EIGHTH ANNUAL MINING DIESEL EMISSIONS CONFERENCE (MDEC)
TORONTO, ONTARIO, CANADA

DIESEL EMISSIONS CONTROL IN MINES WORKSHOP

PRESENTED BY:
NRCAN – CANMET, MSHA, NIOSH, NORANDA

COORDINATED BY: MAHE GANGAL, NRCAN - CANMET

OCTOBER 28, 2002

Diesel Emissions Control in Mines Workshop

8th Annual Mining Diesel Emissions Conference (MDEC)
Toronto, Ontario, Canada
Monday, October 28, 2002

08:15 - 08:30	Welcome and Introduction
08:30 – 09:30	**Section 1 - Diesel Particulate Matter** *(Michel Grenier - NRCan/CANMET)* DPM and Health Issues Ambient and Exhaust DPM Sampling
9:30 – 10:00	**Section 2 - Gas Sampling in Mines** *(Michel Grenier – NRCan/CANMET)* Ambient and Exhaust Measurements Exhaust CO Monitoring
10:00 – 10:15	Coffee Break
10:15 – 11:15	**Section 3 - Emissions Control Strategies** *(Aleksandar Bugarski – NIOSH)* Engine Selection, Fuel and Additives Aftertreatment Devices and Efficiencies
11:15 – 12:15	**Section 4 – Maintaining Diesel Engines** *(Sean McGinn – Noranda)* Auditing Engine Maintenance Quiz
12:15 – 13:15	Lunch
13:15 – 14:00	**Section 5 –Engine Testing & Approval** *(Mahe Gangal – NRCan/CANMET)* Engine Emissions Testing Engine Approval Procedures
14:00 – 15:00	**Section 6 -MSHA's DPM Standard** *(Bill Pomroy & George Saseen - MSHA)* DPM and Compliance Determinations Engine, Fuel and Maintenance
15:00 - 15:15	Coffee Break
15:15 – 15: 45	**Section 7 - Canadian Regulation** *(Mahe Gangal – NRCan/CANMET)* Engine, Fuel and DPM
15:45 – 16:15	**Section 8 - DPM Estimator for Mines** *(George Saseen - MSHA)* Estimator Details and Examples
16:15 – 16:30	Conclusion *(Mahe Gangal – NRCan/CANMET)*

MDEC 2002 Workshop

Diesel Emissions Control in Mines

Diesel Particulate Matter Measurement

Michel Grenier - CANMET
Natural Resources Canada

Mining Diesel Emissions Conference

Markham, Ontario
October, 2002

Measuring for DPM

If I ask you to measure the length of a stick, you get a tape measure...

If I ask for the mass of a rock, you get a balance or a scale...

If I ask you to measure the concentration of diesel particulate matter in a mine…
What do you do? What do you use???

DPM Problems

- We don't agree on the definition of DPM
- It can't always be measured very accurately and directly
- All available methods have serious pros and cons associated with them
- There is general lack of agreement on the toxicity of the material

Presentation Overview

- Health issues
  - Composition, size distribution, effects
- DPM measurement
  - Complexity, various approaches
  - Exposure limits and concentrations
- Sampling for DPM in ambient air
- Sampling in raw exhaust

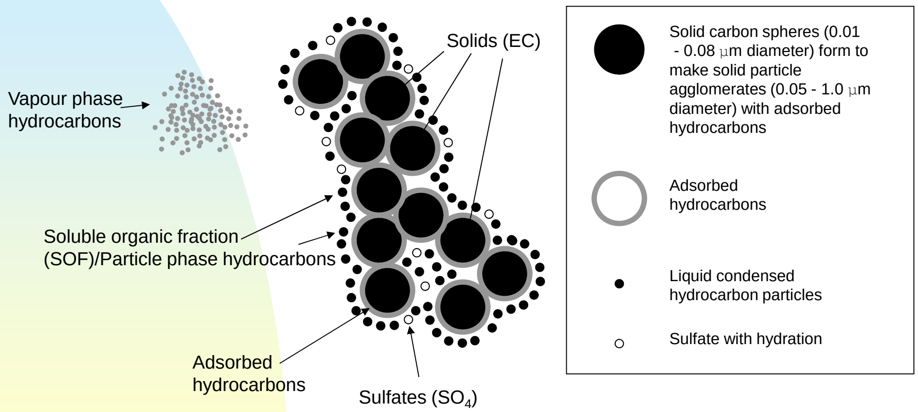
Health Issues

- Why are diesel emissions such a concern
  - Hundreds of different compounds and chemicals
  - 90% of particles are less than 1 micron in diameter (respirable)
  - Gaseous phase contains irritants and toxic chemicals
  - Oxides of nitrogen and carbon monoxide are also present
  - Can be found indoors/outdoors, at work and at home

Diesel Emissions Composition

- Particulate
  - Elemental carbon
  - Organic carbon
  - Sulphates
  - Metals & ashes
- NO, NO_2, SO_2, CO
- Aldehydes, hydrocarbons

Particulate Matter



Reproduced from HEI's Diesel Exhaust: A critical Analysis of Emissions, Exposure, and Health Effects

Health Effects

- Chronic inhalation studies
  - Rats - dose related lung tumors
  - Cause: heavy burden of non-soluble dust or chemical characteristics?
  - Not sure if extrapolation of effects to humans is warranted
- EPA says: DPM are a hazard to humans

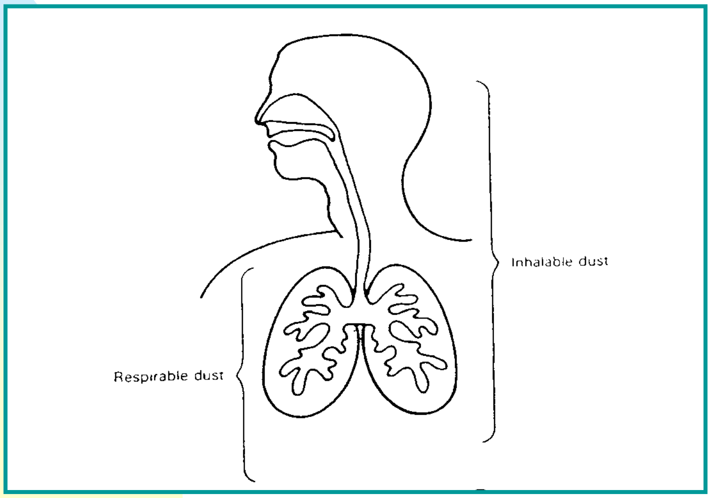
Health Effects

- Exacerbates allergic responses (asthma, etc.)
- Links to developmental effects in rat foetuses
- Nose, throat and eye irritations
- Bad odor and impediment to visibility

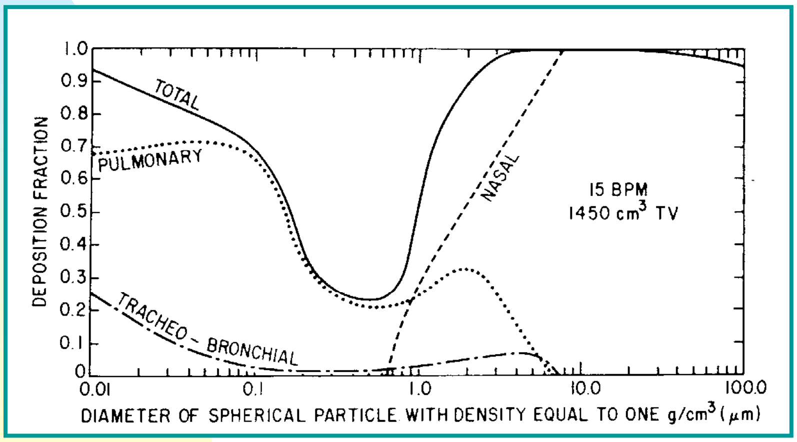
Focusing on DPM

- DPM contains carcinogenic constituents
- It is fully respirable dust
- Penetrates deep into the lung...

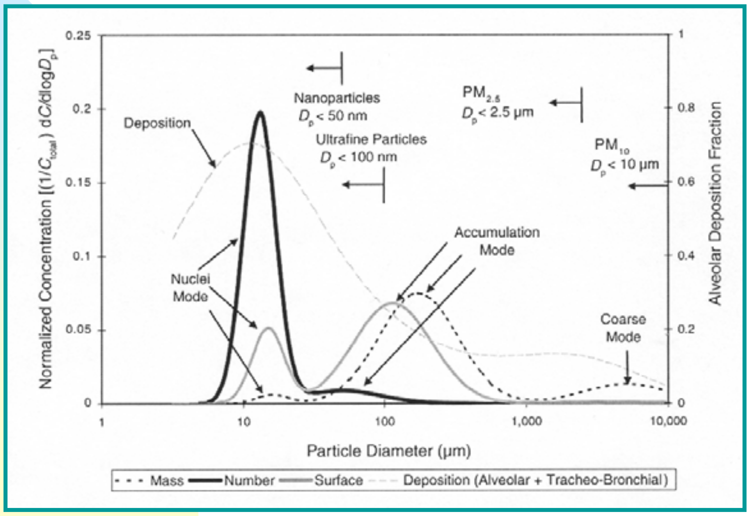
Respiratory System



Lung Deposition vs Size



Size Distribution - DPM



DPM Measurement Background Information

Composition...

- Particulate
  - Elemental carbon (EC)
  - Organic carbon (OC)
  - Sulphates
  - Metals & ashes
- To gauge the exposure to particulate (DPM) we have historically measured EC, OC or both

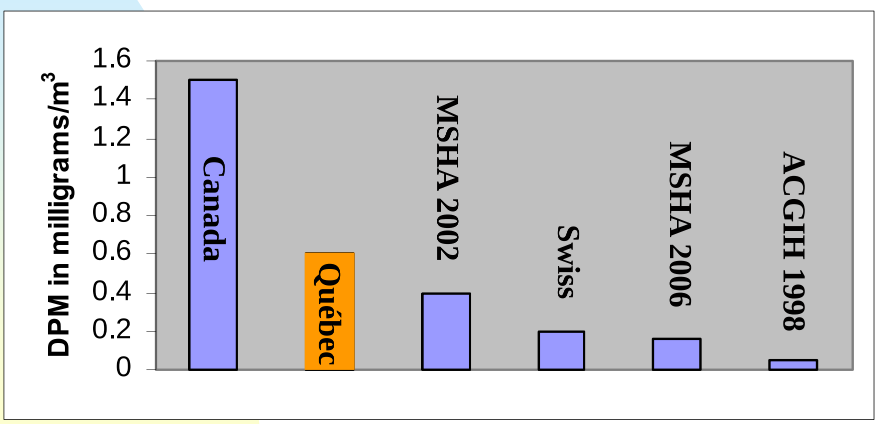
DPM Analysis - Available methods

- Respirable combustible dust (RCD)
  - Somewhat equivalent to total carbon (organic and elemental)
  - both species cannot be separated
- Elemental carbon
  - NIOSH 5040 Method
- Organic carbon
  - NIOSH 5040 Method

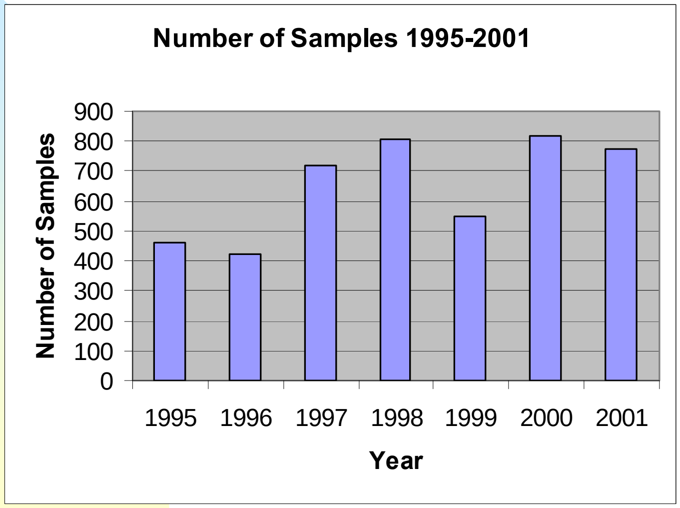
DPM Exposure Limits

Jurisdiction	Exposure Limit (mg/m^3)	Method
Canada (1990)	1.50	RCD
Québec (2002)	0.60	RCD
MSHA (2002)	0.40	TC
Switzerland	0.20	TC
MSHA (2006)	0.16	TC
ACGIH (1998)	0.05	TC

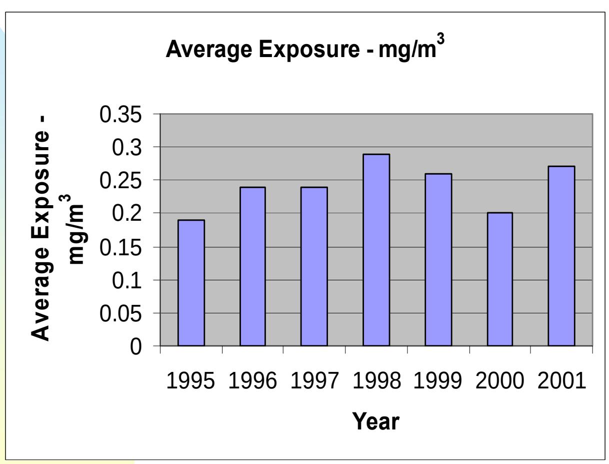
DPM exposure limits



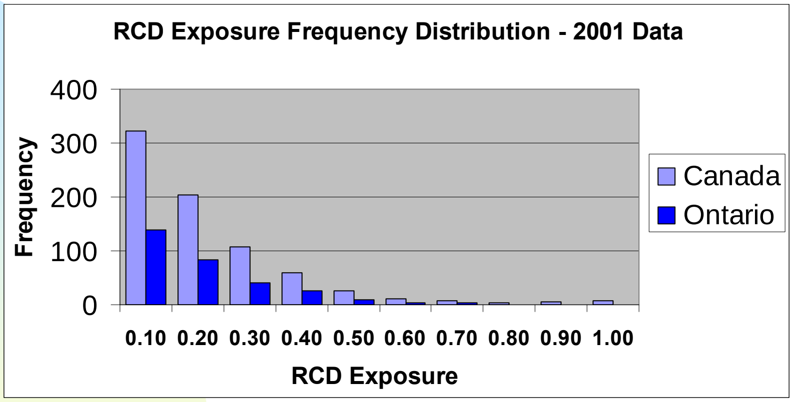
RCD Analysis - CANMET



RCD Analysis - CANMET



RCD Analysis - CANMET



Ontario data - % samples above a concentration of:

1.50 mg/m^3:	**0%**	**0.60 mg/m^3:**	**1%**
0.40 mg/m^3:	**7%**	**0.16 mg/m^3:**	**40%**
0.05 mg/m^3:	**81%**		

DPM Sampling and Analysis

Types of Dust in Mining

- Mineral (e.g. silica, asbestos)
- Combustibles (e.g. diesel soot, drill oil)
- Others (e.g. sulfates, metals)

Dust Sampling

- Usually whole shift sampling for compliance purposes (ACGIH guidelines or specific regulation)
- TWA exposure concept (no time history)

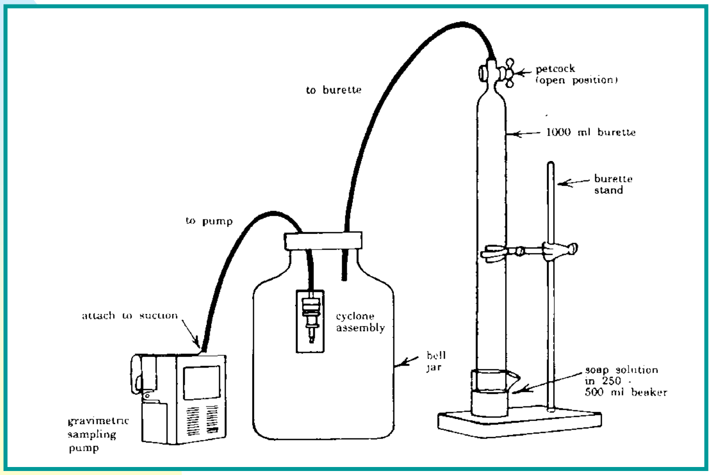
Components of the Sampling Train

- Pump
- Filter/cassette assembly
- Tubing
- Pre-separator

Sampling Pump

- Clean, well maintained, reliable (battery pack capacity)
- Self-regulating for flow (filter back-pressure compensation)
- Comfort and light-weight
- Well calibrated for flow (air density effects)

Pump Flow Calibration



Filter Cassette Assembly

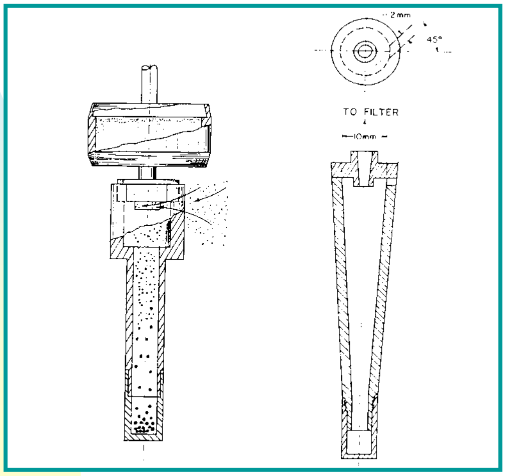
- Selection of the filter media (type, porosity)
- Refer to the analytical method for selecting the filter
- Care in cassette assembly… let the analytical lab do the work

Pre-separators

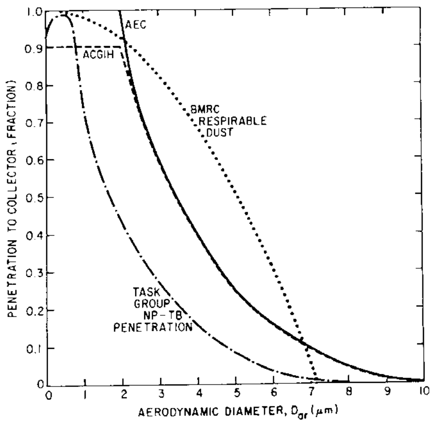
- Used ahead of the filter assembly
- Two-reasons:
  - to select only a portion of a type of dust (i.e. silica dust as respirable)
  - to remove coarser types of other dusts (interference)
- For DPM use is made of cyclones and single-stage impactors depending on the analytical method and regulation used

10-mm Nylon Cyclone

Cyclone Cut-away



Cyclone Penetration Curve



Single Stage Impactor

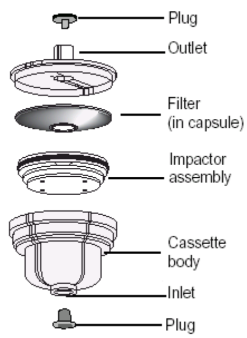


Figure 1. Exploded view of SKC DPM Cassette with Precision-jeweled Impactor (Cat. No. 225-315)

Figure 2. DPM Sampling Train with Cyclone and Holder

Sample Analysis

Available Methods

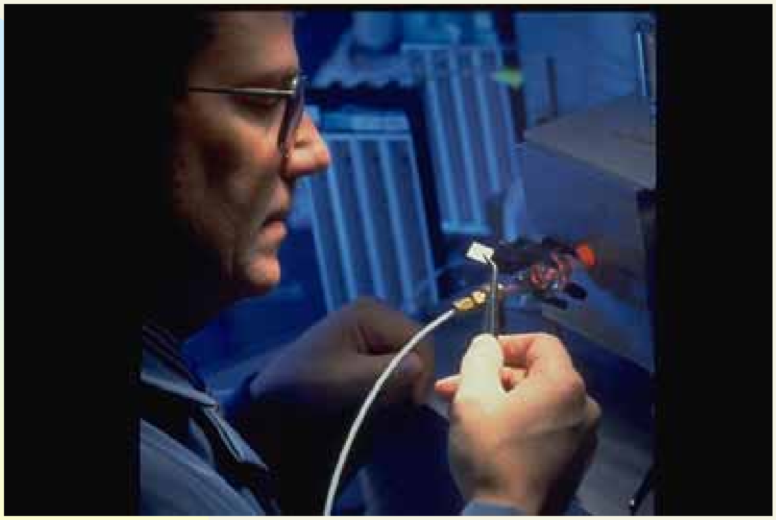
- Respirable Combustible Dust (RCD)
  - Québec, Ontario, N.B., B.C.
  - Exposure limit: 1.50 mg/m^3
- NIOSH 5040 method:
  - Also known as the elemental carbon method
  - Mentioned by name in the new MSHA ruling

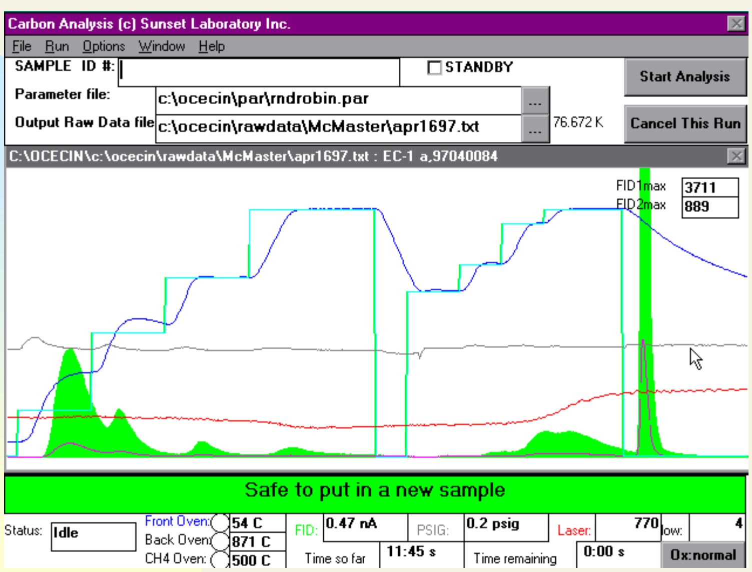
RCD Method

- Respirable combustible dust (RCD)
- Detection limit of 0.04 mg/m^3
- Principle of analysis: determination of mass loss on ashing @ 400°C for 2 hours
- Believed adequate at limits of exposure above 0.60 mg/m^3

NIOSH 5040 Method

- Detection limit: 0.001 mg (elemental carbon) and 0.005 mg (organic carbon)
- Principle of analysis: two-phase heating of sample with measurement of combustion gases




Carbon Analysis (c) Sunset Laboratory Inc.
File Run Options Window Help
SAMPLE ID #:
STANDBY
Start Analysis
Parameter file:
c:\ocecin\par\rndrobin.par
Output Raw Data file
c:\ocecin\rawdata\McMaster\apr1697.txt
76.672 K
Cancel This Run
C:\OCECIN\c:\ocecin\rawdata\McMaster\apr1697.txt : EC-1 a,97040084
FID1max
3711
FID2max
889
Safe to put in a new sample
Status:
Idle
Front Oven:
54 C
Back Oven:
871 C
CH4 Oven:
500 C
FID:
0.47 nA
PSIG:
0.2 psig
Laser:
770
Time so far
11:45 s
Time remaining
0:00 s
Ox:normal

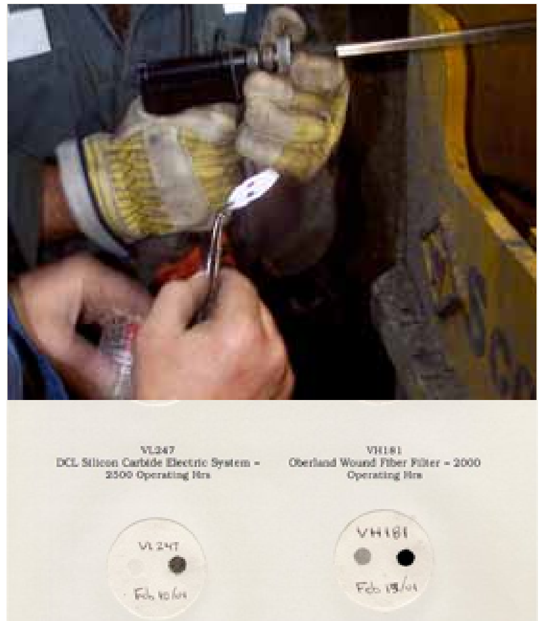
DPM Direct Exhaust Sampling

DPM Direct Exhaust Sampling

- In most cases is a very complex procedures
- Requires specialized equipment, engine test regimes and experience
- Tests have to be performed during steady state engine regimes to be reproducible and also to highlight engine problems
- Test for engine state of maintenance or the efficiency of a DPM filtration unit

Baccharach Index

- Used with ECOM Gas Analyzer
- Is a grey scale index which varies in ten steps from white to black



Undiluted DPM Sampling

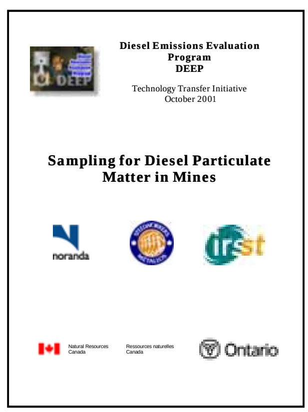
- Developed by CANMET, it is an experimental design
- Used in DEEP's maintenance and light-duty vehicle projects
- In conjunction with NIOSH 5040 Method, measures elemental carbon in exhaust

Nanomet DPM Sampler

- Swiss design
- Developed to determine the efficiency of DPM filters
- Uses a heated dilution sampling head
- Fairly complicated and expensive
- PAS 2000 instrument can be used to monitor airborne DPM in real time

Sampling Report DEEP Web Site

- Maintenance Manual and Training Modules
- 2-page Project Summaries
- Guide to Diesel Sampling in U/G Mines
- Web Site: **www.deep.org**


Diesel Emissions Evaluation Program
DEEP
Technology Transfer Initiative
October 2001

Sampling for Diesel Particulate Matter in Mines

Gas Sampling in Mines

Michel Grenier - CANMET, Natural Resources Canada

Mining Diesel Emissions Conference

Markham, Ontario
October, 2002

Presentation Overview

- A brief look at instrumentation and applications in ambient and exhaust
- Will focus on direct sampling of CO in exhaust
- Look at raw exhaust CO sampling as a maintenance tool

Colorimetric Tubes

Also called stain tubes, these are filled with a chemical which reacts with the target gas. Exposure to this gas causes an indicator to change color.

- Pros:
  - Always calibrated
- Cons:
  - Inaccurate
  - Hard to read (dark places)
  - Sensitive to pressure variations
  - Cross sensitivities (interference)

Colorimetric Tubes - Dräger

Colorimetric Tubes - Gastec

Cooling Probe on Dräger

Real Time Reading Gas Monitors

These are electronic gas monitors with instantaneous read-out. They operate with electro-chemical cells which produce a potential difference and a current when they are exposed to the target gas.

- Pros:
  - Accurate, easy to read
  - Give a time history of gas concentration

Real Time Reading Gas Monitors

- Cons:
  - Need calibration and more expensive
  - More complicated
  - Sensitive to temperature, pressure
  - Cross sensitivities (interference)
  - NO_2, SO_2 (ambient) TLV® are close to the limit of detection of the instruments

Real Time Reading Gas Monitor

Real Time Reading Gas Monitor

Direct Exhaust Sampling

CO Monitoring for Maintenance

- Evaluate impact of exhaust contaminants on ambient air
- As CO goes, usually particulate goes
- Gauge need for maintenance
- Evaluate impact of maintenance

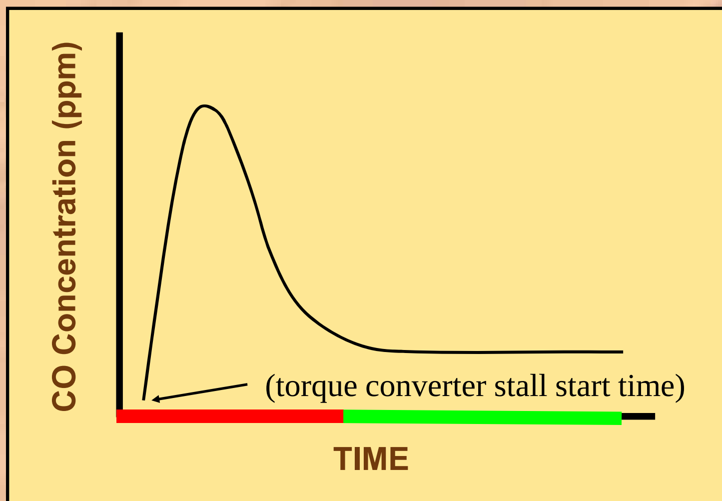
Questions

- Choice of instrumentation
- Measurement technique
- When to measure
- Issues related to Safety & Health

Choice of Engine Regime

- Full Torque Converter Stall is the way to go
- It is reproducible and can be done on all heavy-duty vehicles
- Research shows that if engine needs attention, this is the regime to pick it up
- Not an option for manual transmission vehicles

Torque Converter Stall CO Concentration vs Time



Choice of Instrumentation

- Real time monitor is the way to go
- If colorimetric tubes are used:
  - Use cooling probe with overflow T (Dräger)
  - Use Gastec tube system because with one pump stroke you cover the 25 to 1000 ppm range

Sampling Protocol - Heavy-Duty Vehicles (Torque Converter)

- Full torque converter stall
- Very simple and reproducible procedures (important)
- Wait for CO to stabilize (obvious with real-time monitors, about 15 seconds if using colorimetric tubes)

Sampling Protocol - Light-Duty Vehicles

- Cannot do stall tests with manual transmissions
- Can use high rpm without load, but not very useful
- Solution: In cab sampling port and operate LDV up ramp, ideally same place, same gear and full throttle
- Operator can drive and read monitor

Procedure

1- Verify the integrity of the sampling system (pump seal, calibration records, span gas check)

2- Use of personal protective equipment and well ventilated area

3- Emergency brakes and wheel chocks

4- Warm up engine several minutes (driving if possible)

5- Use a gas cooling tube

Procedure

6- Prepare all equipment prior to going into torque converter stall

7- Depress the accelerator fully and wait 15 seconds or until reading is stable

8- Stop immediately if workers' safety or equipment is compromised

9- Let torque converter oil cool before proceeding to next test

When to sample

- At regular intervals (250 hours?)
- Before and after maintenance (DEEP Maintenance Project makes a good case for that)
- At the request of operators if problems are suspected

How do you use the information???

- Simple question, but…
- Do you use it to make sure you can meet 1500 ppm
- You know you can always meet a regulated limit of 1500 ppm
- Unlikely that an operator would run a piece of equipment which was that dirty

Pennsylvania Regulation

www.dep.state.pa.us/dep/deputate/minres/dms/website/laws/all.htm#ART2A

- Section 217-A… When any diesel-powered machine first enters service at a mine, baseline emission values shall be determined by a qualified mechanic...

Pennsylvania Regulation

- Section 218-A... If the average CO reading for untreated exhaust gas is greater than twice the baseline established under section 217-A(b) or if the average CO reading for treated exhaust gas is greater than 100 ppm, the equipment has failed and must be serviced and re-tested before it is returned to regular service...

Conclusions

- Repeatability and test protocol is key
- Real-time monitors are better
- Their calibration and regular span testing is critical
- Torque converter stall test is sufficient for HD equipment
- LDV can be accommodated, but more complex and expensive
- Baseline testing and action based on twice that reading is a smart approach

Diesel Emissions Control Strategies for Underground Mines

Aleksandar Bugarski
NIOSH PRL

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Diesel Emissions and Occupational Health Standards

- Gaseous emissions
  - **Carbon Dioxide (CO_2), ACGIH TLV-TWA is 5000 ppm**
  - **Carbon Monoxide (CO), ACGIH TLV-TWA is 50 ppm**
  - **Nitric Oxide (NO), ACGIH TLV-TWA is 25 ppm**
  - **Nitrogen dioxide (NO_2), ACGIH TLV-TWA is 3 ppm, ACGIH TLV-STEL is 5 ppm**
- Particulate emissions
  - **Total Carbon (TC) = Elemental Carbon (EC) + Organic Carbon (OC), MSHA 160 µg/m^3 (interim standard is 400 µg/m^3)**

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Control Technologies

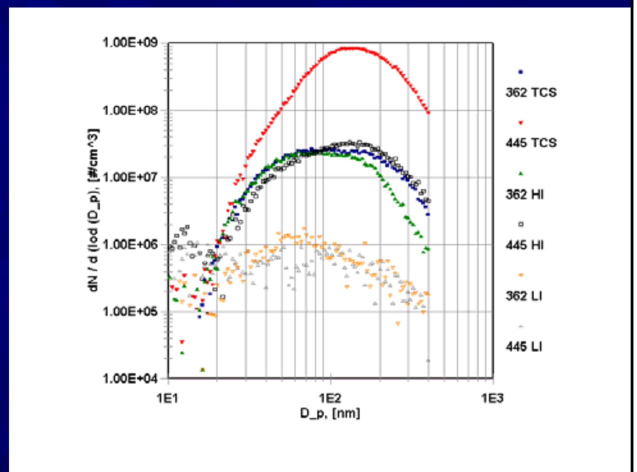
- Engine design and selection
- Fuel formulations and fuel additives
- Aftertreatment technologies
- Maintenance

Engine selection

- All diesel engines introduced in U.S. metal and nonmetal mines must be approved by MSHA or EPA [30 CFR Part 57, 2001].
- Selection should be made between low emitting engines
- Modern engines emits 10% of the the total particulate mass of that emitted by comparable engines designed 15-20 years ago.
  - Higher fuel injection pressures
  - Optimization of combustion process

Engine selection

- Engine Deration
  - High altitude
  - Ventilation requirements
- Example
  - #445 LHD powered by DDEC Series 60 11.1 liter rated at 325 hp
  - #362 LHD powered by DDEC Series 60 11.1 liter rated at 285 hp



Fuel

- Fuel effects on DPM emissions
  - sulfur content:
    - Sulfates, SO_2 to SO_3 + H_2O to H_2SO_4 ,
    - < 500 ppm (avg. 350 ppm) sulfur,
    - < 15 ppm by 2007 (EPA),
    - affects performance of catalyst based technologies,
    - competing with NO for the O_2;
  - cetane number;
  - aromatic content.

Fuel

- **Alternative fuels**
  - **Biodiesel**
    - oxygenated fuel
    - virtually no sulfur
    - NO_2 issue
    - expensive
    - B20 blends
  - **Synthetic diesel**
    - virtually no sulfur
    - low on aromatics
    - significant reductions in regulated emissions
    - expensive and not readily available

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Fuel Additives

- Fuel additives used in U.S. underground mines should be approved by EPA.
- Concern about secondary emissions.
- Additives for stimulating filter regeneration should not be used in the engine which is not equipped with filter:
  - Emissions of transient metals

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Aftertreatment Technologies

- Gaseous Emissions
  - Diesel Oxidation Catalytic Converter (DOC)
- Particulate Emissions
  - Diesel Particulate Filters (DPF);
  - Disposable Paper Filters.

Diesel Oxidation Catalytic Converter (DOC)

- CO to CO_2
  - 70-90% reductions in CO
- Hydrocarbons to CO_2
  - 70% reduction in HC
- Reduce organic portion or soluble organic fraction (SOF) of DPM
  - 20-30 % reductions in total DPM

Diesel Particulate Filters (DPFs)

- **Media**
  - wall flow monoliths
    - ceramic cordierite;
    - silicon carbide (SiC).
  - deep bed filters
    - fiber wounded or knitted.
- **Catalyst**
  - Non-Catalyzed DPF
    - no regeneration aid;
  - Catalyzed DPF
    - wash coat catalyst:
      - platinum, vanadium, palladium…
    - fuel borne catalyst:
      - platinum, cerium, iron, strontium…

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Diesel Particulate Filters (DPFs) Media SiC, Cordierite, and Wounded Fiber

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DPF Efficiency

- DPM = Elemental Carbon + Organic Carbon+ Sulfates + Water + Ash
  - Composition is function of engine design, engine operating conditions, aftertreatment…
- DPFs are primarily designed for curtailment of DPM emissions. The effects on gaseous emissions depend on a catalyst formulation.

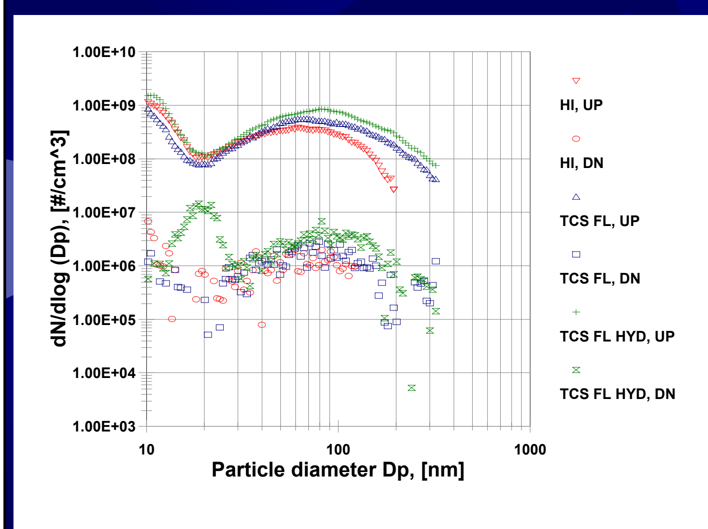
DPF Efficiency

- **Mass**
  - Cordierite 85% (www.msha.gov)
  - Silicon carbide 87% (www.msha.gov)
  - VERT 90% (new), 85% (after 2000 hours)
- **Carbon**
  - Occupational standards based on total (U.S.) or elemental carbon (Germany, U.S. in future)
  - Over 95% on EC.

DPF Efficiency

- **Number**
  - Potential for forming a large number of ultrafine and nanosize particles from semi-volatile hydrocarbons, sulfates, and ash
  - Potential for forming large number of transition metals particles when fuel additive are used .
  - VERT 95% (new), 90% (after 2000 hours)
- **Surface area**
  - Ultrafine particles (<100 nm) have a very larger surface area per unit mass, bioavailability
  - Currently there is no standards
- **Chemical composition**
  - Transition metals
  - PAH

Size Distribution of DPM in the Tailpipe of DDEC Series 60 Powered Truck Retrofitted With SiC DPF



Legend:
HI - rated speed no load
TCS FL - torque converter stall
TCS FL HYD - torque converter stall and hydraulics engaged
UP - upstream
DN - downstream

Filter Efficiency-visual effects

Secondary emissions

- Filter effects on NO_2 emissions:
  - Washcoated platinum based catalysts have tendency to increase NO_2 emissions. Function of:
    - catalyst formulation
    - exhaust temperatures
    - fuel sulfur content…
  - Wascoated base metal catalysts do not have tendency to increase NO_2 emissions.
  - Fuel borne catalysts, even those using platinum based catalyst were not shown to increase NO_2 emissions.

Secondary emissions

- nanoparticles:
  - Evident when fuels with higher sulfur content are used in the catalyzed systems, when fuel borne catalysts are used to stimulate regeneration…
- sulfates:
  - Remedy is ultralow sulfur fuel
- transitional metals:
  - The major source are fuel borne catalysts. Avoid using fuel borne catalyst with engines which are not equipped with DPF system.
- dioxins, nitro-PAHs…

DPF Regeneration
Passive regeneration

Regeneration – burning off carbon collected in a filter

- Approximate regeneration temperatures:
  - Non-catalyzed DPF – over 550 ºC
  - Base metal catalyst – over 390 ºC
  - Nobel metal catalyst – over 325 ºC
- More than 25% of a duty cycle engine should be operated at loads generating exhaust temperatures exceeding regeneration temperatures.
- Engine idling periods should be minimized

DPF Regeneration
Active Regeneration

- Filter should be sized to accumulate DPM between two active regenerations.
- Accumulated DPM burned off periodically using external source of energy
  - electrical heating
    - ON-BOARD: for heavy-duty vehicles heating element on-board of a vehicle and regenerations station with power and compressed air supply off-board of a vehicle:
      - No need to remove filter
      - Regeneration time as short as 40 minutes
      - Suitable for most engines
      - Periodic failure of electrical heaters
      - Regeneration station requirements.

DPF Regeneration
Active Regeneration

- OFF-BOARD: heating element is part of off-board regenerations station.
  - Require removal of the filter from the system
    - Suitable mostly for smaller displacement engines
    - Problem of maintaining integrity of the system
    - Costs associated with replacement of the gaskets
    - Downtime for swapping filter elements
  - Regeneration station requirements

- fuel burner:
  - Relatively complex and expensive design
  - Safety issues

DPF Regeneration
Electrical On-board Regeneration

DPF Regeneration
Passive vs. Active DPFs

- Passive DPFs
  - low operational requirements
  - low maintenance requirements
  - relatively inexpensive, depending on catalyst formulation
  - regeneration is not guarantied
  - concerns about NO_2 emissions

DPF Regeneration
Passive vs. Active DPFs

- Active DPFs
  - guarantied regeneration
  - no secondary emissions
  - high operational requirements
  - high maintenance requirements
  - relatively expensive
  - require changing attitudes
  - regeneration intervals can be extended with use of catalyst…

DPF Regeneration
Ash Accumulation

- Ash originates from lubricating oil, engine wear or fuel additives.
- Ash can not be regenerated as carbon. Accumulation of the ash in the filter results in continuous increase in base backpressure.
- Periodic cleaning of the filter required, usually every 2000 hours.

DPF Backpressure Monitoring

- Reliable backpressure monitoring and logging capabilities are essential for performance of the filtration system.
- Pressure gage and alarm should be included in the filtration system.

Selection of DPF Strategy

- **Ultimate goal is to reduce exposure of the miners to harmful gases and particulate matter**
  - Production vehicles (heavy-duty)
  - Support vehicles (light-duty)
- **DPF is integral part of the vehicle/engine/filter system**
  - Right size of the engine for the application
    - Exhaust temperature
    - DPF concept
  - Maintenance
    - Significant lube oil consumption jeopardizes filter performance and life. Filter can not substitute maintenance.

Selection of DPF Strategy

- **Two scenarios:**
  - Ordering DPF with new equipment
  - Retrofitting existing equipment with DPF
- **Selection of DPF provider**
  - VERT Filter List
  - DEEP Noranda and INCO projects
  - Dieselnet.com

Selection of DPF Strategy

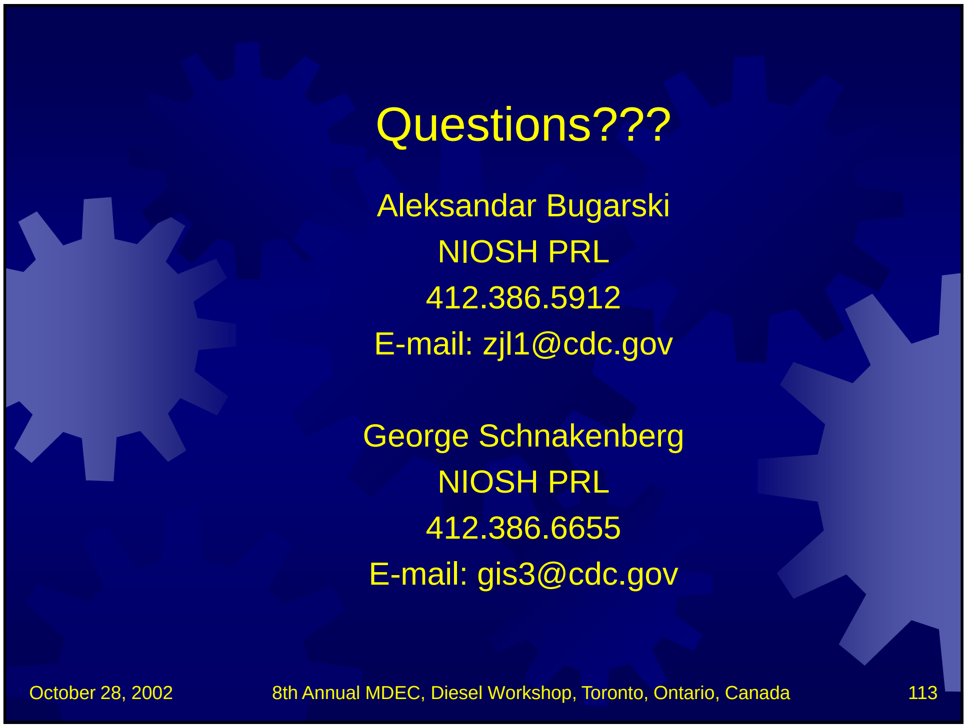
- Underground mining applications require additional considerations:
  - confined space;
  - no sunlight;
  - occupational exposure limits;
  - different set of the mind.
- Uniqueness vs. “one size fits all”

Selection of DPF Strategy

- Vehicle duty cycle
  - Exhaust temperature trace
  - Selection of the regeneration concept
    - Passive vs. active regeneration
  - Selection of the catalyst formulation
    - Regeneration with minimized secondary emissions
- Filter size
  - Engine backpressure – engine limitations
    - Caterpillar 3306 PCNA - 34 in H_20
    - DDEC Series 60 – 42 in H_20

DPF system considerations

- Integrity of a filtration system from an engine to the end of a tailpipe is crucial for reducing concentrations of DPM in mine air.
- An exhaust pipe and filter insulation is recommended for filter systems which use heat from exhaust stream to regenerate.
- Insulation should to be removable so integrity of a system can be periodically inspected.


Questions???
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October 28, 2002
8th Annual MDEC, Diesel Workshop, Toronto, Ontario, Canada
113


October 28, 2002
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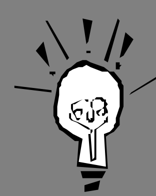
Auditing Engine Maintenance



Page 58...

Auditing Engine Maintenance

AUDIT TEAM

- Cross Disciplined
- Group Breakouts
- Opening & Closing meetings
- Final Report
- Mgmt, OH&S, Union

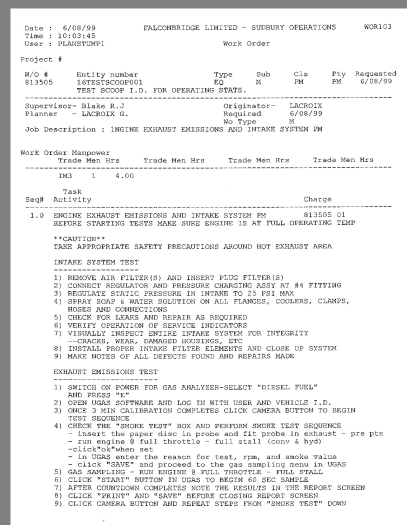
Auditing Engine Maintenance

- ✔ Roles and Responsibilities
- ✔ Operational Issues
- ✔ Training
- ✔ Tools
- ✔ Maintenance Practices
- ✔ Process Detail
- ✔ Engine Subsystems
- ✔ Housekeeping and Organization

Auditing Engine Maintenance

Process Detail

PM and Recording Systems

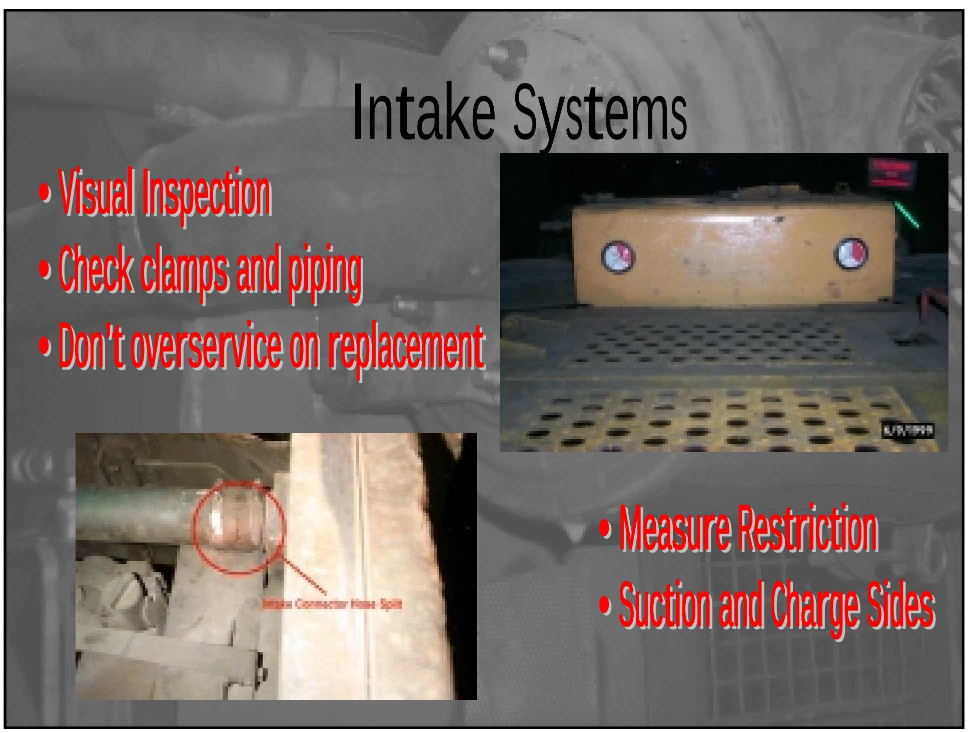


```
Date :  6/08/99          FALCONBRIDGE LIMITED - SUDBURY OPERATIONS      WOR103
Time : 10:03:45
User : PLANSTUMP1                          Work Order

Project #

W/O #     Entity number                  Type     Sub     Cls     Pty  Requested
813505    16TESTSCOOP001                 EQ       M       PM      PM    6/08/99
          TEST SCOOP I.D. FOR OPERATING STATS.
-------------------------------------------------------------------------------
Supervisor- Blake R.J                    Originator-   LACROIX
Planner   - LACROIX G.                   Required      6/08/99
                                         Wo Type       M
Job Description : 1NGINE EXHAUST EMISSIONS AND INTAKE SYSTEM PM

Work Order Manpower
       Trade Men Hrs      Trade Men Hrs      Trade Men Hrs      Trade Men Hrs
-------------------------------------------------------------------------------
       IM3    1    4.00

        Task
Seq#  Activity                                              Charge
-------------------------------------------------------------------------------
 1.0  ENGINE EXHAUST EMISSIONS AND INTAKE SYSTEM PM         813505 01
      BEFORE STARTING TESTS MAKE SURE ENGINE IS AT FULL OPERATING TEMP

      **CAUTION**
      TAKE APPROPRIATE SAFETY PRECAUTIONS AROUND HOT EXHAUST AREA

      INTAKE SYSTEM TEST
      ------------------
      1) REMOVE AIR FILTER(S) AND INSERT PLUG FILTER(S)
      2) CONNECT REGULATOR AND PRESSURE CHARGING ASSY AT #4 FITTING
      3) REGULATE STATIC PRESSURE IN INTAKE TO 25 PSI MAX
      4) SPRAY SOAP & WATER SOLUTION ON ALL FLANGES, COOLERS, CLAMPS,
         HOSES AND CONNECTIONS
      5) CHECK FOR LEAKS AND REPAIR AS REQUIRED
      6) VERIFY OPERATION OF SERVICE INDICATORS
      7) VISUALLY INSPECT ENTIRE INTAKE SYSTEM FOR INTEGRITY
         --CRACKS, WEAR, DAMAGED HOUSINGS, ETC
      8) INSTALL PROPER INTAKE FILTER ELEMENTS AND CLOSE UP SYSTEM
      9) MAKE NOTES OF ALL DEFECTS FOUND AND REPAIRS MADE

      EXHAUST EMISSIONS TEST
      ----------------------
      1) SWITCH ON POWER FOR GAS ANALYZER-SELECT "DIESEL FUEL"
         AND PRESS "E"
      2) OPEN UGAS SOFTWARE AND LOG IN WITH USER AND VEHICLE I.D.
      3) ONCE 3 MIN CALIBRATION COMPLETES CLICK CAMERA BUTTON TO BEGIN
         TEST SEQUENCE
      4) CHECK THE "SMOKE TEST" BOX AND PERFORM SMOKE TEST SEQUENCE
         - insert the paper disc in probe and fit probe in exhaust - pre ptx
         - run engine @ full throttle - full stall (conv & hyd)
         -click"ok"when set
         - in UGAS enter the reason for test, rpm, and smoke value
         - click "SAVE" and proceed to the gas sampling menu in UGAS
      5) GAS SAMPLING - RUN ENGINE @ FULL THROTTLE - FULL STALL
      6) CLICK "START" BUTTON IN UGAS TO BEGIN 60 SEC SAMPLE
      7) AFTER COUNTDOWN COMPLETES NOTE THE RESULTS IN THE REPORT SCREEN
      8) CLICK "PRINT" AND "SAVE" BEFORE CLOSING REPORT SCREEN
      9) CLICK CAMERA BUTTON AND REPEAT STEPS FROM "SMOKE TEST" DOWN
```

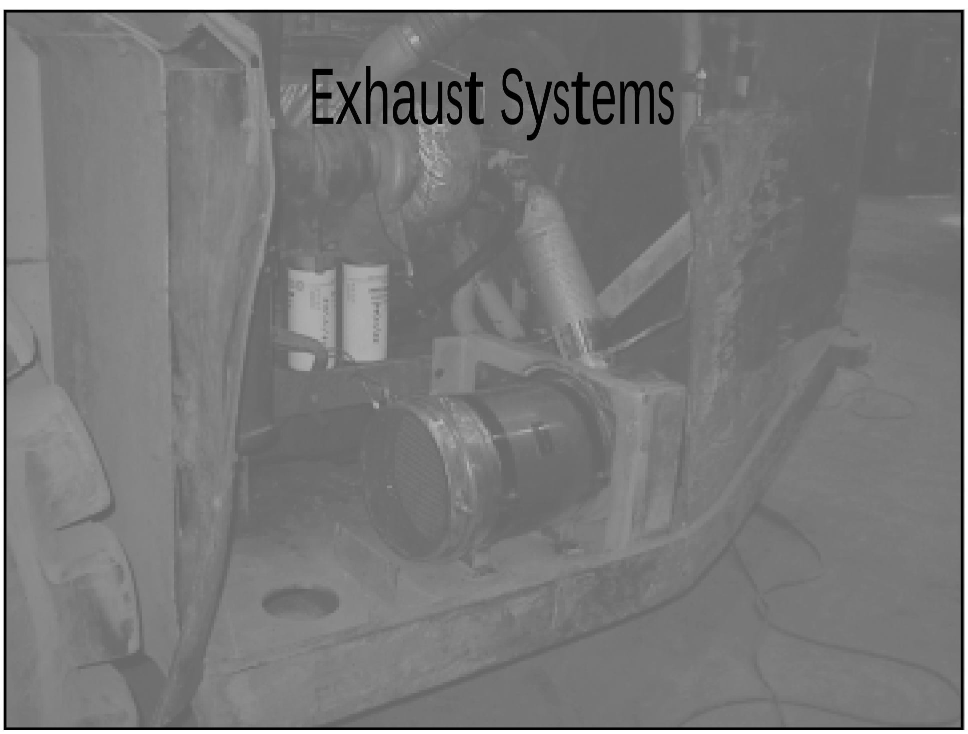
Auditing Engine Maintenance

Housekeeping


Intake Systems


Intake Systems
• Visual Inspection
• Check clamps and piping
• Don't overservice on replacement
Intake Connector Hose Split
• Measure Restriction
• Suction and Charge Sides


Intake Systems
TEST FOR INTEGRTIY OF SYSTEM !!!


Exhaust Systems

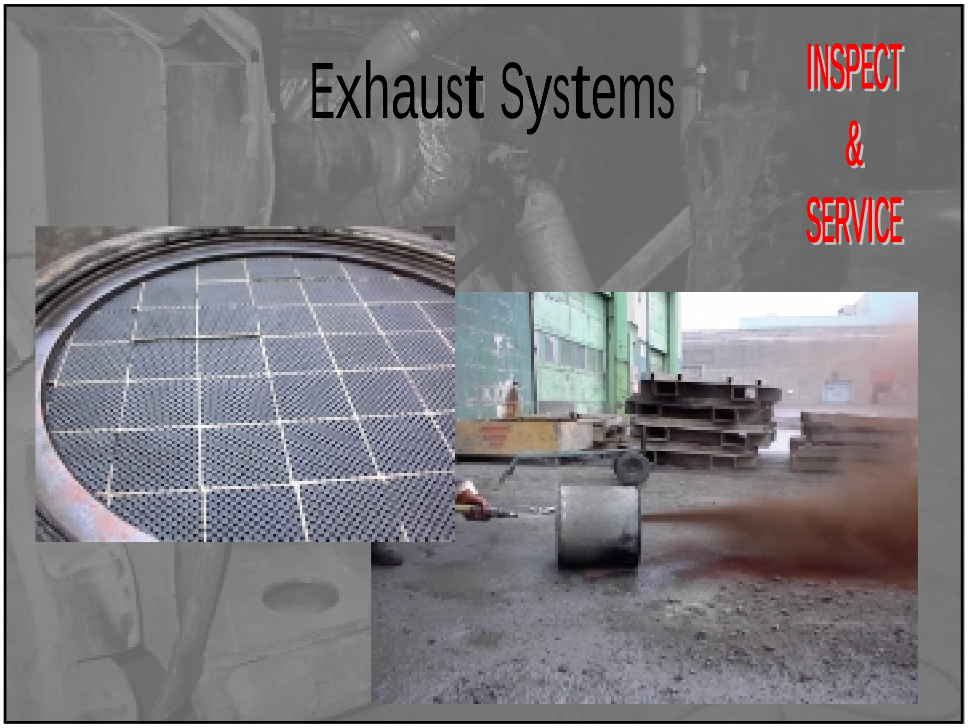
Exhaust Systems

MEASURE

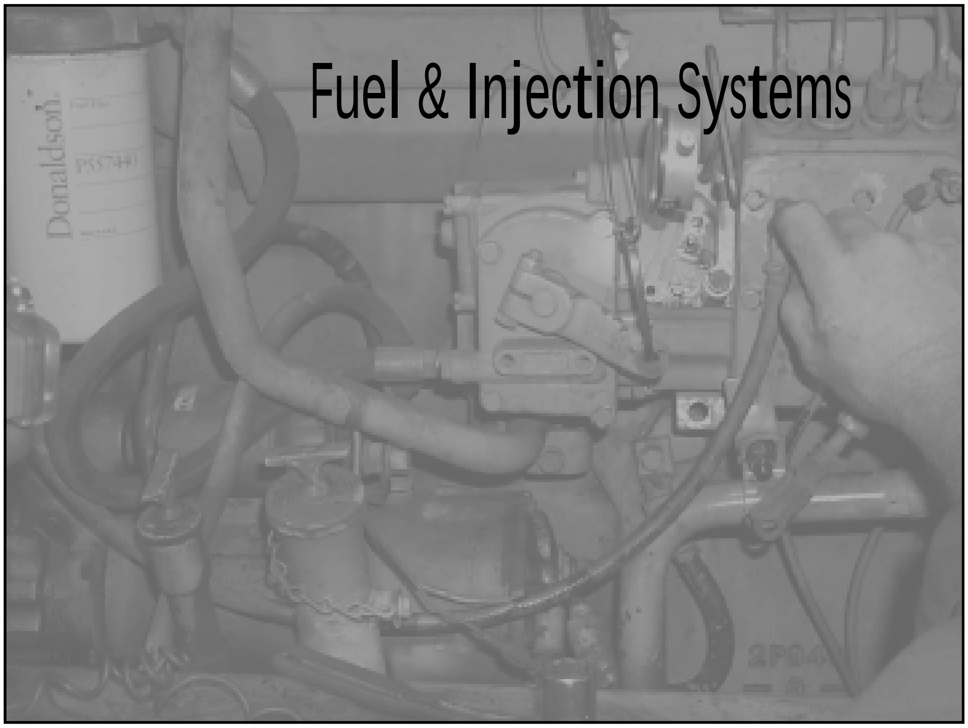
Exhaust Systems

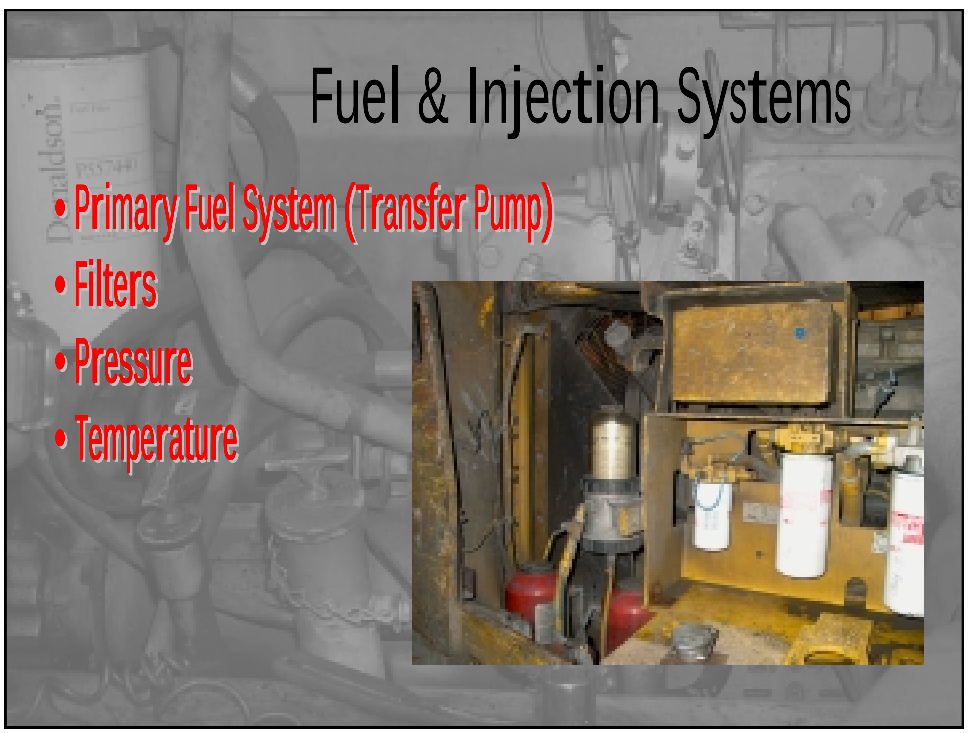
UNDERSTAND

EMISSION	*CAUSE*	*TYPICAL LEVEL IN UNTREATED EXHAUST*	*EFFECTS*
Carbon Monoxide (CO)	**Product of incomplete combustion of fuel. Usually problems with fuel system (injectors, pump, etc.) or plugged intake.**	**100 - 400 ppm**	**Lethal in large doses. Causes headaches and lethargy**
Nitrogen Oxides (NOx)	**Generated in the reaction between oxygen and nitrogen under high temperature and pressure in the engine cylinder. Usually problems with timing or valve settings.**	**650 ppm**	**Creates respiratory difficulties. Partly responsible for smog.**
Sulfur Dioxide (SO2)	**From sulfur content in fuel.**	**5 - 50 ppm**	**Partly responsible for acid rain.**
Hydrocarbons (HC)	**Unburned components of fuel. Could be derived from any of the conditions described above.**	**20 - 200 ppm**	**Responsible for harsh odor and eye / throat irritation.**
Diesel Particulate Matter (DPM) **Incl. Soluble Organic Fraction (SOF)**	**DPM is a product of incomplete combustion of fuel. Composed of the solid, visible particulate suspended in exhaust gas** **SOF: component of DPM hydrocarbons and their derivatives adsorbed on the surface on inorganic carbon (soot) particles. SOF may constitute 30% and more of the total DPM.**	**5 - 100 mg/m3**	**The black, blue and white smoke commonly seen in diesel exhaust.** **Commonly referred to as soot.** **Suspected to be a human carcinogen.**

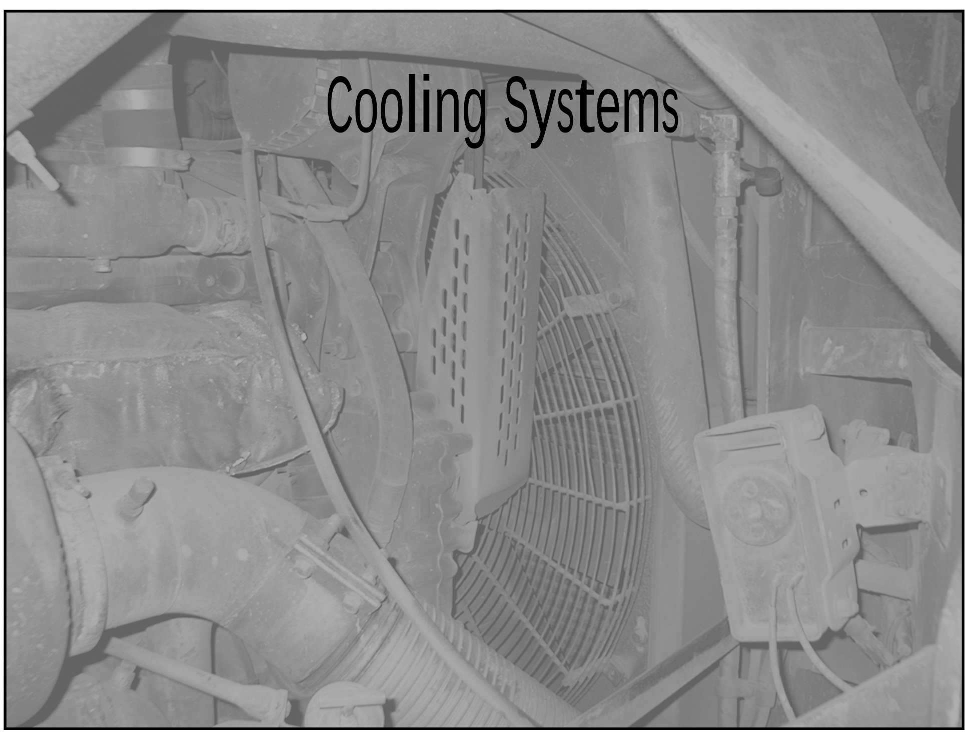

Exhaust Systems
INSPECT
&
SERVICE

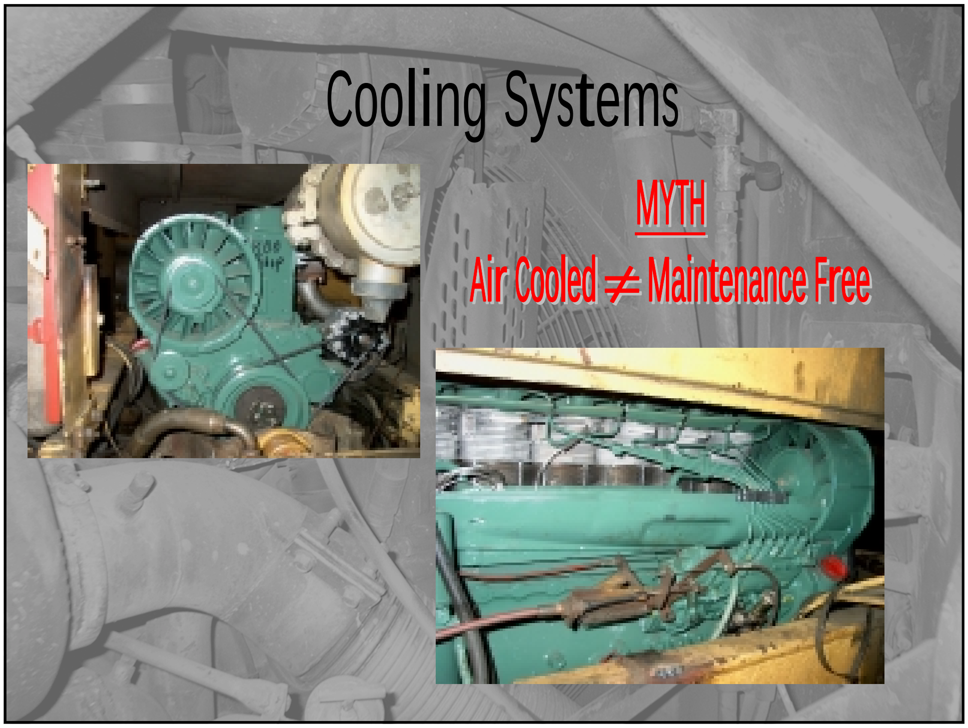

Exhaust Systems
INSPECT
&
SERVICE

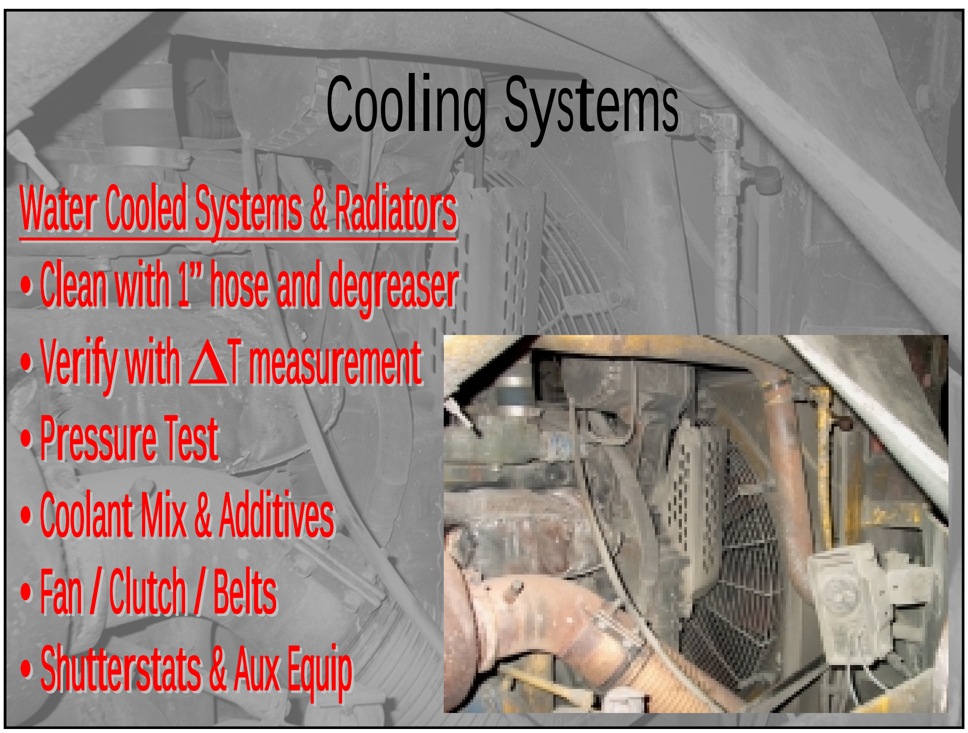

Fuel & Injection Systems
Donaldson.

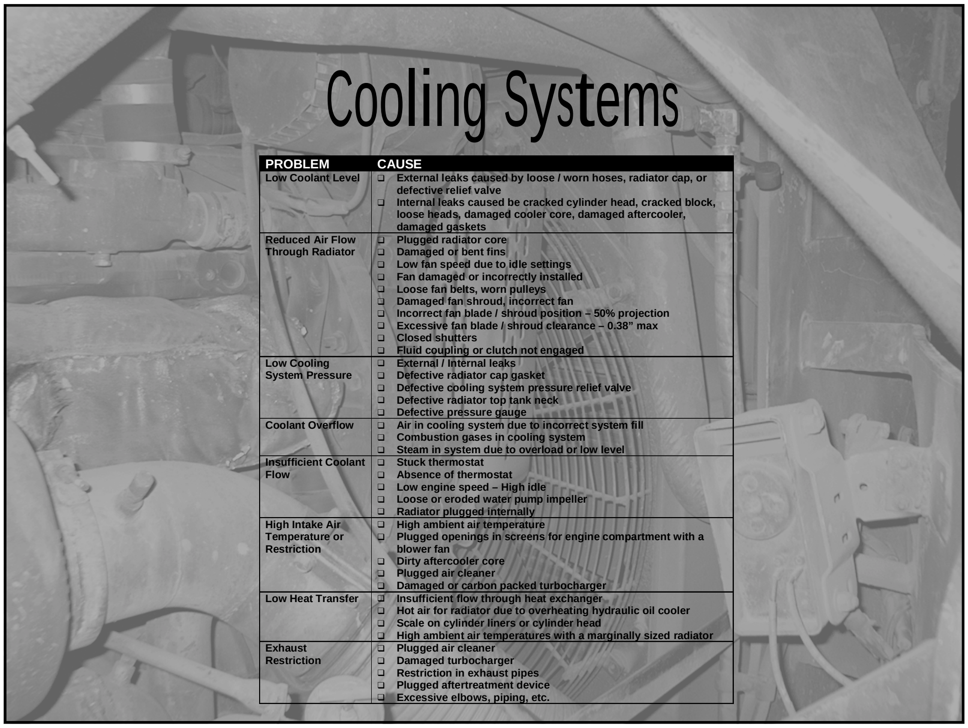

Fuel & Injection Systems
• Primary Fuel System (Transfer Pump)
• Filters
• Pressure
• Temperature


Fuel & Injection Systems
• Injectors / Pumps / Valves
• Air : Fuel
• Justified and Verified by . . . .
• MEASURED EMISSIONS !!!
• Trained & Qualified Mechanics


Cooling Systems


Cooling Systems
MYTH
Air Cooled ≠ Maintenance Free


Cooling Systems
Water Cooled Systems & Radiators
• Clean with 1" hose and degreaser
• Verify with ΔT measurement
• Pressure Test
• Coolant Mix & Additives
• Fan / Clutch / Belts
• Shutterstats & Aux Equip



Cooling Systems

PROBLEM	CAUSE
Low Coolant Level	❑ External leaks caused by loose / worn hoses, radiator cap, or defective relief valve ❑ Internal leaks caused be cracked cylinder head, cracked block, loose heads, damaged cooler core, damaged aftercooler, damaged gaskets
Reduced Air Flow Through Radiator	❑ Plugged radiator core ❑ Damaged or bent fins ❑ Low fan speed due to idle settings ❑ Fan damaged or incorrectly installed ❑ Loose fan belts, worn pulleys ❑ Damaged fan shroud, incorrect fan ❑ Incorrect fan blade / shroud position – 50% projection ❑ Excessive fan blade / shroud clearance – 0.38" max ❑ Closed shutters ❑ Fluid coupling or clutch not engaged
Low Cooling System Pressure	❑ External / Internal leaks ❑ Defective radiator cap gasket ❑ Defective cooling system pressure relief valve ❑ Defective radiator top tank neck ❑ Defective pressure gauge
Coolant Overflow	❑ Air in cooling system due to incorrect system fill ❑ Combustion gases in cooling system ❑ Steam in system due to overload or low level
Insufficient Coolant Flow	❑ Stuck thermostat ❑ Absence of thermostat ❑ Low engine speed – High idle ❑ Loose or eroded water pump impeller ❑ Radiator plugged internally
High Intake Air Temperature or Restriction	❑ High ambient air temperature ❑ Plugged openings in screens for engine compartment with a blower fan ❑ Dirty aftercooler core ❑ Plugged air cleaner ❑ Damaged or carbon packed turbocharger
Low Heat Transfer	❑ Insufficient flow through heat exchanger ❑ Hot air for radiator due to overheating hydraulic oil cooler ❑ Scale on cylinder liners or cylinder head ❑ High ambient air temperatures with a marginally sized radiator
Exhaust Restriction	❑ Plugged air cleaner ❑ Damaged turbocharger ❑ Restriction in exhaust pipes ❑ Plugged aftertreatment device ❑ Excessive elbows, piping, etc.

Fuel Quality & Handling

Fuel Quality & Handling

- Storage Systems
- Verify and Follow Up
- Eliminate Contamination Sources

Fuel Quality & Handling

- QUALITY
- 500 ppm Sulfur max.
- 50 ppm Sulfur best

Ultimate Mine Diesel Fuel

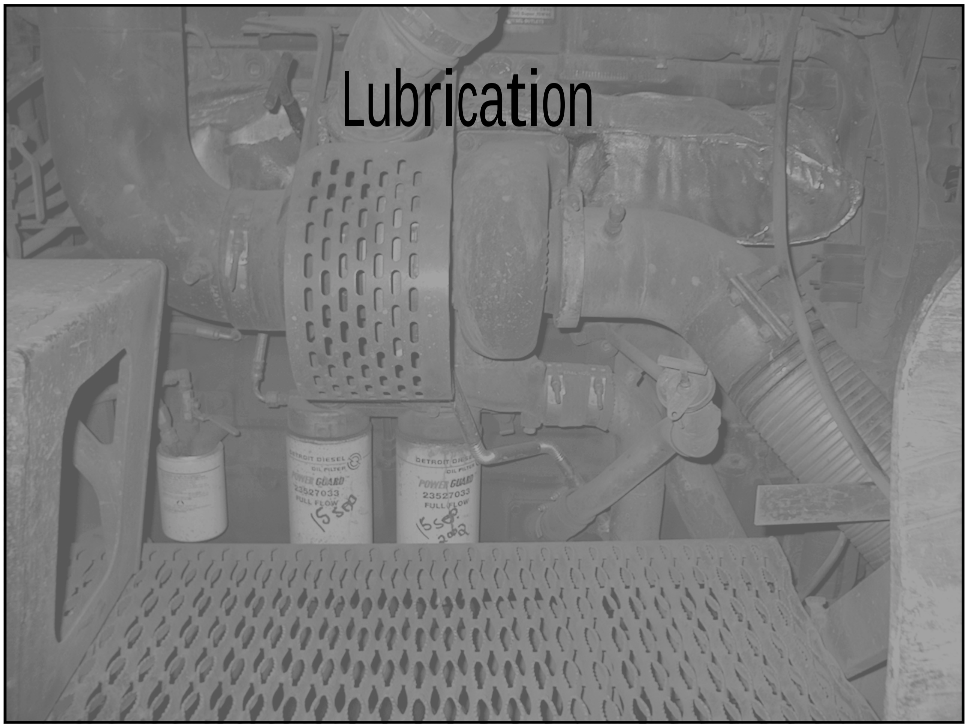
SULPHUR CONTENT - GUARANTEED < 50 ppm

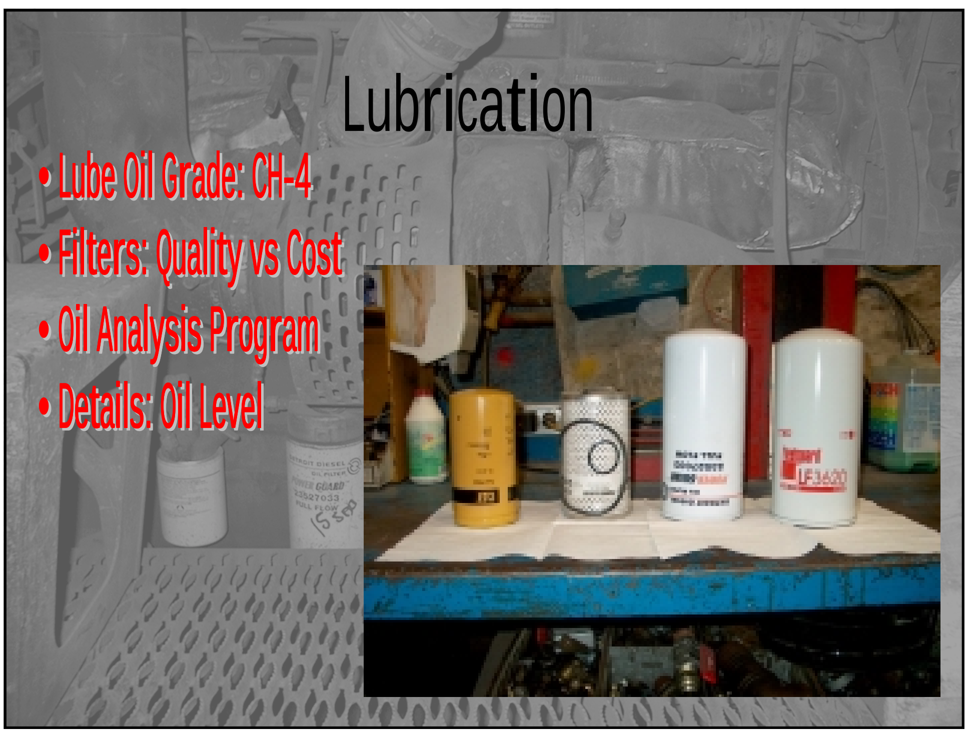
SUPERIOR L-10 PERFORMANCE (PREMIUM ADDITIVE PACKAGE)

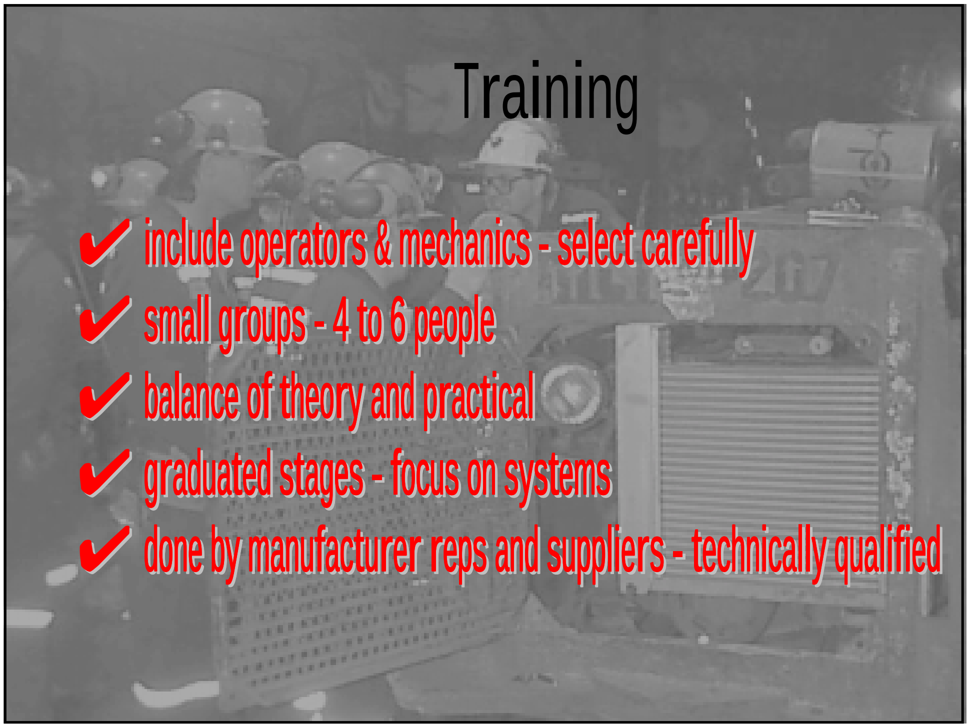
CETANE NUMBER - UNTIL EXPANSION & UPGRADE COMPLETE >43
- AFTER EXPANSION & UPGRADE COMPLETE >48

AROMATICS - WE WILL DETERMINE THROUGH TESTING AND PROVIDE ACTUAL LEVEL AS REQUIRED. THE AROMATIC LEVEL WILL BE LOWER THAN TYPICAL INDUSTRY LEVELS.

OTHERWISE MEET GENERAL STANDARDS BOARD (CGSB) TYPE "A" SPECIFICATIONS (90% POINT-</=290°C, FLASH->/=52°C, LUBRICITY- ETC.). PLEASE SEE CGSB TYPE "A" SPECIFICATION ATTACHED COMPLETE WITH THE ACTUAL PRODUCT SPECIFICATIONS.


Lubrication


Lubrication
• Lube Oil Grade: CH-4
• Filters: Quality vs Cost
• Oil Analysis Program
• Details: Oil Level


Training
✔ include operators & mechanics - select carefully
✔ small groups - 4 to 6 people
✔ balance of theory and practical
✔ graduated stages - focus on systems
✔ done by manufacturer reps and suppliers - technically qualified

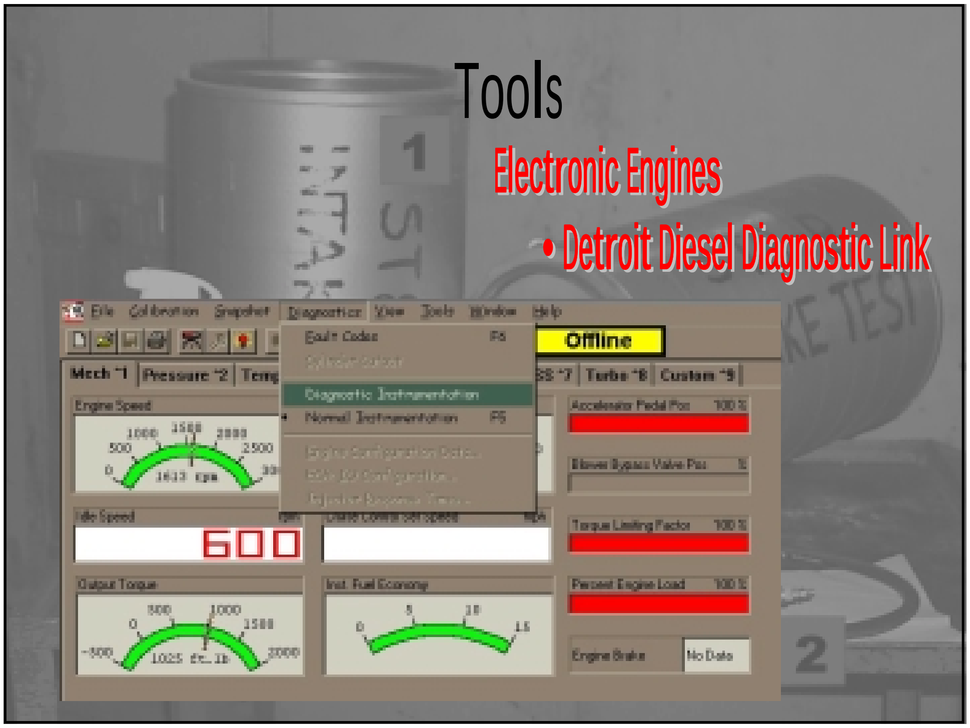

Tools
1
ST8-B
INTAKE TEST
ST8-B
INTAKE TEST
3
2


Tools
Exhaust Emissions - UGAS


Tools
Intake Testing
1
ST8-B
INTAKE TEST
ST8-B
INTAKE TEST
3
2


Tools
Intake & Exhaust
•Pressure / Restriction
Dwyer


Tools
Cooling Systems
•IR Temp Gun
INTAKE TEST


Tools
Electronic Engines
• Detroit Diesel Diagnostic Link
Offline
600


Contact Info
www.deep.org
www.dieselnet.com
Cambrian College
Bob Huzij
(705) 566-8101
rbhuzij@cambrianc.on.ca
Sean McGinn
(514) 918-6597
smcginn@sympatico.ca

Question 1: Maintenance Audit

From the following list of audit findings prioritize the top 5 in order of relevance and do-ability

- Fuel transfer station unfiltered and hi contamination
- PMs are done "on paper" with no focus on engine
- Intake filters are replaced at will or randomly
- Emissions tests done with stain tubes and no protocol
- No engine training for mechanics in past 3 yrs
- Engine in-frame overhauls being done U/G in shop
- Using un-rated straight 30 engine oil
- Old (or new?) injectors sitting on bench covered in dirt in shop
- Replacement filter storage in open shop - very dirty
- Exhaust systems are all falling off and leaking

Question 2: Intake Systems

Operator "Supermucker Vic" comes flying into the shop at lunch time barking in every direction that the engine on his scoop stinks and the mechanics can't ever fix it right ---- change the intake filters NOW or else!!!

You are the mechanic, shop foreman is gone, what will you do?

Question 3: Exhaust Systems

The mechanic has been working on the problem and he has narrowed the problem down to a suspected faulty catalytic converter

You are the shop foreman and the mechanic is asking you what should he do - advice? He has never worked on those before and doesn't really know how they work!

Question 4: Fuel Injection

Next day - Vic's back! He is really losing it now - crimson red and veins popping. The production shifter and the shop foreman have decided that it must be faulty injectors.

Vic has finally been restrained and you need to do this right … do you change the injectors or…… ??

Question 5: Cooling Systems

So you fixed it, but … next week he's back and the engine is cutting out on a Stop Engine code for Hi Temp. Not about to have a repeat of the last fiasco so this time you are really going to nail it right, but… the shop foreman says just steam clean the rad.

What are the major steps in your troubleshooting process?

Question 6: Fuel Handling

A month later … same scoop is in for a PM and you discover dirt and sludge all the way from the fuel tank through the primary fuel filters… and 3 pails of gravel in the bottom of the fuel tank. Resisting the urge for immediate revenge you are going to go through this systematically.

What are the steps, where do you look? List 3 possible solutions.

Question 7: Lubrication

A year later … you and Vic have finally kissed and made up. He is in the shop one night topping up his engine oil and he tells you that he always adds an extra couple of liters because of hi oil consumption.

Being the cool qualified professional that you now are you nicely explain to Vic the following …. But then before you release the scoop you will do what?

Question 8: Tools

If you were to go after the top 3 tools you think would really help maintain engines for emissions and make a difference what would they be and why?

Engine Emissions & Approval Procedures

Diesel Emissions Control in Mines Workshop

8th Annual Mining Diesel Emissions Conference (MDEC)

October 28, 2002
Toronto, Ontario

Mahe Gangal - NRCan/CANMET

Engines are tested for:

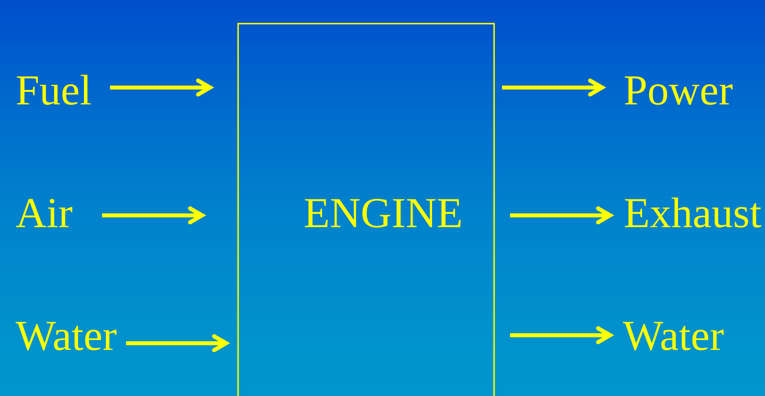
- Fundamental research
- Development
- Performance monitoring
- Routine production testing
- Certification testing

Wide Range of knowledge & skills is required

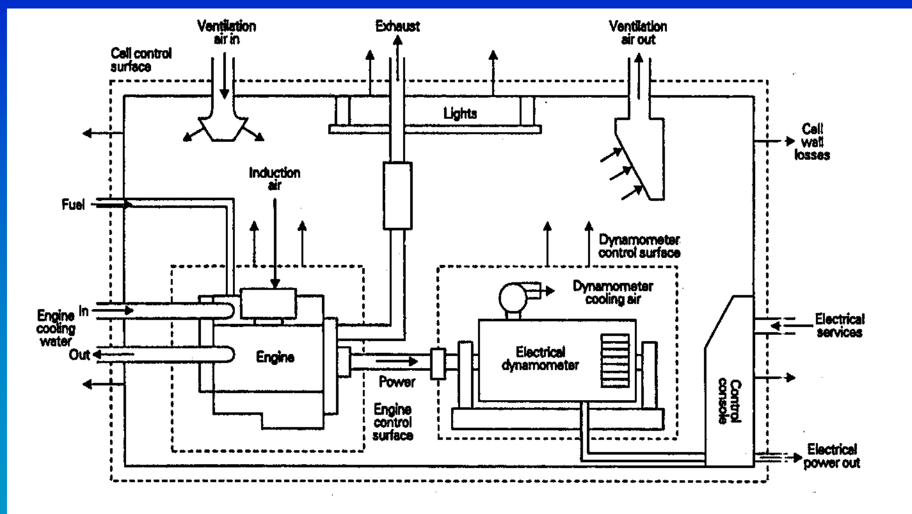
Main Inflows and outflows in a Test Cell

IN	OUT
Fuel	Exhaust
Ventilating air	Ventilating air
Cooling water	Engine cooling water
Electricity for services	Heat

Inflows and outflows - Engine



Engine Test Cell Description



Ref. Engine Testing, M. Plint & A. Martyr, SAE International

Engine Installation

- Coupling of the engine to the dynamometer
- Connections for
  - Combustion air
  - Fuel supply
  - Water supply (engine cooling, after turbo)
  - Exhaust gas (outlet, sampling lines to instruments)
  - Various temperature probes
  - Various pressure sensors
- Trial engine run
- Setup of engine test parameters

Measurements

- Engine speed
- Engine torque
- Engine power
- Fuel rate
- Combustion air
- Temperature (intake air, exhaust gas, oil, fuel, turbo, water..)
- Pressure (intake air restriction, back pressure, oil, turbo..)
- Humidity, dewpoint of combustion air

Exhaust Gas Measurements

- Gases
  - CO, CO_2, O_2, NO, NOx, THC, SO_2
- Particulate Matter
  - Full or micro-dilution DPM system
  - DPM sampling on conditioned filters
  - Sampling flow rate
  - Sampling time
  - Sampling air temperature
- Exhaust Quality Index (EQI) is calculated

Engine Approval Procedures

Definitions:

Applicant - Manufacturer of engine or machine

Certification Officer - Issues certificate

Approval - Document on engine approval

Approval Plate - Installed on equipment

Rejection Letter - Indicates that engine is not suitable for use in mines

Engine Approval Procedures

- **Manufacturer makes an application for equipment testing and certification**
- **Test Lab provides testing schedule & requirements**
- **Applicant sends engine to be tested with related documents**
- **Engine sent should be ready for testing**
- **Testing proceeds as per standard**

Engine Approval Procedures

- **Test results are classified "Industrial Confidential"**
- **Engine not conform to standard requirements**
  - **Applicant informed for reasons, and corrective actions are discussed**
  - **Engine re-tested or approval not granted**

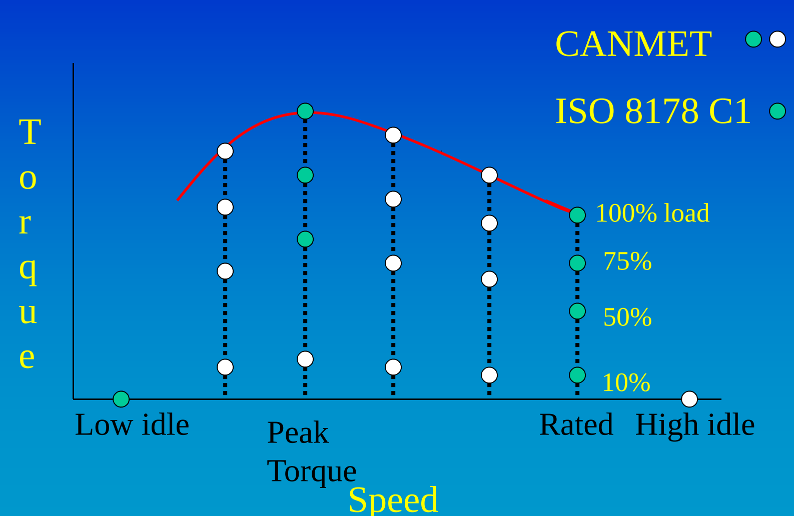
Engine Approval Procedures

- Engine conforms to all standard requirements
  - Test data report and approval provided
  - Ventilation rates are recorded in the ventilation list of approved engines for public distribution
  - Ventilation plates to be installed on the equipment
  - Testing for CANMET, MSHA or other other standards can be done at the same time - manufacturer should discuss requirements prior to any testing

Engine Testing

- Follow required standard (eg. CSA M424.M90)
- Run the engine for power and fuel rate to make sure that engine meets engine specifications
- Perform gas search for CO and NOx covering the entire engine power range to ensure that gas concentrations are within the test pass/fail limits
- Set the engine parameters as per specifications
- Run the engine at as per test cycle modes
- Determine ventilation rates as per standard

Steady State Test Cycle



CSA Ventilation Rate Calculations

Example:

Gas flow rate = 1223 lb/hr CO = 509 ppm

NO = 403 ppm NO_2 = 10 ppm

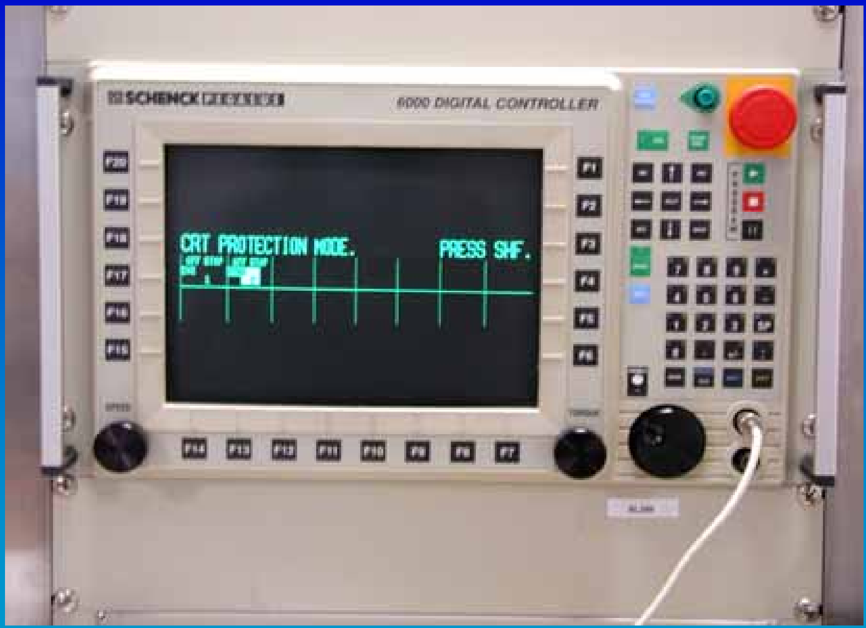
SO_2 = 80 ppm DPM = 90.2 mg/m^3,

EQI = 237.4

$$\text{Vent Rate} = \frac{\text{gas flow rate} \times (EQI/3)}{\text{Air density} \times 60} = 21{,}506 \text{ CFM}$$

The maximum vent rate at all mode point is the CSA prescribed ventilation rate

AC Dynamometer



Dynamometer Digital Controller

AC Dynamometer Drive

Gas Cart

Instrument Calibration Gases

Fuel Meter

Balance Room

Air Intake System

Exhaust Gas System

Data Acquisition System

MSHA'S DPM STANDARD: DIESEL PARTICULATE MATTER EXPOSURE OF UNDERGROUND METAL AND NONMETAL MINERS

Bill Pomroy and George Saseen

MDEC 2002

Background

- Rule published in FR on January 19, 2001
- Legal challenge filed January 29, 2001
- All parties agreed to attempt to negotiate mutually acceptable settlement
- 2 partial settlement agreements thus far
- Provisions on:
  - Fuel, maintenance, engines, training, and recordkeeping in effect July 5, 2001
  - DPM interim limit, compliance determination, environmental monitoring for DPM in effect July 20, 2002

Background

- Provisions effective as of July 20, 2002:
  - §57.5060(a) Interim concentration limit
  - §57.5061 Compliance determinations
  - §57.5065(a) and (b) Fueling
  - §57.5066 Maintenance
  - §57.5067 Engines
  - §57.5070 Miner training
  - §57.5071 Environmental monitoring
  - §57.5075 Diesel particulate records

MSHA'S DPM STANDARD:
DIESEL PARTICULATE MATTER EXPOSURE OF UNDERGROUND METAL AND NONMETAL MINERS

United States Department of Labor
MSHA
Mine Safety and Health Administration

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  - §57.5061 Compliance determinations
  - §57.5065(a) and (b) Fueling
  - §57.5066 Maintenance
  - §57.5067 Engines
  - §57.5070 Miner training
  - §57.5071 Environmental monitoring
  - §57.5075 Diesel particulate records

Background

❖ Other terms of July 15, 2002 partial settlement agreement:
- MSHA will provide compliance assistance (DPM baseline sampling and information on DPM controls) until July 19, 2003
- Violations of interim limit will be cited beginning July 20, 2003
- Feasible engr or admin controls required; PPE required if exposure exceeds limit despite feasible engr and admin controls
- Job rotation not allowed for compliance

Background

- Personal sampling for compliance determinations
- Two step process for determining compliance with interim limit
- Mine operators must develop and implement written compliance strategy
- MSHA may take "appropriate enforcement action" against mine operators who do not take good faith steps toward developing and implementing written compliance strategy

Background

- New rulemaking initiated; addresses:
  - § 57.5060(a) and (b) DPM limits
  - § 57.5060(c) Time extensions to reach limits
  - § 57.5060(d) Exceptions to limits
  - § 57.5060(e) Use of PPE
  - § 57.5060(f) Use of administrative controls
  - § 57.5061(b) Use of EC as DPM surrogate
  - § 57.5061(c) Sampling strategy
  - § 57.5062 DPM control plan
  - Technological and economic feasibility
  - Paperwork burden

Scope and Application

- Covers all MNM mine operators that use diesel equipment underground
- Independent contractors considered mine operators under Mine Act
  - Maintenance and engine requirements *do not apply* if contractor presence is infrequent, short duration, irregular (same for delivery trucks)
- Customers and customer vehicles not covered

§57.5060(a) Interim DPM Limit

- Mine operator must limit exposure to DPM by restricting average 8-hr equivalent full-shift airborne concentration of total carbon to:

$$400_{TC}\ \mu g/m^3$$

§57.5060(a) Interim DPM Limit

- Why limit total carbon ?
  - Can't sample/analyze DPM
  - DPM consistently 80%-85% total carbon
  - sampling/analysis for total carbon meets NIOSH accuracy criteria at low concentration
- §57.5060(a) has 2 components:
  - Limit established at $400_{TC}\ \mu g/m^3$
  - Mine operators must restrict exposures

§57.5060(a) Interim DPM Limit

- Per settlement agreement, restricting exposures requires mine operators to use “hierarchy of controls”
  - Feasible engineering and administrative controls, including work practice controls, must be implemented first (job rotation not allowed as means of compliance);
  - If exposures continue to exceed established limit . . . ;
  - . . . use of personal protective equipment (respirators) is required

§57.5060(a) Interim DPM Limit

- As published in FR in January 2001:
  - Administrative controls prohibited (defined as job rotation)
  - Use of PPE (respirators) greatly restricted
- Per settlement agreement:
  - Administrative controls permitted (includes work practice controls in general, but not job rotation)
  - PPE (respirators) required if DPM exposures exceed interim limit despite feasible engr and administrative controls

§57.5060(a) Interim DPM Limit

- Standard is "Performance Oriented"
  - Mine operator chooses controls
- Engineering controls eliminate hazard through substitution, isolation, enclosure, and ventilation. Examples:
  - DPM exhaust filters
  - Low emission engines
  - Environmental cabs (filtered breathing air)
  - Ventilation upgrades (main or auxiliary)
  - Alternate fuels, fuel additives
  - Remotely controlled equipment

§57.5060(a) Interim DPM Limit

- Administrative, including work practice controls, change the way work tasks are performed to reduce or eliminate hazard
  - Job rotation (an administrative control) as a means of compliance expressly prohibited
  - Limits on unnecessary idling
  - Limits on lugging (low speed, high load)
  - Speed limits, one-way travel
  - Limits on equipment (or hp) in area or split
  - Areas designated "off limits" for personnel or for diesel equipment

§57.5060(a) Interim DPM Limit

- If exposure exceeds interim limit despite all feasible engr and administrative controls, PPE required as means of compliance
- PPE also required while engr and admin controls being established
- When PPE required, respiratory protection program per ANSI Z88.2 also required (written SOP's, fit testing, storage/cleaning training, inspection, surveillance)

§57.5061 Compliance Determinations

- Per settlement agreement:
  - Compliance determination based on single, shift-weighted (8-hr), full shift, personal exposure sample
  - Sampling train includes 10-mm Dorr Oliver nylon cyclone and SKC DPM sample cassette with integral submicron impactor and tandem quartz fiber filters
  - Sample analyzed for elemental carbon (EC) and organic carbon (OC) per NIOSH Method 5040

§57.5061 Compliance Determinations

❖ Per settlement agreement:

- DPM limit expressed as limit on airborne concentration of total carbon (TC)
- EC + OC = TC
- Due to possible interference from other OC sources in mine (tobacco smoke, drill oil mist), TC based on EC + OC may include non-DPM carbon
- If EC + OC exceeds interim DPM limit, TC will also be determined by EC x 1.3 = TC
- EC x 1.3 reasonable estimate of TC based on sampling at 31 MNM mines

§57.5061 Compliance Determinations

❖ Per settlement agreement:

EC + OC = TC

Compliance determination based on LOWER of TC values

EC x 1.3 = TC

§57.5061 Compliance Determinations

- Violations of the interim DPM limit will be cited only if measured DPM concentration exceeds the limit by a sufficient margin to insure, at 95% confidence level, that miner was actually overexposed
  - Compliance determination must take into account normal sampling and analytical errors, referred to as error factor
- Error factor for EC + OC = TC is 1.14
- Error factor for EC x 1.3 = TC is 1.12

SKC DPM filter cassette with submicron impactor and tandem quartz fiber filters

DPM Filter Cassette Mounted
On Cyclone In Lapel Holder

Personal Sampling For DPM In Gypsum Mine

§57.5061 Compliance Determinations

- Sampling and analysis for total carbon per this procedure satisfies NIOSH Accuracy Criterion

§ 57.5065 (a) & (b) Fueling Practices

- Diesel Fuel Used To Power Equipment In Underground Areas Limited To Sulfur Content Of 0.05%
- Operator Must Retain Purchase Records Noting Sulfur Content For 1 Yr
- Fuel Additives Must Be Registered With U.S. Environmental Protection Agency

§ 57.5066 (a) Maintenance Standards

- Approved Engines Must Be Maintained In Approved Condition
- Emissions-Related Components Of Non-Approved Engines Must Be Maintained According To Manufacturer Spec's
- Emissions Or Particulate Control Devices Must Be Maintained In Effective Operating Condition

§ 57.5066 (b) Maintenance Standards

- Equipment operators must be authorized and required to affix a visible and dated tag at any time they note any evidence that the equipment may need maintenance per § 57.5066 (a)
- Equipment tagged under § 57.5066 (b) must be promptly examined by person authorized to maintain diesel equipment
- Tag cannot be removed until examination
- Mine operator must maintain log of tags

§ 57.5066 (c) Maintenance Standards

- Persons Authorized To Maintain Diesel Equipment Must Be Qualified By Virtue Of Training Or Experience
- Mine Operator Must Retain "Appropriate Evidence Of The Competence" Of Any Person Who Performs Specific Maintenance Tasks Per The Maintenance Standards
- "Appropriate Evidence" Must Be Retained For 1 Yr After Any Maintenance

§ 57.5067 (a) Engines

- Any diesel introduced into the underground inventory of engines must either:
  - (a)(1) have affixed a plate evidencing approval under Subpart E of Part 7, or under Part 36
  - (a)(2) meet or exceed the applicable PM emission requirements of the U.S. EPA listed In Table 57.5067-1

§ 57.5067 (a) Engines

- MSHA conducted inventory of engines in all U/G MNM mines by engine serial number (completed Sept. 30, 2002)
- Engines introduced underground after the mine's inventory must be compliant with § 57.5067 (a)

§ 57.5067 (b) Engines

- "Introduced" means any engine added to the underground inventory of engines:
  - Engine in newly purchased equipment
  - Engine in used equipment brought into mine
  - Replacement engine that has different serial number than the one it is replacing
- "Introduced" *does not include* engine previously in mine inventory and rebuilt (must have same S/N), or engine transferred from another U/G mine operated by same mine operator

EPA Emission Requirements

EPA Category		PM Limit
Light Duty Vehicle/Truck		0.1 g/mile
Heavy Duty Highway Engine		0.1 g/bhp-hr
Nonroad Engines		
Tier 1	Less Than 11 hp	0.75 g/bhp-hr
Tier 1	11 hp To < 50 hp	0.60 g/bhp-hr
Tier 2	50 hp To < 100 hp	0.30 g/bhp-hr
Tier 2	100 hp To < 175 hp	0.22 g/bhp-hr
Tier 1	175 hp To 750 hp	0.40 g/bhp-hr

§ 57.5070 Miner Training

- Annual DPM Training Required For All Miners Who Can "Reasonably Be Expected To Be Exposed" To DPM
- Standard Specifies Training Content:
  - Health Risks Of DPM Exposure
  - Methods Used To Control DPM In Mine
  - Identify Persons Responsible For Maintaining DPM Controls
  - Actions Miners Must Take To Ensure Control Function Properly

§ 57.5071 Environmental Monitoring

- Mine operators must monitor as often as necessary to effectively determine if any miners are overexposed to DPM
- If overexposure identified, mine operator must promptly post notice of, and promptly complete corrective action
- MSHA will not cite for DPM overexposure based on mine operator's monitoring
- Violation only if mine operator monitoring indicates an overexposure, and no corrective action taken

§ 57.5075 Diesel Particulate Records

Required DPM records for provisions that are effective as of July 20, 2002:

Record	Retention Time
1. Fuel purchase records noting sulfur content	Purchase date + 1 yr
2. Maintenance log (tagging)	Date equipment tagged + 1 yr
3. Evidence of competence to perform diesel maintenance	Date maintenance performed + 1 yr
4. Annual training for miners potentially exposed to DPM	Training date + 1 yr
5. Environmental monitoring	Sample date + 5 yrs

SUMMARY

- All provisions in effect since July 5, 2001 continue to be effective without change
- Additional provisions on maintenance tagging and moving engines from one U/G to another added March 2002
- Interim DPM limit of 400 $\mu g/m^3$ in effect since July 20, 2002
- Compliance assistance until July 20, 2003
  - DPM limit will not be enforced until 07-20-02 at mines that cooperate in good faith with MSHA during compliance assistance

SUMMARY

- Compliance assistance will consist of
  - DPM baseline sampling - all UG mines
  - Information on feasible DPM controls
- Mine operators must develop and implement written compliance strategy

SUMMARY

- MSHA will Sample for Total Carbon (TC)
- Determining TC concentration requires 2-step process; each step has its own Error Factor
- Lower of TC values used for compliance determination
- For compliance with DPM limit, mine operators required to implement feasible engineering and administrative controls
- Job rotation not allowed for compliance

SUMMARY

- If DPM exposure exceeds limit despite all feasible engineering and administrative controls, respirators and respiratory protection program per ANSI Z88.2 are required
- After compliance assistance period, mine operators must conduct monitoring for DPM and control exposures accordingly
- Rulemaking initiated - - ANPRM issued 09-25-02; comments due by 11-25-2002

Canadian Regulation - Diesel

Diesel Emissions Control in Mines Workshop

8th Annual Mining Diesel Emissions Conference (MDEC)

October 28, 2002
Toronto, Ontario

Mahe Gangal - NRCan/CANMET

Presentation Overview

- Diesel equipment in u/g mines
- Regulations - Engine, Fuel, DPM
- Diesel engine ventilation requirements

(This discussion is for information only, please contact mine regulators for latest information and confirmation)

Diesel Equipment in U/G Mines

- **Over 40 years**
- **Advantage**
  - **Durability**
  - **Mobility**
  - **Fuel Economy**
- **Disadvantage**
  - **Toxic Gases**
  - **DPM**

  ↓

  Requires Control

Diesel Equipment in U/G Mines (1996 Survey Data)

ONTARIO*

LHDs	576		
Haulage	256	=	2250 (Total)
LDV	1418		

Total installed power = 258,000 HP

Diesel fuel consumed = 29,000,000 L

CANADA-Estimation double of above numbers

* OML 1996 Survey, J. Vergunst & C. Paquette

U/G Mine Regulation

- Provinces & Territories Jurisdiction
  - 9 Provinces (no mine in PEI)
  - 3 Territories
- Exemption (Federal)
  - Crown Corporations
  - Uranium mines

Diesel Equipment Standard

- CAN/CSA-M424.2-M90, Non-Rail-Bound Diesel-Powered Machines for use in non-gassy u/g mines
- Prepared by Technical committee on u/g diesel equipment
  - Chief inspectors
  - Labour
  - Mine operators
  - Manufacturers
  - CANMET

Diesel Equipment Standard

- Published by Canadian Standard Association (CSA)
- Approved as National Standard of Canada by the Standards Council of Canada (SCC)
- **Relating items**
  - Fire prevention
  - Equipment lighting
  - Steering
  - Electrical & hydraulic systems
  - Minimum emission standard
  - Minimum ventilation requirement

Diesel Engine Approval Standard CSN/CSA-M424.2-M90

- **Dynamometer emissions tests**
- **Undiluted exhaust gas not to exceed**
  - **2500 ppm of CO,**
  - **1500 ppm NOx**
  - **150 mg/m^3 of DPM**
  - **within full design range of engine output**
- **Reduction in fuel injection rate at higher altitude**

Diesel Engine Approval Standard CAN/CSA-M424.2-M90

- **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), where 3 is the maximum value of ambient AQI**

Exhaust Toxicity Criterion

Quality Index

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

Called EQI when gases (ppm) and DPM (mg/m^3) are measured in raw exhaust gas

Called AQI when gases (ppm) and DPM (mg/m^3) are measured in ambient air

Diesel Engine Approval Standard CAN/CSA-M424.2-M90

- Fuel employed shall conform to CGSB 3.16
- Ventilation rate pertains to worst conditions from an emissions toxicity point of view
- ventilation rate may be changed if permitted by regulatory authority
  - ventilation system efficiency
  - machine loading
  - fuel sulphur
  - multiple machine density, etc.

Diesel Engine Certification/Ventilation Requirements

Province/Territory	Standards CSA	MSHA	Notes
British Columbia	Yes	--	Ventilation as per CSA standard
Alberta	Yes	--	Ventilation as per CSA standards, Minimum of 4025 cfm at active headings
Saskatchewan	--	--	Minimum ventilation 105 cfm/hp
Manitoba	Yes	Yes	Certification by CANMET or MSHA Ventilation as per certification For non-approved engines ventilation 145 cfm/hp For multi-engines, ventilation with 100/75/50 rule and a minimum of 71 cfm/hp
Ontario	--	--	Minimum ventilation 100 cfm/hp
Quebec	Yes		Certification by CANMET or Part 31/32 of MSHA For non-approved engines ventilation 145 cfm/hp For MSHA engines, ventilation with 100/75/50 rule and a minimum of 71 cfm/hp

Diesel Engine Certification/Ventilation Requirements (Continued)

Province/Territory	Standards CSA	MSHA	Notes
New Brunswick	Yes	Yes	Certification for engines above 100hp Minimum ventilation 105 cfm/hp
Nova Scotia	Yes	Yes	Certificate that engine meets various conditions Minimum ventilation 105 cfm/hp
Newfoundland & Labrador	Yes	Yes	Certificate by CANMET or MSHA Ventilation as per certification For multi-engines, ventilation with 100/75/50 rule with a minimum of 74 cfm/bhp
Northewest Territories and Nunavut	--	--	Minimum ventilation 105 cfm/hp
Yukon	(see notes)		Requires approval number by an approved testing laboratory/other acceptable agency, Minimum ventilation of 75 cfm/hp plus normal requirements of the mine

Fuel Sulphur & Flash Point Specifications (CGSB Standards)

Fuel Standards	Maximum Sulphur, %	Minimum Flash Point, °C
*3.16-M86/M88, Regular Special	0.5 0.25	40 52
*3.16-99, Special-LS	0.05	52
**3.517-93, A-LS	0.05	40

* Mining Diesel Fuel ** Automotive LS Fuel

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	0.25	52
Newfoundland & Labrador	CAN/CGSB-3.16, Mining Diesel Fuel	
Northwest Territories and Nunavut	0.25	52
Yukon	0.25	52

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 vent rate increases by 30% by increasing fuel sulphur from 0.25 % to 0.05%

Exhaust Gas Treatment System Requirements

Saskatchewan	**Exhaust gas scrubber to be approved by the chief inspector**
Quebec	**Purifying or diluting exhaust gas**
New Brunswick	**Specifications on device**
Nova Scotia	**Maintain engine to prevent black smoke**
Newfoundland	**As per CAN/CSA-M424.2-M90**
Yukon	**Efficient scrubber for exhaust gases**

DPM Exposure Limits

British Columbia, Ontario, Quebec, New Brunswick, Nova Scotia, Northwest & Nunavut Territories	1.5 mg/m^3
Manitoba, Newfoundland & Labrador	ACGIH*
Alberta, Saskatchewan, Yukon	None

* 0.02 mg/m^3 EC on the notice of intended changes

Example of a CANMET Approved Engine Vent Rate

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

Ventilation Summary (S<0.05% Weight) CANMET Approved Diesel Engines

- Electronic Engines (12), Mechanical (11)
- Engine HP varies from 35 to 650, with an average of 234
- Ventilation rate (cfm/hp) varies from 49 to 148 with an average of 93
- CFM/HP - 22% higher with fuel sulphur of 0.2 % wt

QUESTIONS ?

The DPM Estimator for Metal and Nonmetal Mines

George Saseen

MDEC 2002

United States Department of Labor MSHA Mine Safety and Health Administration

Metal and Nonmetal Diesel Particulate Rule

- Personal exposure limit:
  TC = OC + EC or,
  TC = 1.3 x EC
- Based on technological and economic feasibility

Estimator Background

- Developed and published in proposed rule.
- Peer reviewed and published April 2000 in SME Journal.
- Posted on MSHA home page January 2001.
- Used by NIOSH to estimate technical feasibility of dpm level.

Estimating Effect of DPM Controls Using Estimator

- Concentration is related to:
  - Engine Emission Rate
  - Ventilation
  - Operations (HP, Hours, Duty Cycle)
  - Filtration Efficiency

How The Estimator Calculates DPM Concentrations After Controls Are Implemented

- Ventilation

  $DPM_{AFTER} = DPM_{BEFORE} \times [Q_1 / Q_2]$

- Engine Emission Rate

  $DPM_{AFTER} = DPM_{BEFORE} \times [e_2 / e_1]$

- Filter

  $DPM_{AFTER} = DPM_{BEFORE} \times (1 - n\%)$

Estimator Calculations

- Estimator simultaneously does the calculations for multiple controls on multiple pieces of equipment.

- Considers emissions, airflow, after-treatment (filtration or OCC) and cabs.

General Design

- Excel Spreadsheet
- Two Input Options
  - In-mine DPM Concentration Data Available
  - Laboratory Tailpipe Emission Data Available

General Design

- Excel Spreadsheet
- Column A Option - Concentration Data
  - Works well. The measurement works as a "calibration point".
  - MSHA analysis for 31 mines is based on concentration.
- Column B Option - Emission Data
  - Alternative when concentration data is not available.
  - Operational data must be estimated.
- Both enable "what if" simulations.

Estimator Operation

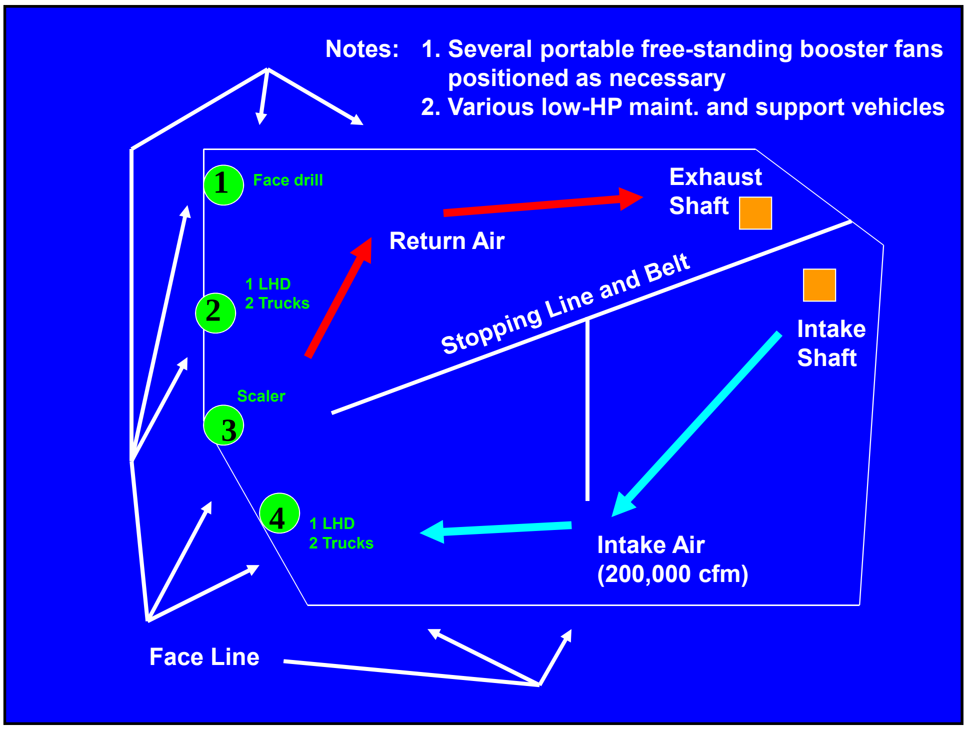
- Input - Engine Emissions
- Input - Ventilation
- Input - Operations Data (HP, Hours, Duty Cycle)
- Input - Efficiency of Controls
- Output - Concentration of dpm based on controls applied.
- *Change controls and repeat until desired dpm concentration is achieved*

Estimator Methodology

- Highest sample result used as basis for simulation
- Identify equipment involved (immediate vicinity and “upstream”)
- Three simulations for mine:
  - Baseline - existing conditions
  - Controls for 400 ug/m3
  - Controls for 160 ug/m3

Diesel Control Strategies

- Performance oriented rule
- Operators wanted ability to pick and choose controls from "toolbox" that best suits operation
- Estimator gives flexibility to assess multiple control scenario
- MSHA made prudent choices when selecting DPM controls based on available data
- *MSHA doesn't claim they are the best or optimum choices !*



WORK PLACE DPM EMISSIONS CONTROL ESTIMATOR **Mine Name: EXAMPLE MINE FOR 2002 DPM ROLLOUT SEMINARS**
(Estimator instructions at bottom of page)

		Column A	Column B
1. MEASURED OR ESTIMATED IN MINE DPM EXPOSURE (ug/m3)		850 ug/m3	---
2. VEHICLE EMISSION DATA			
DPM EMISSIONS OUTPUT (gm/hp-hr)			
INDIRECT INJECTION 0.3-0.5 gm/hp-hr	LHD x 2	0.3 gm/hp-hr	0.3 gm/hp-hr
OLD DIRECT INJECTION 0.5-0.9 gm/hp-hr	Haul Truck x 4	0.3 gm/hp-hr	0.3 gm/hp-hr
NEW DIRECT INJECTION 0.1-0.4 gm/hp-hr	Face drill	0.3 gm/hp-hr	0.3 gm/hp-hr
	Scaler	0.3 gm/hp-hr	0.3 gm/hp-hr
VEHICLE OPERATING TIME (hours)			
	LHD x 2	5 hours	5 hours
	Haul Truck x 4	5 hours	5 hours
	Face drill	3 hours	3 hours
	Scaler	3 hours	3 hours
VEHICLE HORSEPOWER (hp)			
	LHD x 2	460 hp	460 hp
	Haul Truck x 4	1080 hp	1080 hp
	Face drill	160 hp	160 hp
	Scaler	120 hp	120 hp
SHIFT DURATION (hours)		8 hours	8 hours
AVERAGE TOTAL SHIFT PARTICULATE OUTPUT (gm/bhp-hr)		0.27 gm/hp-hr	0.18 gm/hp-hr
3. MINE VENTILATION DATA			
FULL SHIFT INTAKE DIESEL PARTICULATE CONCENTRATION		0 ug/m3	50 ug/m3
VENTILATION AIR QUANTITY (CFM)		200000 cfm	200000 cfm
AIRFLOW PER HORSEPOWER		110 cfm/hp	110 cfm/hp
4. CALCULATED SWA DPM CONCENTRATION WITHOUT CONTROLS		---	992 ug/m3

****

		Column A	Column B
5. ADJUSTMENTS FOR DPM EMISSION CONTROL TECHNOLOGY			
ADJUSTED VENTILATION AIR QUANTITY (CFM)		200000 cfm	200000 cfm
VENTILATION FACTOR (INITIAL CFM/FINAL CFM)		1.00	1.00
AIRFLOW PER HORSEPOWER		110 cfm/hp	110 cfm/hp
OXIDATION CATALYTIC CONVERTER REDUCTION (%)			
	LHD x 2	0 %	0 %
IF USED ENTER 0-20%.	Haul Truck x 4	0 %	0 %
	Face drill	0 %	0 %
	Scaler	0 %	0 %
NEW ENGINE EMISSION RATE (gm/hp-hr)			
	LHD x 2	0.3 gm/hp-hr	0.3 gm/hp-hr
ENTER NEW ENGINE EMISSION (gm/hp-hr).	Haul Truck x 4	0.3 gm/hp-hr	0.3 gm/hp-hr
	Face drill	0.3 gm/hp-hr	0.3 gm/hp-hr
	Scaler	0.3 gm/hp-hr	0.3 gm/hp-hr
AFTERFILTER OR CAB EFFICIENCY (%)			
	LHD x 2	0 %	0 %
USE 65-95% FOR AFTERFILTERS.	Haul Truck x 4	0 %	0 %
USE 50-80% FOR CABS.	Face drill	0 %	0 %
	Scaler	0 %	0 %
6. **ESTIMATED FULL SHIFT SWA DPM CONCENTRATION AFTER IMPLENTATION OF CONTROLS**		**850 ug/m3**	**992 ug/m3**

Instructions:

Insert data values corresponding to initial conditions in the mine into the upper portion of the spreadsheet (above the dotted line) by placing the curser over the blue numbers and typing in the appropriate values. To the extent possible, use actual data values obtained through measurements in the mine (DPM concentrations, ventilation flows, etc.) or from equipment manufacturers (horsepower, emissions output, etc.). Where actual data or measurements are not available, estimate values.

Insert data values corresponding to planned or possible DPM controls into the lower portion of the spreadsheet (below the dotted line) by placing the curser over the blue numbers and typing in the appropriate values. The spreadsheet provides estimated values for the various controls.

Line 6, **ESTIMATED FULL SHIFT DP CONCENTRATION,** will display the estimated DPM concentration after implementation of the specified controls. **REMEMBER, THIS IS ONLY AN ESTIMATE, AND IT IS ONLY AS GOOD AS THE DATA USED TO CALCULATE IT.**

If you know the DPM concentrations in your mine (through sampling, for example), input all relevent data into both Column A and Column B, but note that only Column A results will be meaningful. If you do not know the DPM concentrations in your mine (ie. you have not conducted DPM sampling), input all relevent data into both Column A and Column B, but in this case, only Column B results will be meaningful.

For a more detailed description of this spreadsheet, and more detailed instructions in its use, see "Estimation of Diesel Particulate Concentrations in Underground Mines" by Robert Haney and George Saseen. This paper can be downloaded from MSHA's Internet web site (www.msha.gov).

WORK PLACE SWA DPM EMISSIONS CONTROL ESTIMATOR **Mine Name: EXAMPLE MINE FOR 2002 DPM ROLLOUT SEMINARS**
(Estimator instructions at bottom of page)

		Column A		Column B	
1. MEASURED OR ESTIMATED IN MINE DPM EXPOSURE (ug/m3)		850	ug/m3	---	
2. VEHICLE EMISSION DATA					
DPM EMISSIONS OUTPUT (gm/hp-hr)					
INDIRECT INJECTION 0.3-0.5 gm/hp-hr	LHD x 2	0.3	gm/hp-hr	0.3	gm/hp-hr
OLD DIRECT INJECTION 0.5-0.9 gm/hp-hr	Haul Truck x 4	0.3	gm/hp-hr	0.3	gm/hp-hr
NEW DIRECT INJECTION 0.1-0.4 gm/hp-hr	Face drill	0.3	gm/hp-hr	0.3	gm/hp-hr
	Scaler	0.3	gm/hp-hr	0.3	gm/hp-hr
VEHICLE OPERATING TIME (hours)					
	LHD x 2	5	hours	5	hours
	Haul Truck x 4	5	hours	5	hours
	Face drill	3	hours	3	hours
	Scaler	3	hours	3	hours
VEHICLE HORSEPOWER (hp)					
	LHD x 2	460	hp	460	hp
	Haul Truck x 4	1080	hp	1080	hp
	Face drill	160	hp	160	hp
	Scaler	120	hp	120	hp
SHIFT DURATION (hours)		8	hours	8	hours
AVERAGE TOTAL SHIFT PARTICULATE OUTPUT (gm/bhp-hr)		0.27	gm/hp-hr	0.18	gm/hp-hr
3. MINE VENTILATION DATA					
FULL SHIFT INTAKE DIESEL PARTICULATE CONCENTRATION		0	ug/m3	50	ug/m3
VENTILATION AIR QUANTITY (CFM)		200000	cfm	200000	cfm
AIRFLOW PER HORSEPOWER		110	cfm/hp	110	cfm/hp
4. CALCULATED SWA DPM CONCENTRATION WITHOUT CONTROLS		---		992	ug/m3

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		Column A		Column B	
5. ADJUSTMENTS FOR DPM EMISSION CONTROL TECHNOLOGY					
ADJUSTED VENTILATION AIR QUANTITY (CFM)		200000	cfm	200000	cfm
VENTILATION FACTOR (INITIAL CFM/FINAL CFM)		1.00		1.00	
AIRFLOW PER HORSEPOWER		110	cfm/hp	110	cfm/hp
OXIDATION CATALYTIC CONVERTER REDUCTION (%)					
	LHD x 2	0	%	0	%
IF USED ENTER 0-20%.	Haul Truck x 4	0	%	0	%
	Face drill	0	%	0	%
	Scaler	0	%	0	%
NEW ENGINE EMISSION RATE (gm/hp-hr)					
	LHD x 2	0.3	gm/hp-hr	0.3	gm/hp-hr
ENTER NEW ENGINE EMISSION (gm/hp-hr).	Haul Truck x 4	0.3	gm/hp-hr	0.3	gm/hp-hr
	Face drill	0.3	gm/hp-hr	0.3	gm/hp-hr
	Scaler	0.3	gm/hp-hr	0.3	gm/hp-hr
AFTERFILTER OR CAB EFFICIENCY (%)					
	LHD x 2	80	%	80	%
USE 65-95% FOR AFTERFILTERS.	Haul Truck x 4	80	%	80	%
USE 50-80% FOR CABS.	Face drill	0	%	0	%
	Scaler	0	%	0	%
6. **ESTIMATED FULL SHIFT DPM CONCENTRATION AFTER IMPLENTATION OF CONTROLS**		**237**	**ug/m3**	**313**	**ug/m3**

Instructions:

Insert data values corresponding to initial conditions in the mine into the upper portion of the spreadsheet (above the dotted line) by placing the curser over the blue numbers and typing in the appropriate values. To the extent possible, use actual data values obtained through measurements in the mine (DPM concentrations, ventilation flows, etc.) or from equipment manufacturers (horsepower, emissions output, etc.). Where actual data or measurements are not available, estimate values.

Insert data values corresponding to planned or possible DPM controls into the lower portion of the spreadsheet (below the dotted line) by placing the curser over the blue numbers and typing in the appropriate values. The spreadsheet provides estimated values for the various controls.

Line 6, **ESTIMATED FULL SHIFT DP CONCENTRATION,** will display the estimated DPM concentration after implementation of the specified controls. **REMEMBER, THIS IS ONLY AN ESTIMATE, AND IT IS ONLY AS GOOD AS THE DATA USED TO CALCULATE IT.**

If you know the DPM concentrations in your mine (through sampling, for example), input all relevent data into both Column A and Column B, but note that only Column A results will be meaningful. If you do not know the DPM concentrations in your mine (ie. you have not conducted DPM sampling), input all relevent data into both Column A and Column B, but in this case, only Column B results will be meaningful.

For a more detailed description of this spreadsheet, and more detailed instructions in its use, see "Estimation of Diesel Particulate Concentrations in Underground Mines" by Robert Haney and George Saseen. This paper can be downloaded from MSHA's Internet web site (www.msha.gov).

WORK PLACE DPM EMISSIONS CONTROL ESTIMATOR **Mine Name: EXAMPLE MINE FOR 2002 DPM ROLLOUT SEMINARS**
(Estimator instructions at bottom of page)

		Column A		Column B	
1. MEASURED OR ESTIMATED IN MINE DPM EXPOSURE (ug/m3)		850	ug/m3	---	
2. VEHICLE EMISSION DATA					
DPM EMISSIONS OUTPUT (gm/hp-hr)					
INDIRECT INJECTION 0.3-0.5 gm/hp-hr	LHD x 2	0.3	gm/hp-hr	0.3	gm/hp-hr
OLD DIRECT INJECTION 0.5-0.9 gm/hp-hr	Haul Truck x 4	0.3	gm/hp-hr	0.3	gm/hp-hr
NEW DIRECT INJECTION 0.1-0.4 gm/hp-hr	Face drill	0.3	gm/hp-hr	0.3	gm/hp-hr
	Scaler	0.3	gm/hp-hr	0.3	gm/hp-hr
VEHICLE OPERATING TIME (hours)					
	LHD x 2	5	hours	5	hours
	Haul Truck x 4	5	hours	5	hours
	Face drill	3	hours	3	hours
	Scaler	3	hours	3	hours
VEHICLE HORSEPOWER (hp)					
	LHD x 2	460	hp	460	hp
	Haul Truck x 4	1080	hp	1080	hp
	Face drill	160	hp	160	hp
	Scaler	120	hp	120	hp
SHIFT DURATION (hours)		8	hours	8	hours
AVERAGE TOTAL SHIFT PARTICULATE OUTPUT (gm/bhp-hr)		0.27	gm/hp-hr	0.18	gm/hp-hr
3. MINE VENTILATION DATA					
FULL SHIFT INTAKE DIESEL PARTICULATE CONCENTRATION		0	ug/m3	50	ug/m3
VENTILATION AIR QUANTITY (CFM)		200000	cfm	200000	cfm
AIRFLOW PER HORSEPOWER		110	cfm/hp	110	cfm/hp
4. CALCULATED SWA DPM CONCENTRATION WITHOUT CONTROLS		---		992	ug/m3

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		Column A		Column B	
5. ADJUSTMENTS FOR DPM EMISSION CONTROL TECHNOLOGY					
ADJUSTED VENTILATION AIR QUANTITY (CFM)		200000	cfm	200000	cfm
VENTILATION FACTOR (INITIAL CFM/FINAL CFM)		1.00		1.00	
AIRFLOW PER HORSEPOWER		110	cfm/hp	110	cfm/hp
OXIDATION CATALYTIC CONVERTER REDUCTION (%)					
	LHD x 2	0	%	0	%
IF USED ENTER 0-20%.	Haul Truck x 4	0	%	0	%
	Face drill	0	%	0	%
	Scaler	0	%	0	%
NEW ENGINE EMISSION RATE (gm/hp-hr)					
	LHD x 2	0.1	gm/hp-hr	0.1	gm/hp-hr
ENTER NEW ENGINE EMISSION (gm/hp-hr).	Haul Truck x 4	0.3	gm/hp-hr	0.3	gm/hp-hr
	Face drill	0.3	gm/hp-hr	0.3	gm/hp-hr
	Scaler	0.3	gm/hp-hr	0.3	gm/hp-hr
AFTERFILTER OR CAB EFFICIENCY (%)					
	LHD x 2	80	%	80	%
USE 65-95% FOR AFTERFILTERS.	Haul Truck x 4	80	%	80	%
USE 50-80% FOR CABS.	Face drill	80	%	80	%
	Scaler	80	%	80	%
6. **ESTIMATED FULL SHIFT SWA DPM CONCENTRATION AFTER IMPLENTATION OF CONTROLS**		**139**	**ug/m3**	**205**	**ug/m3**

Instructions:

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