Diesel Particulate Management

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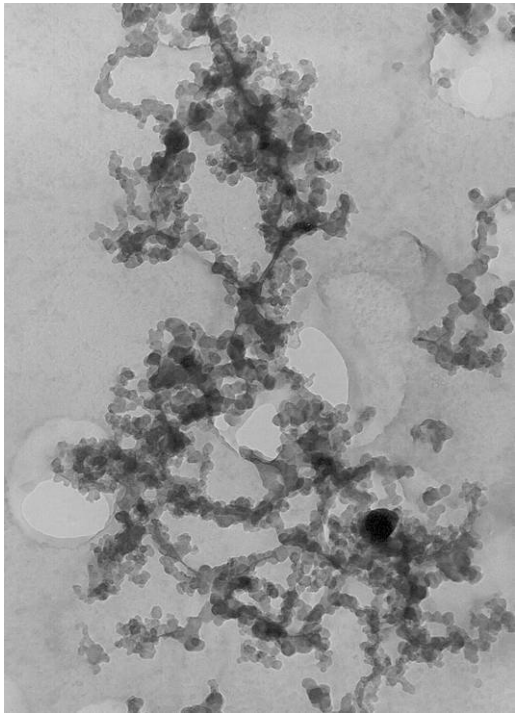
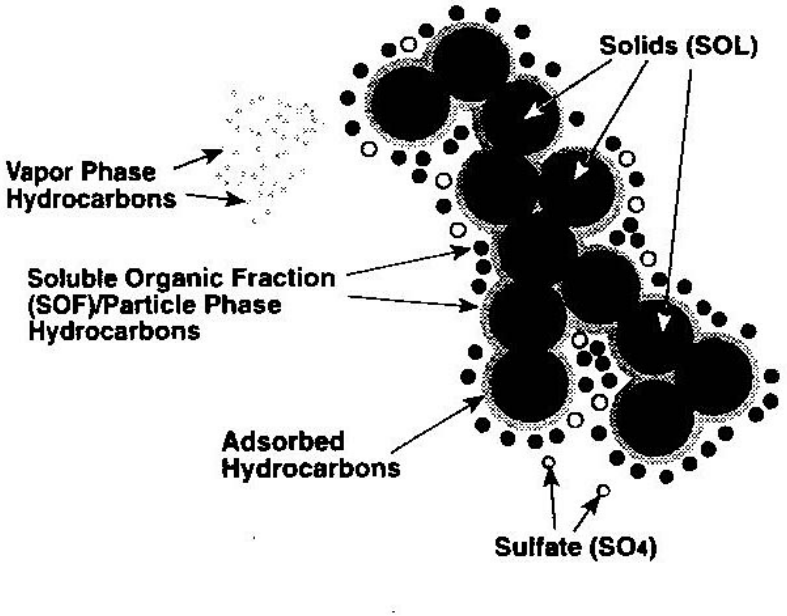
What are Diesel Particulates?

- Small particles (8-30 nm) called spherules disordered graphite structure (Elemental C)
- Rapidly agglomerate to form larger particles (<1 μm in aerodynamic diameter)
- Absorb significant quantities hydrocarbons and other organic compounds (Organic C)
- Contain traces of inorganic compounds
- Respirable size – lower end size spectrum reach deep into lungs

Diesel Particulate - Composition



Electron micrograph – mine diesel particulates showing spherules, chains and agglomerates



Schematic – mine diesel particulate showing spherules, chains and agglomerates

Source: A Rogers

OVERVIEW – HEALTH EFFECTS

- DPM has been studied since early 1950s
- Very strong lung and eye irritant at high exposure levels from the particles (largely overlooked)
- Some epidemiology studies show a weak but consistent trend of increased risk lung cancer (RR 1.2-1.5)
- IARC (2012) declared DP as a human carcinogen however its potency has not been quantified beyond reasonable doubt (probably never will be)
- Non malignant health effects probably the major issue of the future

My Opinion

- DP is a carcinogen however its potency is not quantified beyond reasonable doubt (probably never will be)
- Non malignant health effects probably the major issue of the future
- Very strong irritant (largely overlooked)
- Significant litigation possible in future

Management of Diesel Particulate

- There is NO single simple solution
- What may work for one operation may not be applicable for another
- Attention to detail is fundamental to success
- Structured approach necessary

Site Management Plans – Initial

- Need to be based on risk of employee exposure and have a clear implementation timetable
- Should include:
  - Low emission fuel (if available)
  - Emissions based maintenance programme
  - Workforce & driver education programme
  - Ventilation strategies consistent with the control of DP
  - Low emission engine purchasing policy
  - Controls on contractor or hire vehicles

Site Management Plan – Secondary

- If the initial plan isn't successful in lowering exposures
  - Low emission engines
  - Diesel exhaust filters
  - Air-conditioned & filtered operator cabins
  - Alternative power systems (electric)

Low Emission Fuel

- Generally available in developed countries but difficult to source in developing countries
- Most are ultra low sulphur (10ppm)
- Most “over the road” fuels have significant aromatics (10 – 30%)
- Some ultra low fuels are aliphatic based but may have increased sulphur content (100ppm)

Emissions Based Maintenance

- Routine monitoring of raw exhaust emissions by onsite personnel
- Interpreting those results in terms of maintenance faults
- Profiling engines over time
  - Scheduled maintenance or replacement
  - Improved fleet availability
- Monitoring control technologies
  - DPFs & DOCs

Emissions Based Maintenance

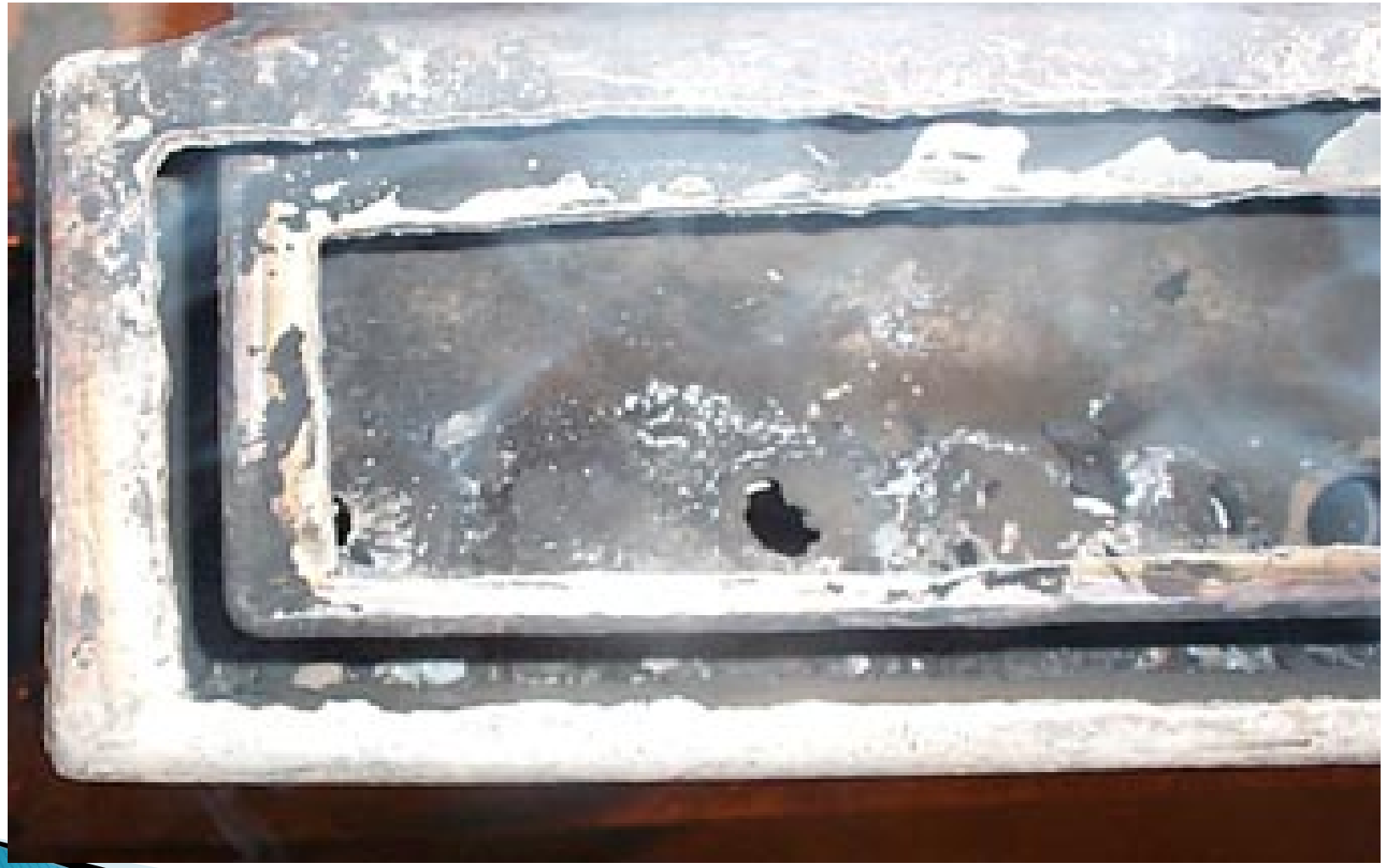
US Bureau of Mines – 1985

- Hydrocarbons :
  - Timing adjustment – up 306%
- Carbon monoxide:
  - Intake restriction & excess fuel – up 445%
- Oxides of Nitrogen:
  - Timing adjustment – up 50%
- Particulates:
  - Intake restriction & excess fuel – up 1038%

Particulate Results Vs Maintenance

Vehicle No.	Pre Maintenance EC mg/m^3	Post Maintenance EC mg/m^3	Maintenance Performed
PJB 132	139	46	New fuel pump Cleaned scrubber tank
PJB 114	131	40	New scrubber tank New injectors Adjusted fuel
Ram Car 1	159	71	Replaced injectors
PJB 103	102	61	Replaced injectors Cleaned scrubber tank & air intake system

Blocked Scrubber Tank



Source: B Davies

Comparison To Previous Data

Vehicle No.	EC mg/m^3 Pre Emissions Based Maintenance	EC mg/m^3 Post Emissions Based Maintenance
PJB 108	56-224	17
PJB 115	148-209	51
PJB 118	116-177	43
PJB 132	178-223	46

New Issues with Electronic Engines

- **What happens with a mechanical engine does not necessarily happen with an electronic engine in regard to emissions**
- **Sensors play a major role**
- **We are in a learning period as to what influences what!!**

Detroit Series 60 Engine Tests

Simulated faults at Rated power	% Change HC	% Change CO	% Change NOx	% Change DPM
Intake & exhaust Restriction	+13	+28	+8	+56
Severe Intake & exhaust Restriction	Nil	+79	+15	+114
Loss of Turbo Boost Pressure	-71	+1190	-21	+867

Source: CANMET 2014

Education

- Need for an integrated site education approach
- Workforce general awareness
- Operator specific training
- Maintenance personnel specific training

Production & Operator Practices

- Training and attitudes of operators key to a successful emission reduction programme
- Need for standard operating procedures which incorporate best practices

Ventilation

- Historically prime method of controlling emissions
- Some authorities require a set amount of air (typically 0.06 $m^3/s/kW$) irrespective of engine type or condition
- Considerably more air is required to ventilate for particulates than for gases

Low Emission Engine Purchasing Policy

- Upgrade when possible to low emission engines but seek out the experiences of operations using the chosen engines
- Beware OEM hype on engine emission performance. Some so called low emission engines have produced more emissions than those they replaced

Controls on Contractors

- Need for contractors to observe emissions based maintenance practices
- If the site has exhaust filters fitted to vehicles so should contractor vehicles
- No exceptions for limited use

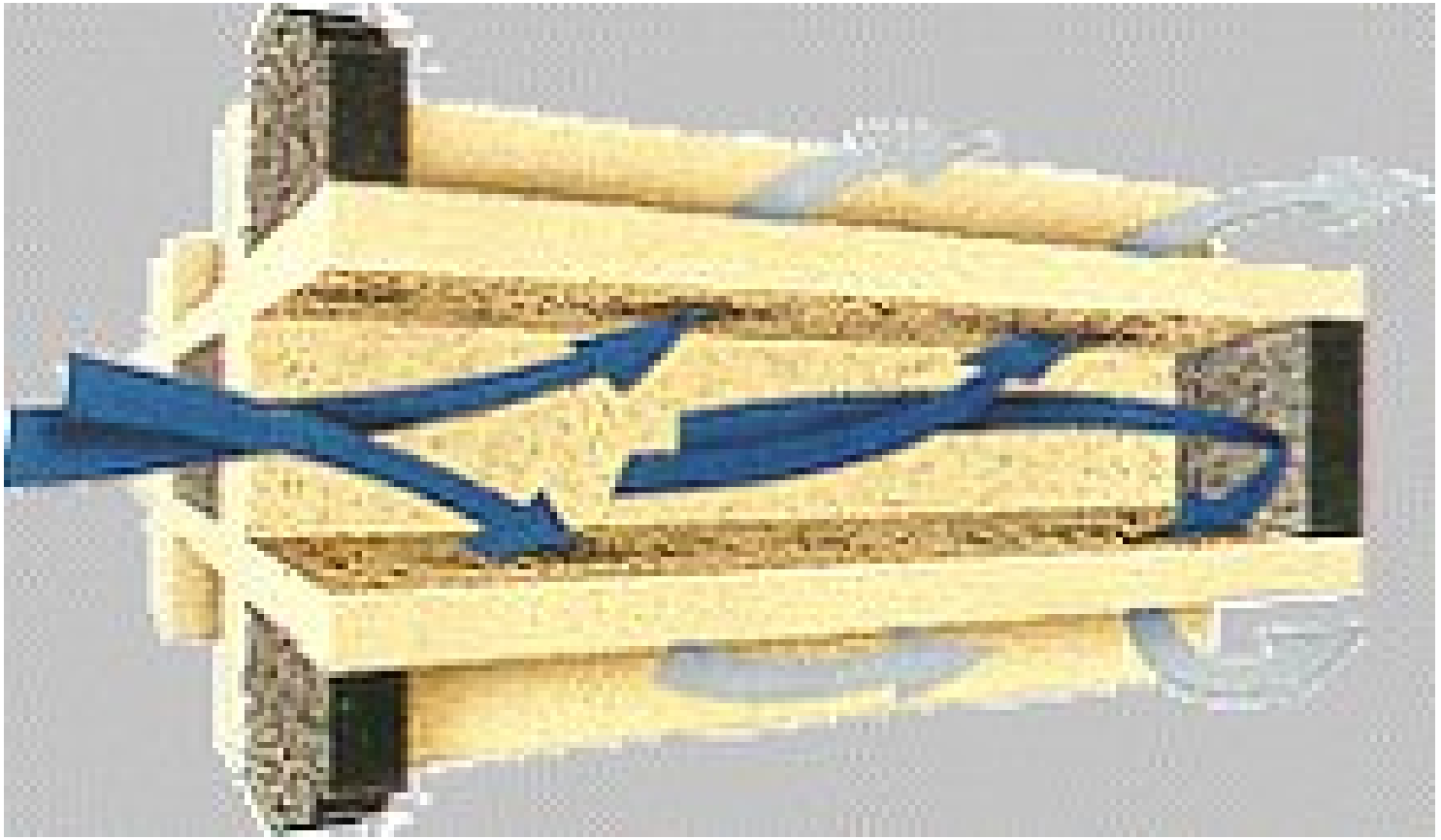
Engine Design

- Focus on combustion process (in-cylinder emission control)
- Electronically controlled
- Exhaust gas recirculation (EGR)
- Waste gated turbochargers
- Selective catalytic reduction (SCR) for NOx (need to add urea to exhaust)
- New fuel & lubricant formulations
- Caterpillar (2013) – DPFs as final step

Exhaust Treatment Devices

- Diesel Particulate Filters (DPF)
  - Mainly in metal/non metal mines
  - Active & passive designs
- Disposable Diesel Exhaust Filters (DDEF)
  - Mainly in coal mines

DPF Design



Source: BOM

DPF Selection

- Critical to match DPF to engine, vehicle and duty cycle
- Duty cycle and exhaust temperature profile required to aid selection
- Invest in an application engineering evaluation before purchasing

Diesel Test Rig for Engine –Filter Evaluations

Operating Considerations

- Keep idling to a minimum
- Keep engine working as hard and as hot as possible
- Monitor exhaust backpressure
- Ensure active systems get plugged in and are working

Maintenance Considerations

- Engine performance critical to make DPF work efficiently
- Check for leaks and damage regularly
- Measure and check DPF performance routinely (measure backpressures and DPM pre/post on regular basis)

Disposable Exhaust Filters

- Non flammable material
- Reduction in DP levels of >85%
- Introduced in USA coal mines in 1991 & Australian coal mines in 1995
- Significant ongoing cost but effective

New & Used DDEF

Source: B Davies

Air-conditioned & Filtered Operator Cabins

- Certainly decreases the exposure of operators
- Experience has shown that aggressive driving by some operators increases exposure of nearby workers

Respiratory Protective Equipment

- Respirators used in mines are generally used to protect against mechanically generated dusts
- Few RPEs have been specifically tested with EC as the challenge contaminant
- 3M 9913v has been tested against EC and has a filtration efficiency of >95% although recent research suggests this may be incorrect
- Major RPE research project currently being conducted by University of Wollongong and NSW WorkCover

Does All This Work?

Personal Monitoring for EC Pre & Post Control Strategy

LHD Operators in a Coal Mine

	Pre	Post
No. Samples	13	36
MVUE (mg/m^3 EC)	0.12	0.05
GSD	1.91	1.75
Lands (mg/m^3 EC) (95% LCL & UCL)	0.09–0.18	0.04–0.06

Source: B Davies

Summary

- DP isn't an issue that will disappear quickly
- No one single simple control technology currently exists. Operations need to determine the best package for their activities
- Effective control technologies do exist and can be made to work but it takes effort and attention to detail
- Maintenance is a key issue which has the potential for quick emission reduction gains with productivity returns as a bonus