meter for visual smoke measurement.
- Procedure is in-use already for Ontario, BC and other jurisdiction for highway vehicles.

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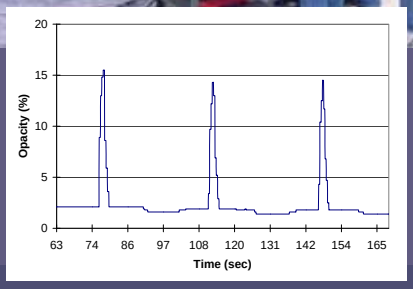
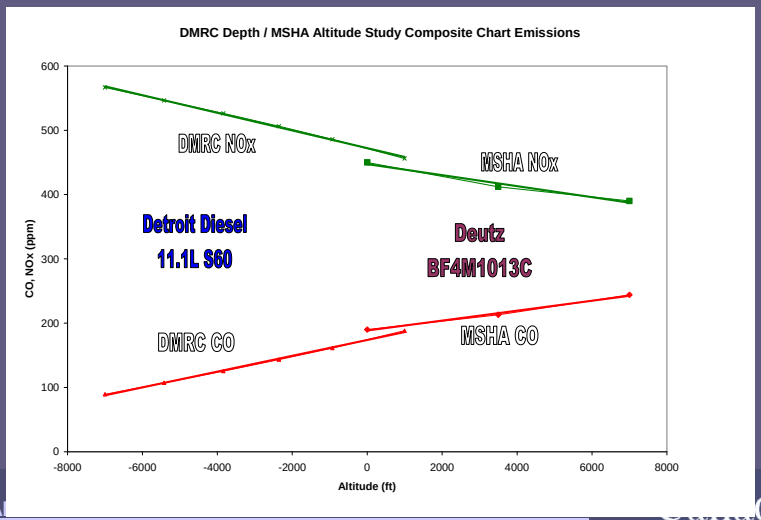
SAE J1667

Snap test of Holder diesel tractor



Altitude / Depth Effects

- **Emissions are affected by altitude.**



Role of Diesel Emission Control Technologies

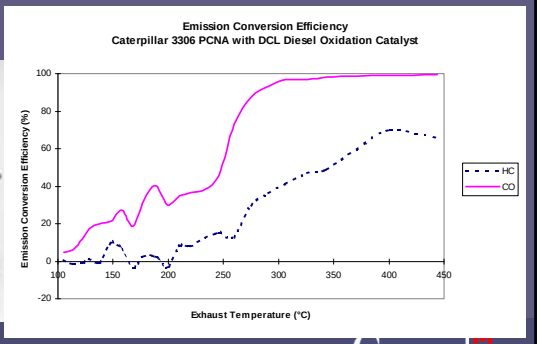
- Can address localized air quality problems.
- Control emissions at the source.
- Reduce overall mine emissions burden.
- Future regulations.
- OEM applications.

Best Available Diesel Emissions Control Technologies

- Diesel Oxidation Catalysts (DOC)
- Diesel Particulate Filters (DPF)
- Active Diesel Particulate Filters (A-DPF)
- Selective Catalytic Reduction (SCR)

Diesel Oxidation Catalyst

- Most basic type of control CO HC & some DPM only.
- $CO + ½O_2 \rightarrow CO_2$
- $HC + O_2 \rightarrow H_2O + CO_2$
- Older formulations may oxidize NO to NO_2.



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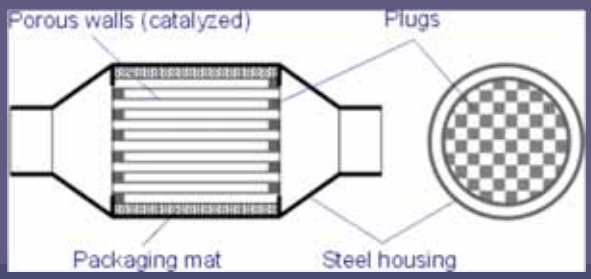
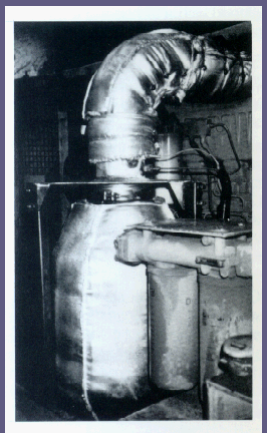
Diesel Particulate Filter (DPF)

- Ceramic monolith
- Closed channel – wall flow
- Best available control technology for DPM





MINE-X SOOTFILTER installed in a Wagner ST8B loader with a Cat 3406 PCTA engine.

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DPF - Performance – DPM filtration efficiency (% by mass)

	Mode A	Mode B	Mode C	Mode D	Average
Clean	80.3	66.7	75.9	87.1	77.5
Charged	95.5	90.0	88.9	91.1	91.4
Average	87.9	78.3	82.4	89.1	84.4

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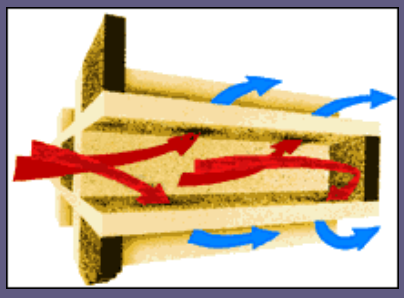
DPF Loading and Regeneration

- Collect DPM at high efficiency (>80%).
- Burn off DPM to CO_2.
- Ignition temperature very high 550°C
- Assist needed for regen: catalyst, fuel additive, active, etc.



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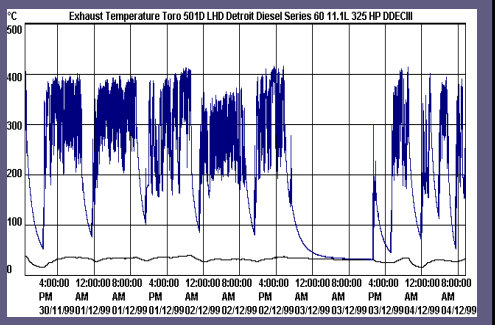
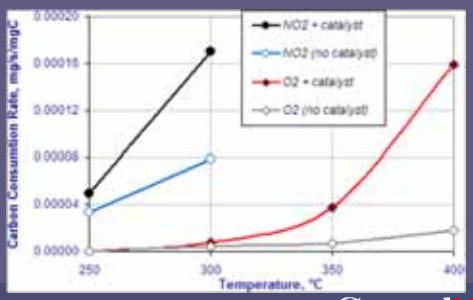
Regeneration Strategies

- Very important!
- Without periodic regeneration, DPF will clog and fail.
- This regeneration may happen automatically with sufficient exhaust temperatures – or may require external heat input.



Catalyzed DPFs

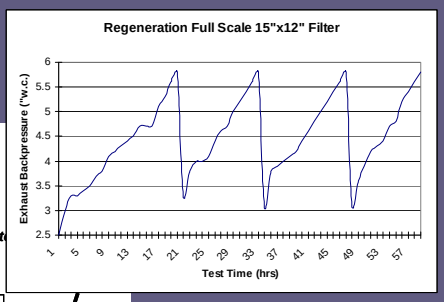
- Catalyst lowers the required regeneration temperature so that more vehicle applications can use the DPF technology
- Catalyst can be applied directly to the filter monolith – where it works on the accumulated DPM directly.

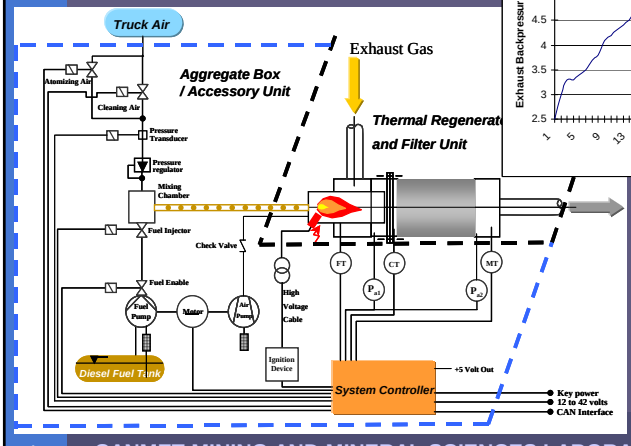


Active Regeneration - DPF

- Electrical / Diesel fuel
- On-board / exchangeable
- Additional heat input for periodic regen.

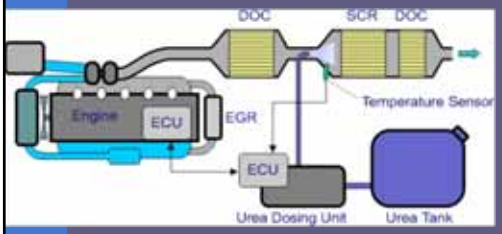
Diesel Burner for Active Regen

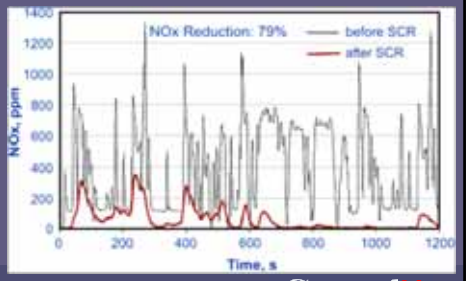




Selective Catalytic Reduction

- SCR for NO and NO_2 emissions control
- NOx reduction in lean environment
- Addition reductant sprayed into exhaust
- $4NO + 4NH_3 + O_2 \rightarrow 4N_2 + 6H_2O$
- $6NO_2 + 8NH_3 \rightarrow 7N_2 + 12\ H_2O$





SCR in U/G Mines

- Strong potential for mines with NO_2 issues.
- Field trials are currently underway.
- Urea handling and dosing.
- Dosing and feedback emissions control.

Control Technology Summary

Constituent	Oxidation Catalyst	Diesel Filter	Catalysed Filter	SCR	
CO2	0	0	0	0	
CO	60 - 80	0	60 - 80	60 - 80	
HC	60 - 80	0	60 - 80	60 - 80	
NO	0	0	0	60 - 80	
NO2	0 or increase	0	0 or increase	60 - 80	
SO2	0	0	0	0	
DPM	20 - 30	85 - 95	85 - 95	0	

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Maintenance

- Some maintenance required!
- Inspection for physical damage and emissions performance.

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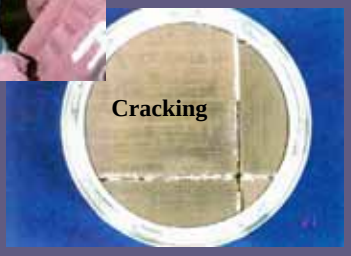
Recognizing Device Failure

- Visual inspection at regular PM service:
  - Disassembly and cleaning as required.
- Engine backpressure increase over baseline.
  - Smoking exhaust.
  - Engine performance loss.
- Emissions-based maintenance program.
  - Regularly quantify device performance.

DOC Failure Modes

- Diesel Oxidation Catalyst:
  - Clogging / masking of active sites (DPM).
  - Poisoning – fuel sulphur, metals.
  - Loss of washcoat and catalyst material.
  - Physical damage:
    - Melting of ceramic.
    - Cracking (impact / thermal).
    - Separation of metal foils – vibration.

DOC Failures



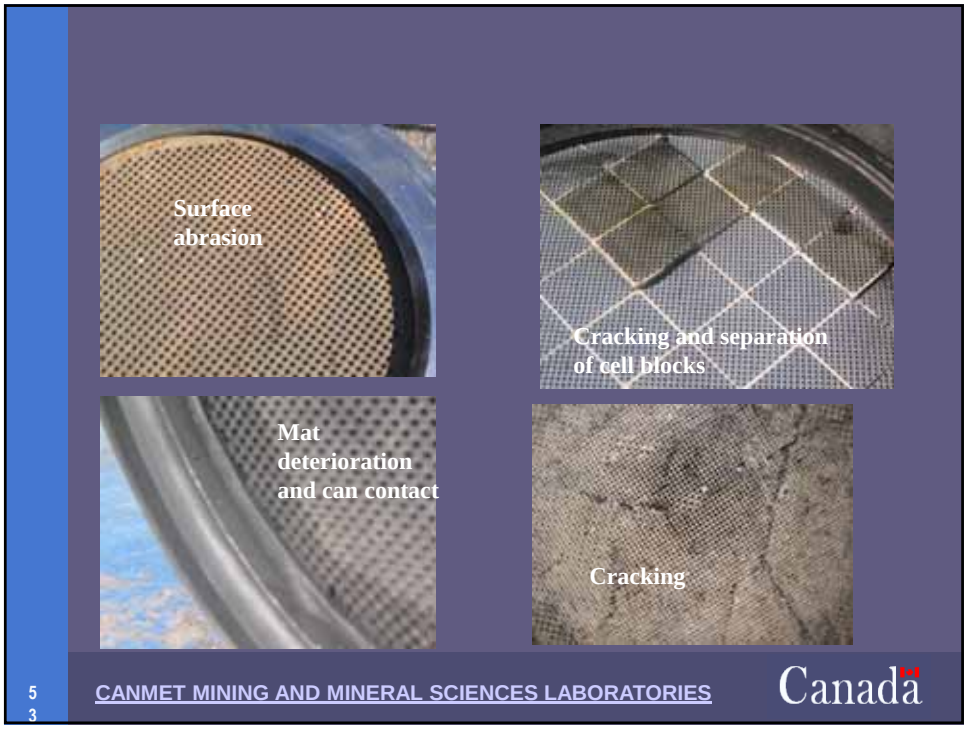
- Visual Inspection:

Particulate Filter (DPF) Failure Modes (1)

- Operational / Application:
  - Clogging DPM – insufficient regeneration.
  - Clogging ash – overdosing additive.
  - Water ingress – vehicle cleaning.
  - Oil ingress – turbocharger seal failure.
  - Melting – uncontrolled regeneration.

DPF Failure Modes (2)

- Physical Damage:
  - Surface damage:
    - Impact abrasion – mishandling.
    - Substrate contact with can or retaining rings – vibration / deterioration of mat.
  - Melting – uncontrolled regeneration.
  - Cracking – vibration / impact / thermal stress (regeneration).


Surface abrasion
Cracking and separation of cell blocks
Mat deterioration and can contact
Cracking
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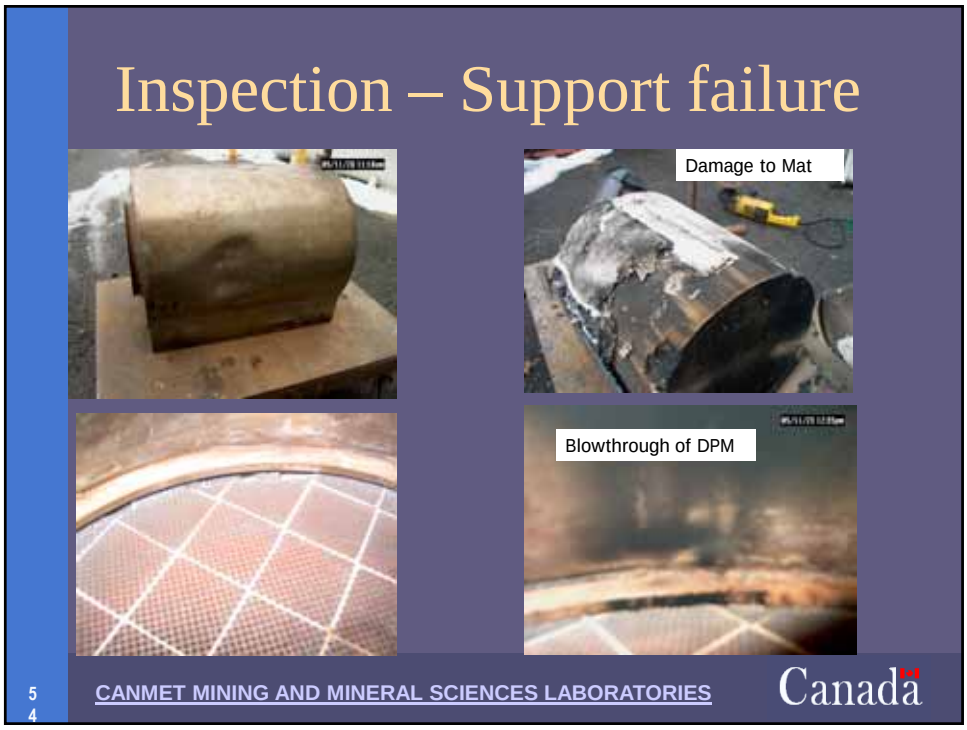
Inspection – Support failure
Damage to Mat
Blowthrough of DPM
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Emissions Testing for Oxidation Catalyst Faults

- Diesel oxidation catalysts (DOC) can exhibit several faults: poor conversion due to blockage, soot accumulation, poisoning.
- Important to maintain and verify emissions performance.
- Older DOC's may increase NO_2 emissions. This can be monitored with EC analyzer.

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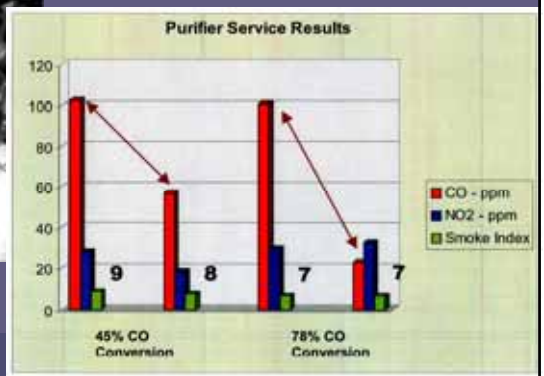
DEEP Catalyst Tests

- Systematic approach to maintenance.
- Fault diagnosis based on emissions testing.
- Testing of emission control devices.



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Catalyst Tests at Agnico

- Recent work at Agnico mine.
- Emissions testing comparing ECOM EC cell to stain tubes.
- Evidence of NO_2 formation.
- Note MSHA lug curve CO for Mercedes 904 (220ppm)

Camion 3102 (Detroit Diesel 60)		
Emission	Before Catalyst	After Catalyst
CO ppm	75	55
NO ppm	474	530
NO_2 ppm	0	56
CO_2 %	10.2	10.9

Vehicule de Service VS3104 (Merc. 904)		
Emission	Before Catalyst	After Catalyst
CO ppm	201	47
NO ppm	504	515
NO_2 ppm	0	0
CO_2 %	10.1	10.4

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DPF Fault Testing

- DPM vs smoke
- Partial vs total failure
- Smoke dot (ECOM)
- PAS EC analyzer

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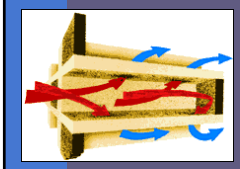
DPF DEEP Study Tests



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9

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Wound fibre DPF

- Partial failure – blowing
- Fibre material broke up
- DPM passed through filter

6
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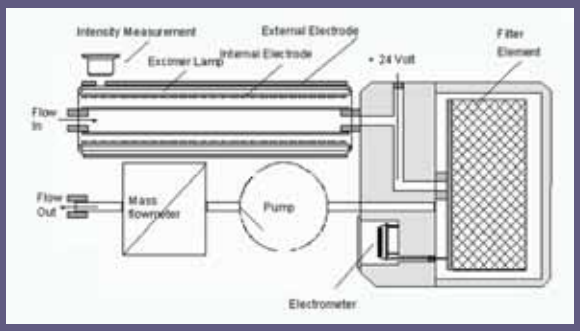
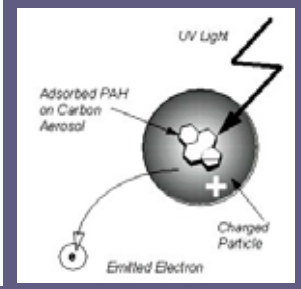
PAS EC Analyzer

- UV light responsive to PAH on carbon.
- Excitation of DPM particle.
- Expensive…..





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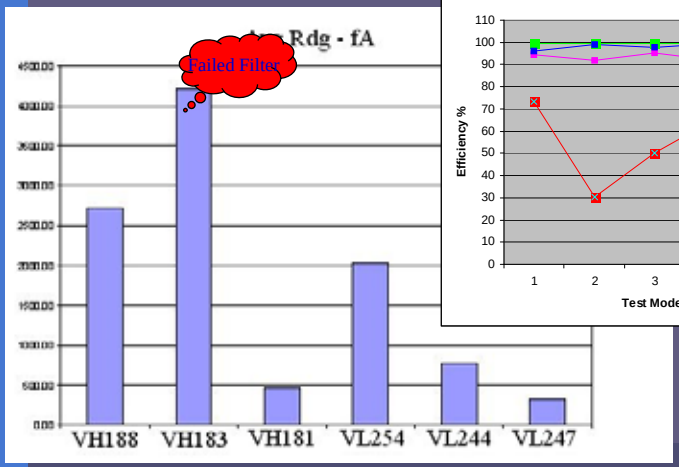
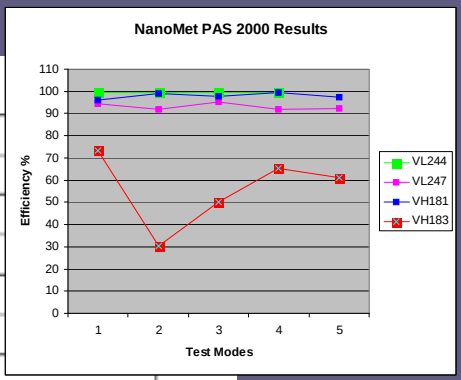
DPF Failure with PAS





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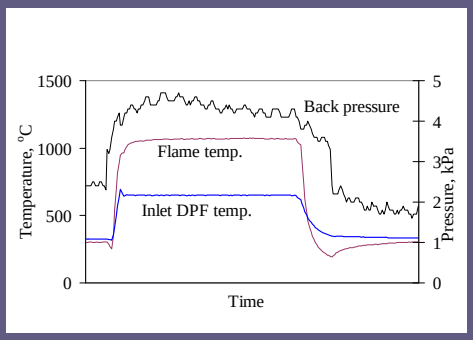
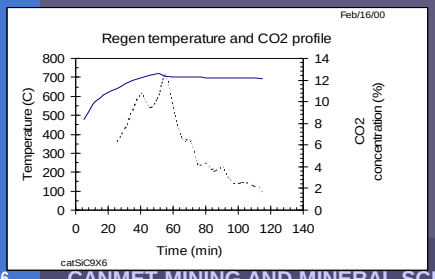
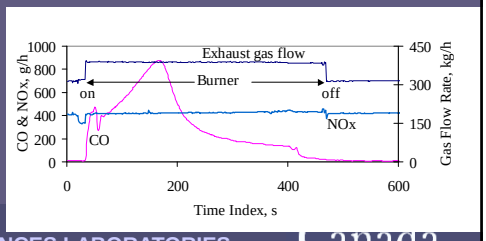
Regeneration Emissions Control

- Regeneration of filter produces emissions.
- Regeneration must take place in a controlled area with adequate ventilation.





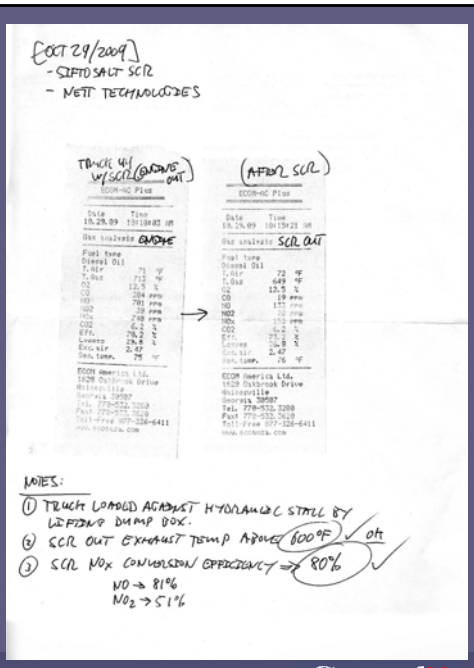


Advanced SCR Testing

- Field verification of NO / NOx reductions.
- Must be done with engine loaded since ammonia is not dosed below 250°C exhaust temperature.

SCR Test

- NOx reduction at 80% during steady state test.
- Exhaust temp high enough for dosing.
- Ammonia slip…



Conclusions

- Measurement technology is now available to reliably determine the emissions from diesel engines and aftertreatment.
- With adequate calibration, training, and safety audits; a diesel monitoring program can be implemented at any mine that will significantly improve emissions control.
- Aftertreatment devices are becoming more widespread and your mine's know-how must keep up.

Recommendations

- Start your testing program today!
- Lots of resources are available for base-lining emissions, training, etc.
- Real measurement and documentation is the only way to verify technologies and avoid maintenance by guesswork.

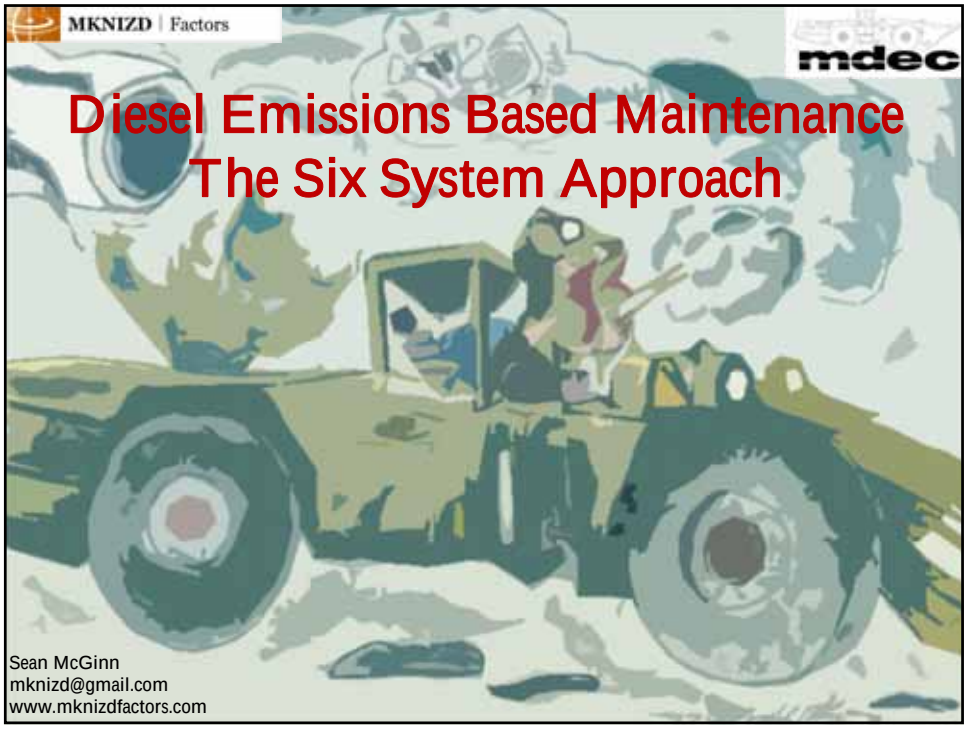
Acknowledgements

- Ontario Ministry of Labour – Mining Legislative Review Committee (MLRC).
- DEEP Maintenance Project
- NRCan Diesel Emissions Laboratory
- Vale / Agnico / Xstrata
- NIOSH
- MSHA

Resources

- DEEP Maintenance Project
  - www.deep.org
- NIOSH EAMP Procedures
  - http://www.cdc.gov/niosh/mining/topics/diesel/eamp/eamp.html
- MSHA Diesel page CO database
  - http://www.msha.gov/01-995/coal/actiontable/actiontable.asp

Questions



WHY ?

- To be able to detect operating faults in diesel engines working at underground operations using emissions measurement and performance criteria
- To be able to maintain diesel engines working at underground operations to as-certified levels (CAN/CSA & MSHA)
- To establish emissions based maintenance as the first line of defence – the primary control – in a diesel emissions management strategy

WHY ?

- Health – Safety – Environment
- Sustainable Development
- Productivity
- Operating Costs

Background

- USBM Study - 1985
- NIOSH Emissions-assisted Maintenance Program (EAMP)
- MSHA
- Australia NSW – Coal Services
- NRCan CANMET Effects of Simulated Faults
- DEEP Maintenance Project – 1999
- Noranda Technology Centre – 1996 to 2002

Background

- Noranda Technology Centre consultations with NRCan CANMET in 1996
- Dr. Mahe Gangal recommendations for development of emissions verification tool:
  - **Steady-state sampling** for minimum 60 seconds at rated speed and power
  - Baseline individual emissions and combine to use as surrogate for EQI formula ($CO/25 + NO/25 + NO_2/3$) for verification against engine certification
  - Use of EC cell gas analyzer with heated condensate trap capability
  - UGAS System - United States patent 6,079,251

Emissions Based Maintenance

- DEEP Maintenance Project
- Engine specific PM's
- Quantified results
- Emissions
- Power, pressures, temps
- Measure-Measure-Measure
- Baseline and Control

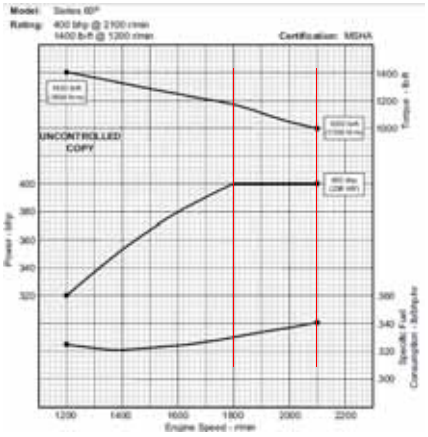
SIX SYSTEMS

1. **INTAKE**
2. **EXHAUST**
3. **FUEL INJECTION**
4. **COOLING**
5. **LUBRICATION**
6. **ECM & CONTROLS**

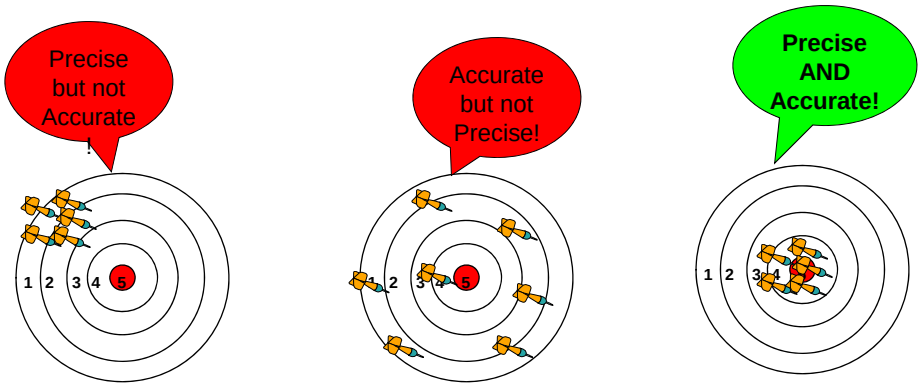
Emissions Measurement

Emissions Measurement

Rated @ full power – steady state



Emissions Measurement



Instrument Error

Process / Mechanic Error

Measurements you can make good decisions with!

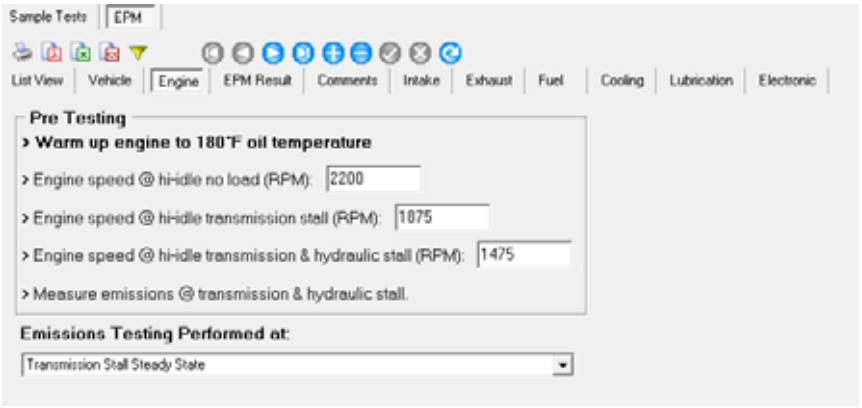
Emissions Measurement

Interpreting Emissions Test Results

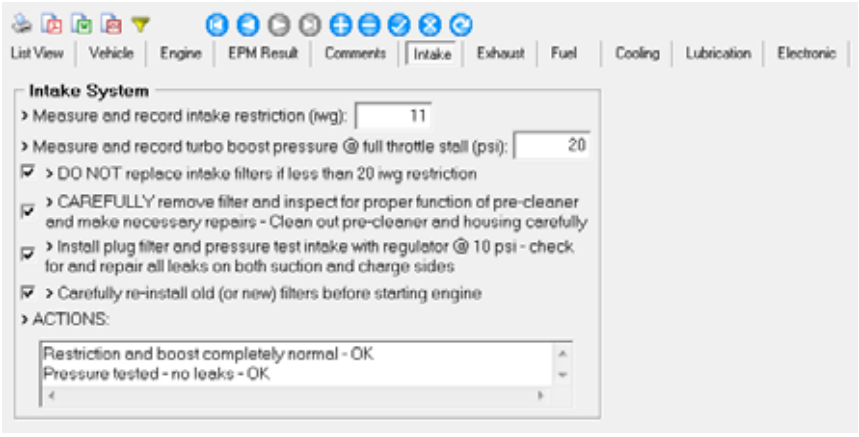
EPM Results

Param Name	Inlet DOC	Outlet DOC	TV
SMOKE	8	8	7
O2	11.1	10.9	11
CO	224.7	85.1	100
NO	266.3	275.8	300
NO2	26.1	25.2	25
CO2	7.3	7.4	6
T.GAS	676	677.1	600
Pressure	1	0.9	
MEQI	28.3	22.8	
NOx	292.4	301.1	325

6 Systems – Power Pre-Check



6 Systems – Intake

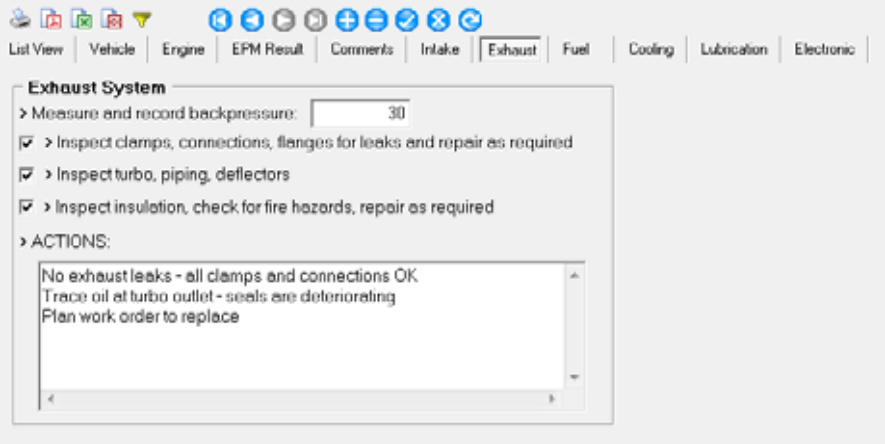


6 Systems - Intake

- Visual Inspection
- Check clamps and piping
- Don't overservice on replacement

- Measure Restriction
- Suction and Charge Sides

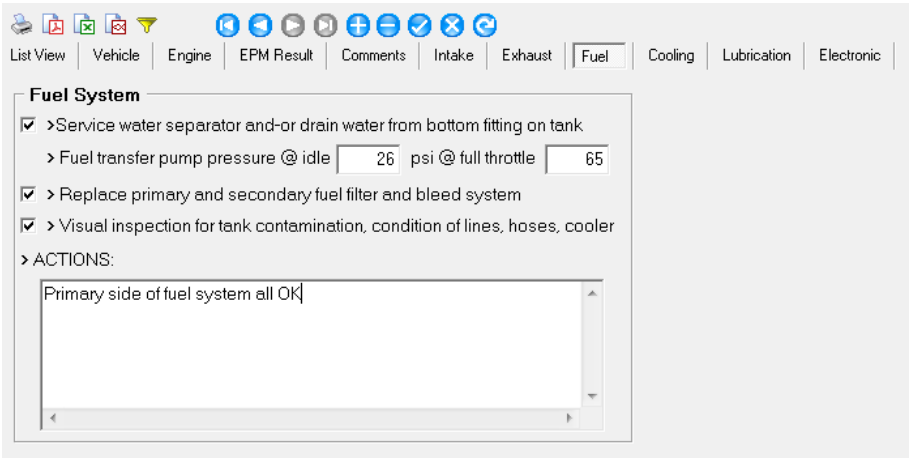
6 Systems – Exhaust



6 Systems – Exhaust

- Backpressure
- DOC Performance
- DPF Performance
- Leaks
- Turbocharger

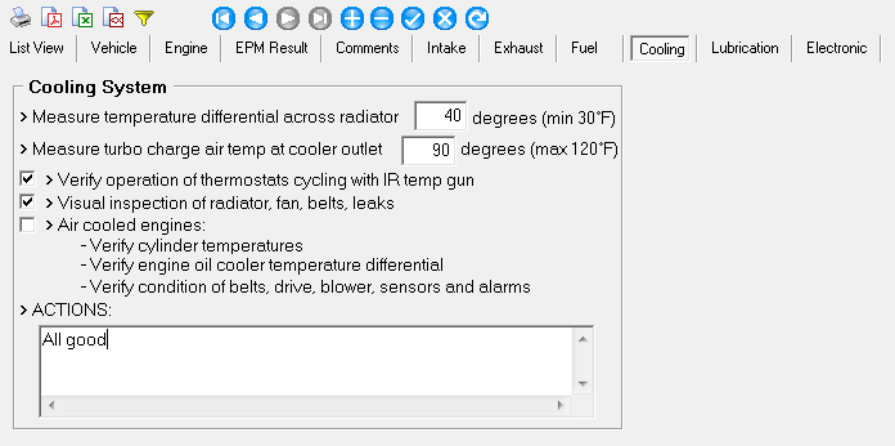
6 Systems – Fuel Injection



6 Systems – Fuel Injection

- Problems most often sourced to primary side
- Transfer pump
- Filters
- Contamination
- Pressure (measure)
- Temperature (measure)

6 Systems – Cooling



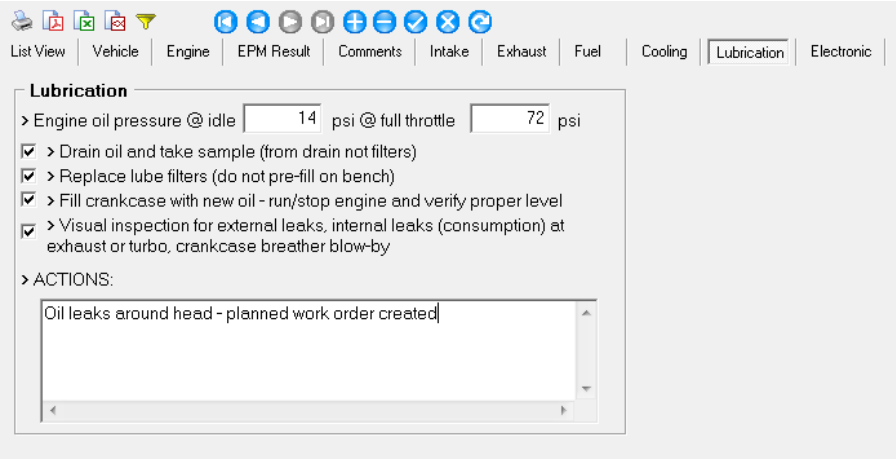
6 Systems – Cooling

Measure Δ Temperature

- **Engine Temp**
- **Charge Air Temp**
- **Fuel Temp**

Δ 30° F Minimum

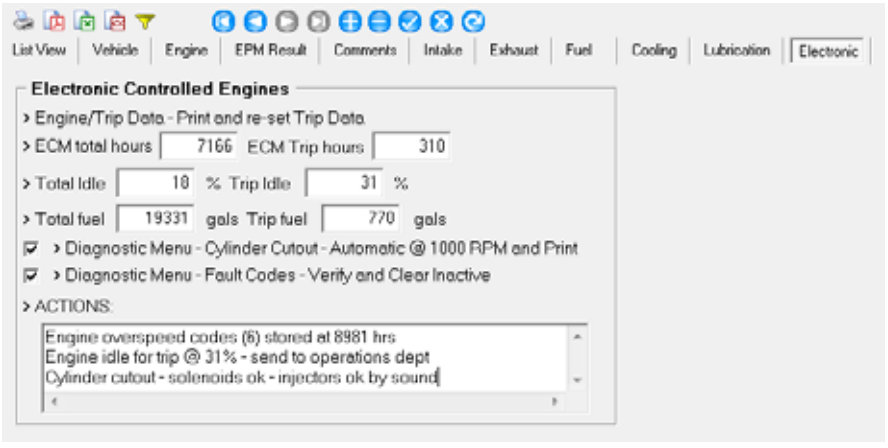
6 Systems – Lubrication



6 Systems – Lubrication

- Filling Practices
- Oil analysis & filter dissection
- Measure Oil Level
- Measure Oil Pressure

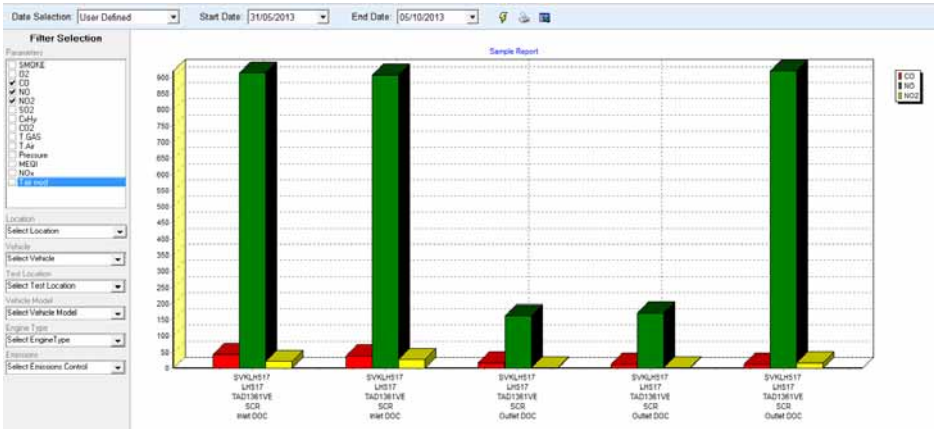
6 Systems – Electronic / ECM



6 Systems – Database

Vehicle ID	Engine Type	Manufacturer	Model	Location	Emissions Control
#2 AIRPAK WELDER	V 3600 T-E102	LINCOLN	K 2325-2	UNDERGROUND	
#3 AIRPAK WELDER	V 3600 T-E102	LINCOLN	K 2325-2	UNDERGROUND	
#3 WASTE TRUCK	3406E ACERT	CAT	AD-30	UNDERGROUND	DOC
106 BOLTER	3304	FLETCHER	AR-D	UNDERGROUND	DOC
107 BOLTER	C7	FLETCHER	AAR-D	UNDERGROUND	DOC
108 BOLTER	3126B	FLETCHER	3124 AD	UNDERGROUND	DPF
109 BOLTER	C7	FLETCHER	3024 AD-E	UNDERGROUND	DOC
110 BOLTER	3306PC	CANNON	DPI-HD-RB	UNDERGROUND	DOC
1412	3306PCNA	Emco	T-30	UNDERGROUND	Paper Filters
320 LOADER	6D DDEC® 12.7L	TAMROCK	400	UNDERGROUND	DOC
321 LOADER	6D DDEC® 12.7L	TAMROCK	400	UNDERGROUND	DOC
325 LOADER	3176C EUI	CAT	R2900X	UNDERGROUND	DOC
326 LOADER	3176C EUI	CAT	R2900X	UNDERGROUND	DOC
327 LOADER	C15	CAT	R2900 XTRA	UNDERGROUND	DOC
328 LOADER	C15 ACERT	CAT	R2900 XTRA	UNDERGROUND	DOC
329 LOADER	C15 ACERT	CAT	R2900 XTRA	UNDERGROUND	DOC
407 SCALER	C6.6 ACERT	GETMAN	S324NAWD	UNDERGROUND	DOC
408 SCALER	C6.6 ACERT	GETMAN	S324NAWD	UNDERGROUND	DOC
410 SCALER	DM904LA	GETMAN	S324NAWD	UNDERGROUND	MUFFLER
411 SCALER	C6.6 ACERT	GETMAN	S324NAWD	UNDERGROUND	DOC
412 SCALER	C6.6 ACERT	GETMAN	S324NAWD	UNDERGROUND	DOC

6 Systems – Managing Data



6 Systems – The Tools

Measure-Measure-Measure

- ❑ Intake Restriction
- ❑ Exhaust Backpressure
- ❑ Stall Speed RPM
- ❑ Fuel Pressure
- ❑ Oil Pressure
- ❑ Turbo Boost Pressure
- ❑ Temperatures

6 Systems – The Tools

Intake Leak Testing – Suction & Boost Sides

Because where the rubber hits the road….

Without reliable and repeatable measurements and performance data ….

It’s just an opinion !!!

mdec

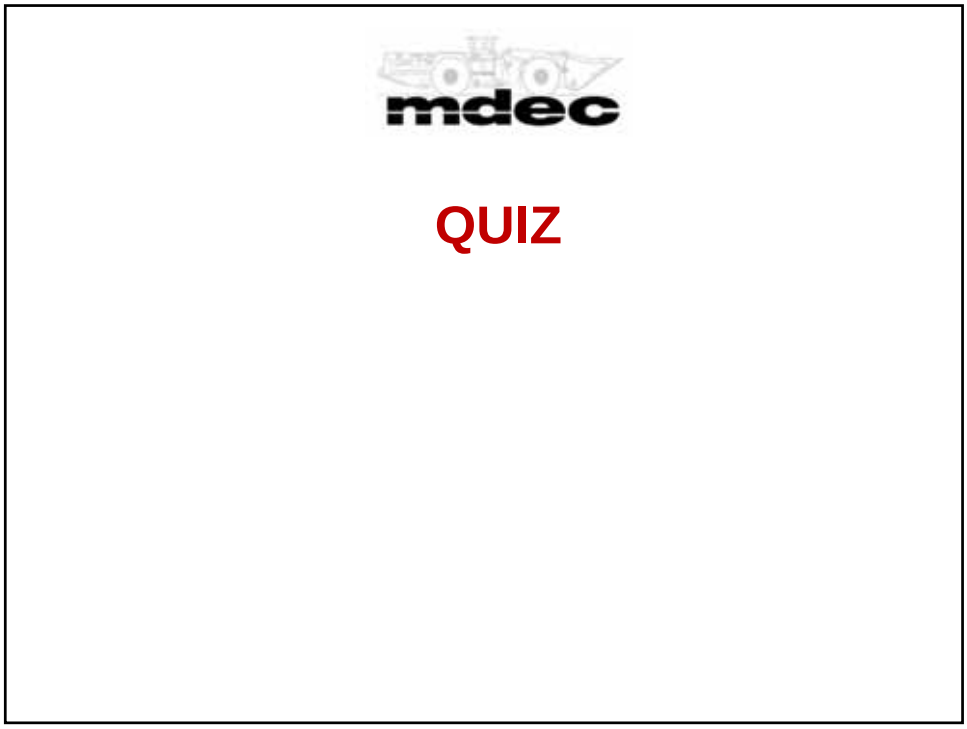
QUESTIONS ?

Common sense just doesn’t seem to be all that common!

HandyBob

MKNIZD | Factors

www.mknizdfactors.com


mdec
QUIZ

2100	1900	1750	RPM
Hi Idle	Trans Stall	Trans-Hyd Stall	

Series 60 12.7 L

Engine Speed rpm		Rated Power bhp		Rated Torque lb•ft
2100	@	400	@	1000
1950	@	400	@	1077
1800	@	400	@	1167
1650	@	385	@	1225
1500	@	367	@	1285
1350	@	345	@	1342
1200	@	320	@	1400

Diesel Oxidation Catalyst

	INLET	OUTLET	
CO	150	30	ppm
NO	600	600	ppm
NO_2	30	30	ppm
O_2	12	12	%
CO_2	7	7	%
TGas	750	725	°F

Turbo Boost Press	21	psi
Intake Restriction	10	inches water
Charge Air Temp	105	°F
Backpressure	25	inches water
Fuel Pressure	65	psi
Coolant Δ Temp	34	°F

2100	1700	1500	RPM
Hi Idle	Trans Stall	Trans-Hyd Stall	

Series 60 12.7 L

Engine Speed rpm		Rated Power bhp		Rated Torque lb•ft
2100	@	400	@	1000
1950	@	400	@	1077
1800	@	400	@	1167
1650	@	385	@	1225
1500	@	367	@	1285
1350	@	345	@	1342
1200	@	320	@	1400

Diesel Oxidation Catalyst

	INLET	OUTLET	
CO	400	100	ppm
NO	600	600	ppm
NO_2	30	30	ppm
O_2	12	12	%
CO_2	7	7	%
TGas	750	725	°F

Turbo Boost Press	16	psi
Intake Restriction	30	inches water
Charge Air Temp	105	°F
Backpressure	25	inches water
Fuel Pressure	65	psi
Coolant Δ Temp	34	°F

2100	1850	1750	RPM
Hi Idle	Trans Stall	Trans-Hyd Stall	

Series 60 12.7 L

Engine Speed rpm		Rated Power bhp		Rated Torque lb•ft
2100	@	400	@	1000
1950	@	400	@	1077
1800	@	400	@	1167
1650	@	385	@	1225
1500	@	367	@	1285
1350	@	345	@	1342
1200	@	320	@	1400

Diesel Oxidation Catalyst

	INLET	OUTLET	
CO	100	200	ppm
NO	600	600	ppm
NO_2	30	30	ppm
O_2	12	12	%
CO_2	7	7	%
TGas	750	725	°F

Turbo Boost Press	20	psi
Intake Restriction	10	inches water
Charge Air Temp	105	°F
Backpressure	40	inches water
Fuel Pressure	65	psi
Coolant Δ Temp	34	°F

2100	1700	1500	RPM
Hi Idle	Trans Stall	Trans-Hyd Stall	

Series 60 12.7 L

Engine Speed rpm		Rated Power bhp		Rated Torque lb•ft
2100	@	400	@	1000
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1800	@	400	@	1167
1650	@	385	@	1225
1500	@	367	@	1285
1350	@	345	@	1342
1200	@	320	@	1400

Diesel Oxidation Catalyst

	INLET	OUTLET	
CO	400	100	ppm
NO	600	600	ppm
NO_2	30	30	ppm
O_2	12	12	%
CO_2	7	7	%
TGas	750	725	°F

Turbo Boost Press	12	psi
Intake Restriction	12	inches water
Charge Air Temp	105	°F
Backpressure	25	inches water
Fuel Pressure	65	psi
Coolant Δ Temp	34	°F

2100	1850	1750	RPM
Hi Idle	Trans Stall	Trans-Hyd Stall	

Series 60 12.7 L

Engine Speed rpm		Rated Power bhp		Rated Torque lb•ft
2100	@	400	@	1000
1950	@	400	@	1077
1800	@	400	@	1167
1650	@	385	@	1225
1500	@	367	@	1285
1350	@	345	@	1342
1200	@	320	@	1400

Diesel Oxidation Catalyst

	INLET	OUTLET	
CO	100	20	ppm
NO	1000	1000	ppm
NO_2	50	50	ppm
O_2	12	12	%
CO_2	7	7	%
TGas	750	725	°F

Turbo Boost Press	20	psi
Intake Restriction	10	inches water
Charge Air Temp	180	°F
Backpressure	20	inches water
Fuel Pressure	65	psi
Coolant Δ Temp	34	°F

2100	1700	1500	RPM
Hi Idle	Trans Stall	Trans-Hyd Stall	

Series 60 12.7 L

Engine Speed rpm		Rated Power bhp		Rated Torque lb•ft
2100	@	400	@	1000
1950	@	400	@	1077
1800	@	400	@	1167
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1350	@	345	@	1342
1200	@	320	@	1400

Diesel Oxidation Catalyst

	INLET	OUTLET	
CO	400	100	ppm
NO	600	600	ppm
NO_2	25	25	ppm
O_2	12	12	%
CO_2	7	7	%
TGas	750	725	°F

Turbo Boost Press	15	psi
Intake Restriction	10	inches water
Charge Air Temp	110	°F
Backpressure	20	inches water
Fuel Pressure	35	psi
Coolant Δ Temp	34	°F

2100	1700	1500	RPM
Hi Idle	Trans Stall	Trans-Hyd Stall	

Series 60 12.7 L

Engine Speed rpm		Rated Power bhp		Rated Torque lb•ft
2100	@	400	@	1000
1950	@	400	@	1077
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1650	@	385	@	1225
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1350	@	345	@	1342
1200	@	320	@	1400

Diesel Oxidation Catalyst

	INLET	OUTLET	
CO	400	100	ppm
NO	600	600	ppm
NO_2	25	25	ppm
O_2	12	12	%
CO_2	7	7	%
TGas	750	725	°F

Turbo Boost Press	15	psi
Intake Restriction	10	inches water
Charge Air Temp	110	°F
Backpressure	20	inches water
Fuel Pressure	65	psi
Coolant Δ Temp	34	°F

Series 60 12.7 L

Engine Speed rpm		Rated Power bhp		Rated Torque lb•ft
2100	@	400	@	1000
1950	@	400	@	1077
1800	@	400	@	1167
1650	@	385	@	1225
1500	@	367	@	1285
1350	@	345	@	1342
1200	@	320	@	1400

Diesel Particulate Filter

2100	1850	1750	RPM
Hi Idle	Trans Stall	Trans-Hyd Stall	

	INLET	OUTLET	
CO	100	100	ppm
NO	600	600	ppm
NO_2	25	25	ppm
O_2	12	12	%
CO_2	7	7	%
TGas	750	725	°F
Smoke	7	0	

Turbo Boost Press	20	psi
Intake Restriction	10	inches water
Charge Air Temp	110	°F
Backpressure	40	inches water
Fuel Pressure	65	psi
Coolant Δ Temp	34	°F

2100	1850	1750	RPM
Hi Idle	Trans Stall	Trans-Hyd Stall	

Series 60 12.7 L

Engine Speed rpm		Rated Power bhp		Rated Torque lb•ft
2100	@	400	@	1000
1950	@	400	@	1077
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1650	@	385	@	1225
1500	@	367	@	1285
1350	@	345	@	1342
1200	@	320	@	1400

Diesel Particulate Filter

	INLET	OUTLET	
CO	100	100	ppm
NO	600	600	ppm
NO_2	25	25	ppm
O_2	12	12	%
CO_2	7	7	%
TGas	750	725	°F
Smoke	7	5	

Turbo Boost Press	20	psi
Intake Restriction	10	inches water
Charge Air Temp	110	°F
Backpressure	25	inches water
Fuel Pressure	65	psi
Coolant Δ Temp	34	°F

Series 60 12.7 L

Engine Speed rpm		Rated Power bhp		Rated Torque lb•ft
2100	@	400	@	1000
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1650	@	385	@	1225
1500	@	367	@	1285
1350	@	345	@	1342
1200	@	320	@	1400

Diesel Particulate Filter

2100	1700	1500	RPM
Hi Idle	Trans Stall	Trans-Hyd Stall	

	INLET	OUTLET	
CO	200	200	ppm
NO	600	600	ppm
NO_2	25	25	ppm
O_2	12	12	%
CO_2	7	7	%
TGas	900	800	°F
Smoke	7	1	

Turbo Boost Press	16	psi
Intake Restriction	10	inches water
Charge Air Temp	110	°F
Backpressure	90	inches water
Fuel Pressure	65	psi
Coolant Δ Temp	34	°F

ANSWERS

SLIDE #

1. Normal with a DOC (catalytic converter)
2. Intake Restriction
3. Plugged DOC – Catalytic Converter
4. Charge Air Leak
5. Charge Air Temp
6. Fuel Pressure
7. Injectors
8. Normal with a DPF (diesel particulate filter)
9. Blown DPF
10. Plugged DPF