Reducing diesel particulate matter in underground mines: Two successful examples

Workplace Safety North™

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Foreword

Diesel engine exhaust (DEE), including the diesel particulate matter (DPM) and the gaseous/vapour phase, has been classified by the International Agency for Research on Cancer (IARC) of the World Health Organization (WHO) as carcinogenic to humans (Group 1). For many years, diesel engines have been the workhorse in a large number of industries including mining. The exhaust from diesel engines contains particulate matter, nitrogen oxides, carbon monoxide, carbon dioxide, polycyclic aromatic hydrocarbons, sulfur oxides, metals, and many other chemicals [1].

This reference document is intended as a resource to assist Ontario mining operations in developing awareness regarding the complex mixture of DEE created during diesel fuel combustion. It also addresses associated health effects and the development of internal programs for controlling DEE/DPM exposures. Finally, this guide also contains examples based on site successes in controlling DEE/DPM exposures.

Although it is recognized that elimination by using alternate energy sources such as electrification of equipment is the most efficient strategy for eliminating worker exposure to DEE/DPM, this document focuses on engineering and administrative controls used for reducing the DPM component of the DEE.

This document was prepared by the Workplace Safety North (WSN) Workplace Environment Technical Advisory Committee (WE-TAC). WSN gratefully acknowledges the contributions of all members as well as the companies that submitted and participated in gathering information to develop this document for industry.

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Reducing diesel particulate matter in underground mines: Two successful examples

1. Introduction

Diesel engines provide power to a wide variety of vehicles, heavy equipment, and other machinery used in many industries including mining, transportation, construction, agriculture, maritime, and manufacturing operations. The exhaust from diesel engines contains particulate matter, nitrogen oxides, carbon monoxide, carbon dioxide, polycyclic aromatic hydrocarbons, sulfur oxides, metals, sulphates, and many other chemicals [1]. The composition of the mixture varies depending on many factors including engine type, operating conditions, lubricating oil, additives, emission control systems, maintenance, and fuel composition [2]. Diesel exhaust exposure presents an inhalation health hazard to workers.

This document will focus mainly on the particulate component of diesel exhaust, commonly referred to as diesel particulate matter (DPM). Results from animal studies indicate that this component contributes more to lung cancer outcomes than the gas/vapour phase component. Key studies of cancer in humans have focused on assessment of airborne elemental carbon [1] as a surrogate measure of DPM exposure. The International Agency for Research on Cancer (IARC) classifies diesel engine exhaust as a known human carcinogen (IARC Group 1) associated with lung cancer. It is also associated with acute health effects including irritation of the eyes and upper respiratory tract, light-headedness, nausea, cough, phlegm, and allergic reactions.

The objective of the project is to provide a resource regarding:

- the complex mixture of DEE, DPM, and other chemical agents emitted during diesel fuel combustion,
- the associated health effects,
- methods of controlling exposures, with a focus on the particulate phase component of DEE, and
- examples of site successes of controlling DEE/DPM exposures.

2. Definition

DPM is a component of DEE that includes soot particles that are made up primarily of elemental carbon, metallic abrasion particles, sulfates, and silicates. DPM particulates have a solid core consisting of elemental carbon, combined with other substances condensed onto the surface during generation, including polycyclic aromatic hydrocarbons (PAHs) [3].

3. Who can be exposed to diesel exhaust and particulates?

Occupations with potential exposure to DEE/DPM include miners, construction workers, heavy equipment operators, bridge and tunnel workers, railroad workers, oil and gas workers, loading dock workers, truck drivers, material handling operators, farmworkers, long-shoring workers, and auto, truck and bus maintenance garage workers.

Most heavy- and medium-duty trucks are equipped with diesel engines, as well as mining equipment, buses, locomotives and ships, bulldozers, tractors, and other types of equipment such as bucket lifts and diesel-fueled generators.

Approximately 9,100 workers in the Ontario mining industry are estimated to be exposed to DEE emissions [4]. CAREX Canada estimates that approximately 56% of mine workers exposed to DEE in Ontario are exposed at high levels due to the accumulation of emissions in underground operations.[4]

4. Health effects

4.1 Short-term (acute) health effects

Elevated short-term inhalation exposure to DEE is associated with coughing, headache, dizziness, dyspnea, bronchial constriction, and eye and respiratory tract irritation that can be severe enough to distract or disable miners and other workers. Exposures at very high levels can lead to systemic asphyxiation due to carbon monoxide poisoning.

4.2 Long-term health effects

Long term exposure to DEE is associated with an increased risk of chronic health effects, including cardiovascular, cardiopulmonary and respiratory diseases, lung cancer, and possibly bladder cancer. DPM is classified as a Group 1 (carcinogenic to humans) by the IARC. Exposure to DEE is associated with lung cancer, with limited evidence that it may also cause bladder cancer [1]. Cardiovascular disease is also linked to exposure to particulate matter air pollution, of which diesel emissions are a major contributor [5].

5. Standards in place to protect miners and other workers from diesel exposures

In Ontario, health and safety in mining operations fall under the jurisdiction of Regulation 854 - *Mines and Mining Plants*, made under the *Occupational Health and Safety Act* (OHSA). Specifically, the requirements for limiting worker inhalation exposure to DEE are prescribed under Subsection 183.1 (5). Worker exposure to DEE in industrial, agricultural, and construction sectors is regulated under other regulations made under the OHSA.

The Ministry of Labour, Training and Skills Development (MLTSD) enforces legislative requirements governing DEE and DPM. The MLTSD is proposing to add a new listing for DPM under Table 1 (Ontario Table of Occupational Exposure Limits) prescribed under Regulation 833 (*Control of Exposure to Biological or Chemical Agents*), with a time-weighted average limit (TWA) of 160 µg/m^3 as total carbon (TC). Considering that this change is expected to occur in the near future, as it has happened in the other provinces such as Saskatchewan [6], it will be important for companies to review existing controls for the required efficacy to appropriately reduce worker's exposure to DEE/DPM.

5.1 Underground mines

- Under Subsection 183.1(5) of Regulation 854, a miner's personal exposure to DPM must not exceed a time-weighted average (TWA) exposure of 400 micrograms per cubic metre (µg/m^3) as TC, which is approximately equivalent to 308 µg/m^3 as elemental carbon (EC) in the mining environment.
- Feasible engineering and administrative controls are required to reduce a miner's exposure to or below the TWA or the action level imposed by the operation.
- Respiratory protection must be used to supplement feasible engineering and administrative controls if such controls do not reduce a miner's exposure to DPM to levels below prescribed requirements, or if the use of engineering and administrative controls is not feasible. Requirements of a Respiratory Protection Program are noted in Sections 9 to 13 in Regulation 833 made under the OHSA.
- Other requirements may include:
  - fueling practices, including sulfur content and fuel additives,
  - maintenance of diesel-powered equipment,
  - limits on engine emissions,
  - annual training for miners,
  - use of diesel control boards to limit the allowable amount of equipment that can run in a workplace based on available air flow,
  - exposure monitoring, and
  - recordkeeping under Section 183 of Regulation 854.

6. Controlling diesel exhaust and particulate exposure

Control strategies should be developed and maintained to eliminate, where practicable, DEE/DPM exposure. Where elimination is impracticable, potential and existing hazards associated with worker exposure to DEE/DPM should be controlled. A reasonable strategy is best developed following the Hierarchy of Controls, where control strategies are ranked from the most effective (elimination or substitution) to the least effective (personal protective equipment). The Hierarchy of Controls is depicted to the right.

Eliminating the hazard or substituting the process by replacing diesel powered engines with electric or other types of power sources is the most effective strategy to eliminate worker exposure to DEE/DPM. The use of alternate fuels, such as biodiesel, is an example of substitution to reduce exposure, but potential risks introduced by alternative power sources or fuels must be taken into consideration.

Where elimination or substitution are not possible or practical, **engineering controls** provide the most effective strategy for reducing worker exposure to DEE/DPM. A combination, or layering, of controls is often required. Examples include [3]:

- performing routine preventive maintenance of diesel engines to minimize emissions and to help with their efficiency,
- installing engine exhaust treatment systems such as diesel particulate filters (DPFs), catalysts and/or converters, along with implementing a strict maintenance program that can achieve a particle trapping efficiency ranging from 80 to 99% [7,8].
- installing cleaner burning or low-emission diesel engines (e.g., Tier 4+ engines),
- using special fuels or fuel additives (e.g., biodiesel),
- providing positive pressure cabs with filtered air,
- maintaining the body of a vehicle to make sure that exhaust is not leaking into the cab or passenger area, and
- installing or upgrading the main or auxiliary ventilation systems, such as tailpipe or stack exhaust vents, to capture and remove emissions in maintenance shops or other indoor locations.

If a ventilation control system (VCS) such as ventilation-on-demand (VOD) is available, manually or automatically modify ventilation airflow distributions to accommodate diesel-powered total engine horsepower operating in the working area.

Administrative controls refer to changes in the way people work or how work tasks are performed to reduce or eliminate the hazard. Examples include [3]:

- awareness training for workers about the exposure to diesel exhaust and proper use of control measures,
- following regular maintenance of diesel engines,
- limiting speeds and using one-way travel routes to minimize traffic congestion,
- prohibiting and/or restricting unnecessary idling or lugging of engines (i.e. idling policies),
- restricting the amount of diesel-powered equipment and total engine horsepower operating in a given area,
- ensuring that the number of vehicles operating in an area does not exceed the capacity of the ventilation system (e.g. diesel control boards, dispatch system controls, etc.),
- designating areas that are off-limits for diesel engine operation and/or personnel travel, and
- reducing the hours of work exposed to diesel exhaust through scheduling.

Further to what was noted previously on **personal protective equipment** (PPE), such as respirators, PPE must only be used as a measure if the more effective measures under the Hierarchy of Controls are not obtainable, are impracticable, or do not eliminate or fully control the hazards.

Although it is recognized that the elimination of diesel exhaust hazards, through the use of alternate energy sources such as electrification of equipment, is the most efficient strategy for eliminating worker exposure to DEE/DPM, this document focuses more on engineering and administrative controls used for reducing worker exposure to the DPM component of diesel exhaust.

7. Examples of control strategies applied by operating mines

Two illustrative case studies are provided for sites that have successfully implemented controls to reduce exposure to diesel particulate matter:

1. Barrick Hemlo DPM Management 2014-2021
2. Musselwhite Mine DPF Installation Project

Example 1 - Barrick Hemlo DPM Management 2014-2021 [9]

Barrick Hemlo has been working to reduce DPM exposure. To achieve this, several different control strategies have been implemented. **Table 1** summarizes the Barrick Hemlo experience in controlling DPM. An accompanying slide deck is also presented in **Appendix A**. The table presents the challenges faced while implementing the control strategy, how the challenges were overcome, and the results/benefits of implementing changes.

Based on discussion with Barrick Hemlo, it was noted that the success of these different control strategies were dependent on the collaborative effort of all departments. This included weekly department meetings, especially at the onset of the project, to discuss the issues so that solutions could be put into place. In addition, it was important to work on one variable (control strategy) at a time to determine what worked and what did not. Once a particular control strategy was deemed successful, another control strategy was tried to determine its effect in lowering diesel emissions.

Moreover, Barrick's rationale was to start with the equipment that had the majority of the horsepower in the fleet, which included the larger equipment (such as scoop trams and haulage trucks). The specific issues with the smaller diesel equipment, which can generate a lot of emissions, have not been specifically addressed in this document. Note however that, generally, smaller engines do not create the heat for passive regeneration filters to burn off particulate, which leads to plugging of the filters (and subsequently, more cleaning and replacing of the filters).

Although 'active' diesel particulate filters assist with generating the heat required to burn off particulate, Barrick Hemlo (at the time) decided against implementing 'active' filters due to the costs of implementation. Currently, Barrick is working with a manufacturer to help find solutions for the smaller diesel engines. Some of the possible solutions include testing 'passive filters' with a DOC (Diesel Oxidation Catalyst—piece before the filter), or to coat the filter itself with the catalyst to help lower the regeneration temperature. The results of these strategies may be communicated in a future revision of this document.

Example 2 – Musselwhite Mine DPF Installation Project [10]

Similar to Barrick Hemlo, Musselwhite Mine has been working at reducing workers' exposure to DPM through the implementation of different control strategies. Their experience at controlling DPM at Musselwhite Mine, in particular through the use of diesel particulate filters (DPF), is presented in a slide deck in **Appendix B**. Beginning in the fall of 2013, various areas of the mine had started to become affected by high concentrations of DPM, such as the mechanical shop at the 488 metre level. Initially, to reduce worker's exposure to DPM, Musselwhite Mine reduced shift lengths in the shop and implemented mandatory respiratory protection in other areas of the mine that were affected by DPM. This resulted in adversely affecting the equipment output in the shop and the morale of those workers that had to wear respirators in designated locations of the mine.

Furthermore, providing additional ventilation in a timely manner, was not considered feasible or cost effective based on the existing mine configuration.

Since these control strategies were not considered viable or the most effective, Musselwhite decided to try DPFs. Like the Barrick Hemlo experience, Musselwhite worked with a supplier of DPFs to first target the larger pieces of equipment, such as scoop trams and haulage trucks. The maintenance department, using a collaborative approach with other departments, was instrumental in developing the business cases by testing, documenting, planning, and bringing experts to site to assist in the proper implementation of DPFs. Since the implementation of the filters, the DPM levels have decreased to well below the Occupational Exposure Limits (OELs) and Corporate Action Limits.

Although the results have been very sustainable and positive, the DPF's are "maintenance intensive" requiring a coordinated team effort along with investment to keep them performing optimally. To provide a cost-effective approach and to minimize delays, Musselwhite decided to clean their filters in-house with the use of an FSX filter cleaning system.

8. References

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7. OCRC - Diesel Particulate Matter Control Strategies in Mining - April 2017, http://www.occupationalcancer.ca/wp-content/uploads/2017/04/Diesel-Particulate-Controls_Mining_Final-1.pdf
8. OCRC - Controlling Diesel Particulate Matter in Underground Mines - June 2017, https://www.occupationalcancer.ca/2017/controlling-dpm-in-mining/
9. Barrick Hemlo DPM Management 2014-2021 (Hannah Demers).
10. Musselwhite Mine DPF Installation Project – MDEC 2017 conference

Table 1: Summary of control strategies for managing diesel particulate matter (DPM) for case example 8.1.

Control strategy	Control type	Challenge of implementation	How challenges were overcome (Solutions)	Results/benefits of change
Updating the underground equipment fleet	**Substitution**	• Cost of new equipment	• Increased investment into the mine and life of mine was extended	• Replacing older lower-tier engines with equipment containing Tier 4 Final engines creates lower emissions.
Engine filtration (diesel particulate filter-DPF)	**Engineering**	• Determining which equipment should have filters (DPF)	• Many area (fixed) air sampling monitors were placed strategically throughout the mine with repeated sampling over one year • Personal sampling on operators of specific equipment	• Sampling showed that the larger amount of horsepower put out by the smaller amount of the larger pieces of equipment was the biggest issue.
		• Finding a supplier to work with us	• Reached out to other sites • Maintenance department reaching out to their contacts. • Conducting research	• Filter change-out times dropped from half a shift to approximately 30 minutes on our large AD30 trucks.
		• Ease of Installation and removal of filters	• Supplier working hands on with maintenance underground to modify equipment, allowing for ease of installation and removal of filters	
		• Not knowing when to clean filters (no means of indication-back pressure monitor) • Logistics of cleaning DPF filters at a location far from site	• Installed back pressure monitors to determine when filters were plugging and to know when they needed to be cleaned (i.e. light in	• More timely cleaning of filters resulted in fewer emissions and was easier on the equipment and the filter.

Control strategy	Control type	Challenge of implementation	How challenges were overcome (Solutions)	Results/benefits of change
		causing shipping and quick turnaround of filters • Cleaning report was very basic with supplier not being available to answer questions (e.g. although cleaned, what is the state of the filter—damaged, etc.)	operator cab flashed to indicate cleaning required) • Considered in-house versus finding a contractor closer to site; benefit was to use a contractor closer to site to resolve issues	• A contractor was found closer to site to deal with logistical issues. Clear expectations were set with the contractor performing the cleaning.
Engine filtration (diesel particulate filter-DPF)	**Engineering**	• Knowing when to replace filter after (X) amount of filter cleaning	• Conduct emissions testing at certain number of hours (e.g. 250 hour PM) to monitor filter efficiency and health • Company can determine threshold in conjunction with manufacturer • Indicators of efficiency and health: CO and NO_2 emissions and smoke dot tests were worse with time; air sampling showed increase in DPM concentrations	• The benefits of using emissions testing and air sampling as an indicator of filter efficiency and health are decreased emissions due to proper filter change out schedules.
		• Achieving engine temperatures required for regeneration	• Directed as much hauling as possible up ramp while loaded to achieve required engine temperatures for regeneration • Catalyst coatings on DPFs and fuel borne additive to allow for a lower regeneration temperature ○ Supplier assisted with developing these options	• Filters regenerated more often with higher reliability, reducing the frequency of required filter changes.

Control strategy	Control type	Challenge of implementation	How challenges were overcome (Solutions)	Results/benefits of change
		• Operator buy-in and understanding	• Training with operators from diesel specialist and filter suppliers • Sharing sampling results and smoke dot test results • A lot of discussion with operators during change implementation; what results were expected, then confirming and sharing results	• Operators were much more engaged in the project when they started to see actual changes, such as noticing a physical difference to how much soot was in equipment tailpipes. • Operator ownership was paramount to ensuring that filters were changed if the back pressure lights came on or if any other issues occurred.
Fuel management - biodiesel	**Substitution**	• Seasonal temperature variations cause issues for fuel • Finding a supplier to provide biofuel despite temperature challenges for part of the year	• Finding a local supplier who understands temperature challenges and was willing to work with the mine to adjust fuel blend to meet seasonal temperature variations	• A reliable fuel supply from Thunder Bay was found that can be adjusted as required for temperature fluctuations. • Changing fuel was the first control put into place, and sampling showed a marked decrease in DPM levels in the underground mine when higher bio blends were used.
Emissions-based maintenance	**Engineering**	• Training of operators on testing equipment	• Bring diesel specialist in for training operators • Regular repetition of task allowed operators to become proficient	• Regular testing was done, and results were tracked and shared. • These results were used to indicate pieces of

Control strategy	Control type	Challenge of implementation	How challenges were overcome (Solutions)	Results/benefits of change
		• Getting regular emissions testing done	• Included as part of the 250-hour preventative maintenance (PM) cycle • Backpressure testing done as part of weekly checks	equipment that may have issues to address if the results were "off-trend." • This became a reliable tool to help with decision making and evaluating any changes.
		• Buy-in from maintenance department	• Doing the tests and sharing results, especially smoke dot test results	
Multi-disciplinary effort	**Administrative**	• DPM seen as only an "Industrial Hygiene problem" • Lack of understanding of what DPM is composed of • Lack of understanding of sampling for DPM as opposed to previous standard for Respirable Combustible Dust (RCD)	• Providing training on what DPM was and how it wasn't something that could be managed from one perspective. • Reaching out to other sites to see how they have managed this issue.	• We created the "DPM Management Committee" with representatives from different departments (H&S, maintenance, IH, engineering, reliability, management). • This committee met on a weekly basis in the beginning and all changes were made through group consensus.

APPENDIX A: Example 1 - Barrick Hemlo DPM Management 2014-2021

1

Project Background

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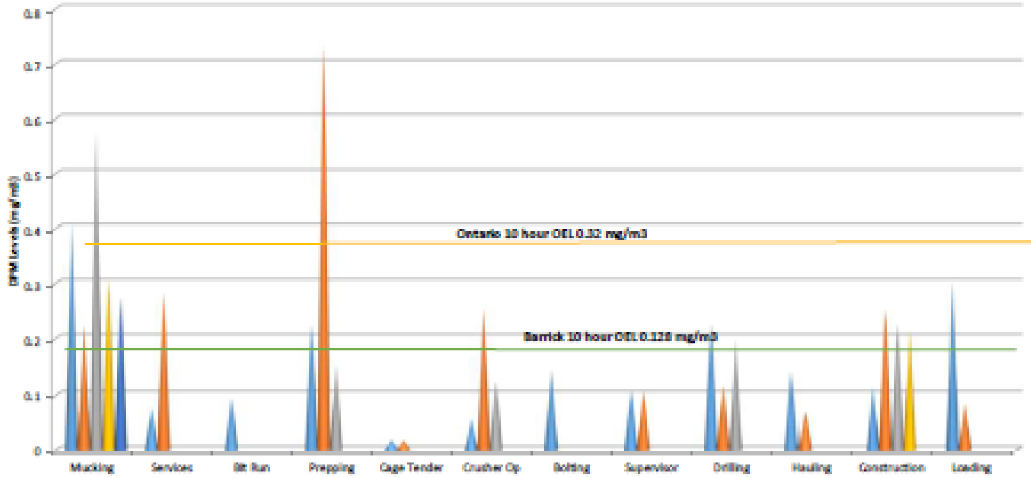
- Required to adhere to all Barrick Occupational Exposure Limits (OELs) unless a more stringent legal limit exists
- Ontario: 0.4mg/m³
- Barrick: 0.16mg/m³
- Initial sampling completed to determine baseline in the underground

2

DPM Personal Monitoring 2013-2014

BARRICK



3

Considerations

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- Multi-faceted, interdepartmental approach
- Emissions Based Maintenance
- Biofuel
- Filtration of equipment
- Ventilation changes/upgrades

4

Area Sampling Results – Biofuel 2016

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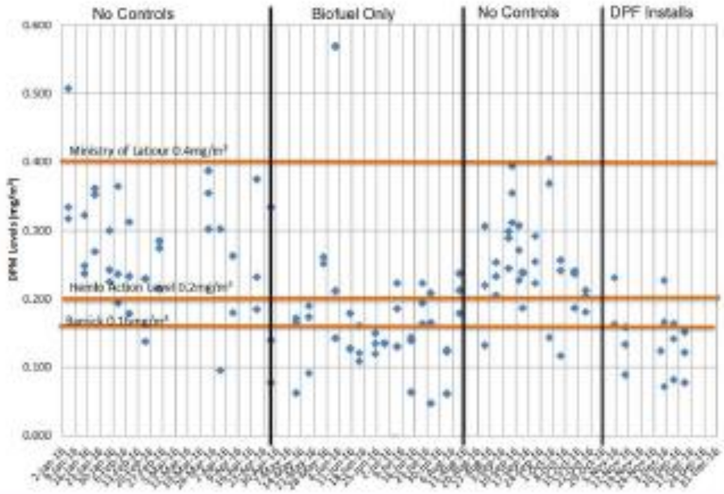

5

Equipment Filtration

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- Where to start?
  - Auxiliary equipment (personnel carriers, tractors etc.) vs. Heavy mining equipment (scoop trams, haul trucks)
- Auxiliary Equipment
  - Large percentage of fleet
  - Lots of movement – locations not easily accounted for
- Heavy Equipment
  - Approximately 72% of the fleet horsepower
    - Therefore, largest emissions volume
  - Working in proximity in mining areas

6

Heavy Equipment Filtration

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- CAT R1700G Scoops, CAT AD30 Haul Trucks
  - 9 units of each – both company and contractor units

- Considerations:
  - Passive vs. Active DPF regeneration systems
  - Passive: ceramic vs. silicon carbide
  - Ease of changing on equipment ("plug and play")
  - Cleaning options/locations

- **Conclusion:**
  - Passive regeneration, wallflow, silicon carbide filters
    - Test filters installed and run end of 2015-2016
    - Fleet wide installation began November 2016 – contractor equipment completed February 2017

7

DPF Installations

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- Emissions testing on all scoops and trucks at engine outlet and exhaust outlet, includes CO, CO_2, NO, NO_2 and smoke dot test capabilities
- Mechanics monitor backpressure with Magnehelic precision gauges
- Installation of data loggers to indicate engine back pressure levels – will alarm in operator's cab
- Backpressure Rule – 40 / 60 / 80 iwg

8

R1700Gs

- Minimal issues with installation – Plug and play
  - Crane and cables to remove/replace filter

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9

AD30 Haul Trucks

- Difficult installation location
- High backpressures upon installation and plugging quickly – some within 2-3 days of installation
- Not achieving passive regeneration – low duty cycles (not achieving the required 400°C over 30% of the shift)
- **Difficult Installations/Removals + Frequent changes = PRODUCTION LOSS**

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10

Filter Installation Challenges

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- Minimal room to maneuver filter
- Must go in on a tight angle
- Risk of injury and filter damage

11

Solution – Installation from Beneath

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- Remove a section of the undercarriage and create a removable "belly plate" that the filter will clamp onto

12

Installation/Removal

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13

Backpressure Issues

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- Initial pressure tests after installation were in range of 30-35 iwg for some trucks
  - Adjustment made to outlet area to reduce restriction provided approximately 10-15 iwg reduction in pressure

Before

After

14

Catalyzed DPF – assist with passive regen

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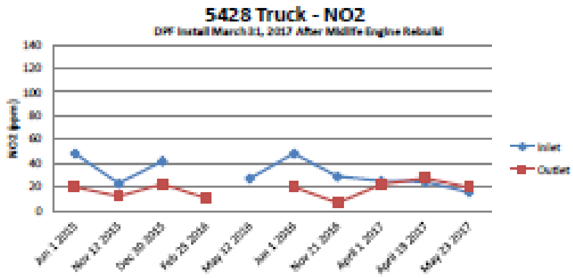
- Low duty cycles (exh. temp) created passive regen challenge
  - Low NO_2 results at outlet showed opportunity to change DOC catalyst formulation – raise NO_2 slightly to improve regen
  - Target NO_2 @ 50 ppm max. outlet side – significantly improved passive regen



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Results of Catalyzed DPF

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- As of the end of August 28 Truck has had 2 filter changes – 1st was over 500 hours, the second was at 490 hours
- In comparison 32 truck has had 7 filter changes in the same time frame (compare changing filters 2x weekly to once every 3-4 weeks)
  - Positive side to so many filter changes is that the maintenance department has become very efficient with it – change out time down to approximately 35 minutes

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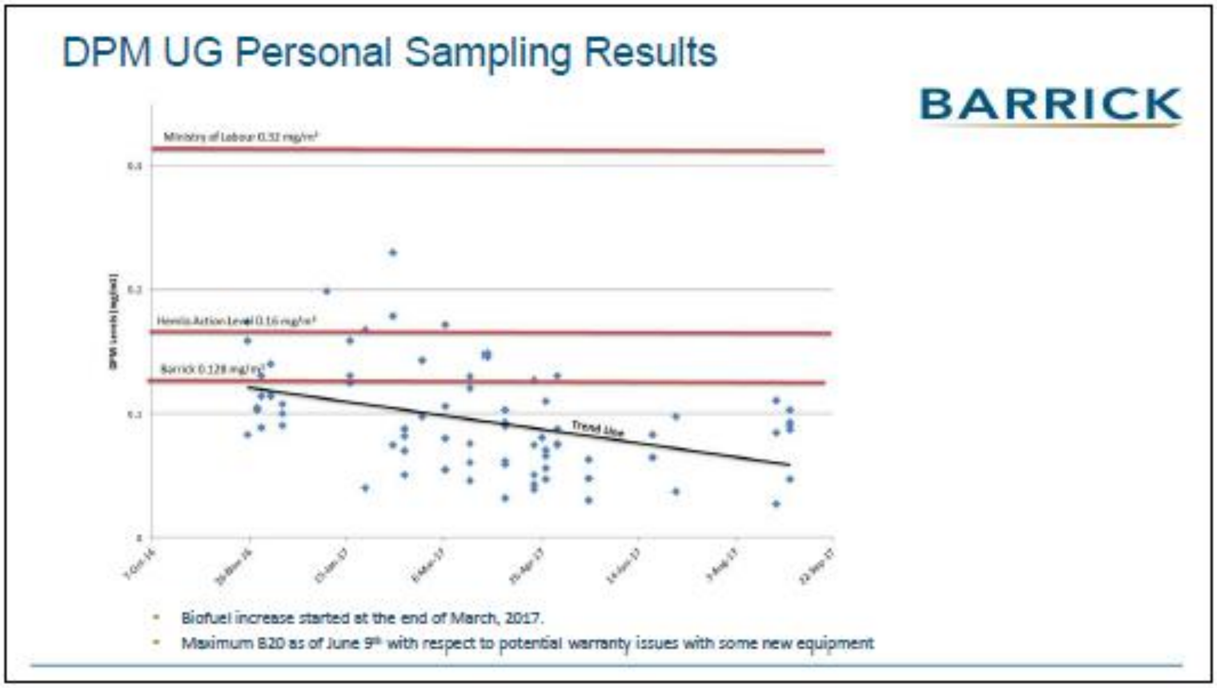
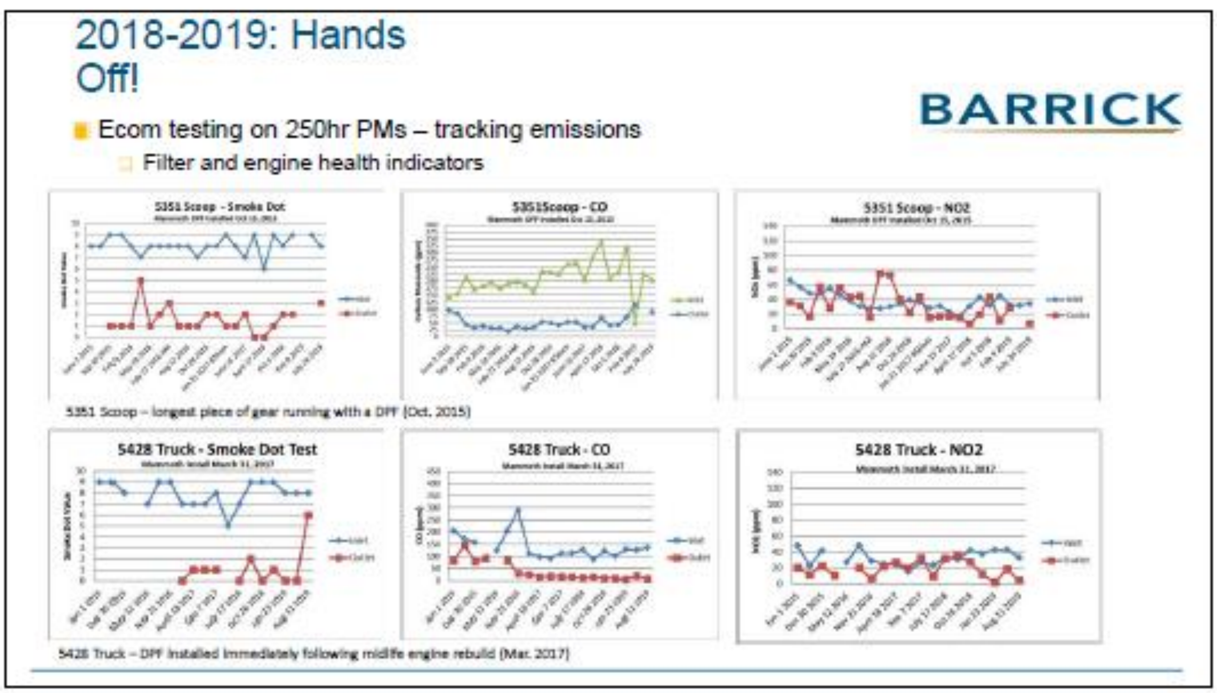

DPM UG Personal Sampling Results
BARRICK
Ministry of Labour 0.32 mg/m³
Hemlo Action Level 0.16 mg/m³
Barrick 0.128 mg/m³
Trend line
Biofuel increase started at the end of March, 2017.
Maximum B20 as of June 9th with respect to potential warranty issues with some new equipment

17


2018-2019: Hands Off!
BARRICK
Ecom testing on 250hr PMs – tracking emissions
Filter and engine health indicators
5351 Scoop - Smoke Dot
5351Scoop - CO
5351 Scoop - NO2
5351 Scoop – longest piece of gear running with a DPF (Oct. 2015)
5428 Truck - Smoke Dot Test
5428 Truck - CO
5428 Truck - NO2
5428 Truck – DPF installed immediately following midlife engine rebuild (Mar. 2017)

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Filter Changes and Cleaning

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- Cleaning continuing to be conducted with a local shop – turn around time approximately 24 - 36 hours barring unforeseen circumstances
- Provide a report on condition of filters, changes, damage etc.
- Scoop filters regularly go 500 hours between changes
- Truck filters are more problematic due to a lack of consistent engine temperatures, but generally have been reaching the 250 hour PM cycle
- Most filter changes can be planned and are relatively quick (30 minutes)
  - Practice makes perfect

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Personal Sampling 2018-2019

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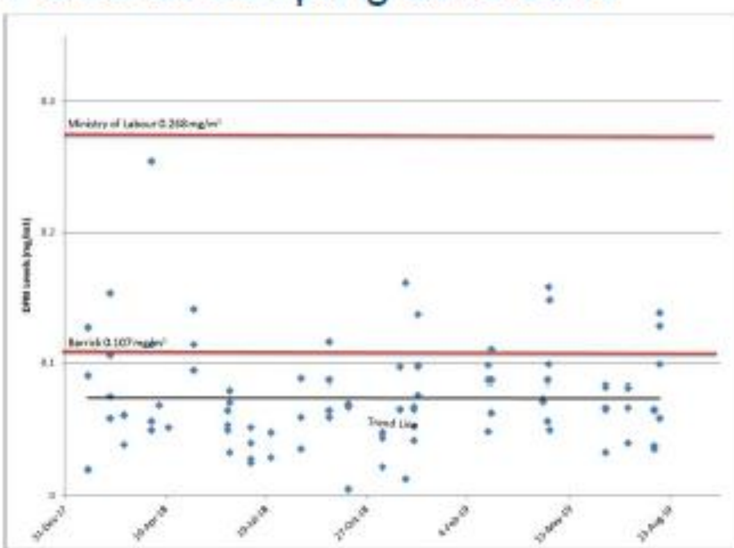

- With the introduction of the DPFs, the amount of exceedances decreased
- Most recent exceedences are caused by overloading of a vent zone
  - Human behavior plays a large role

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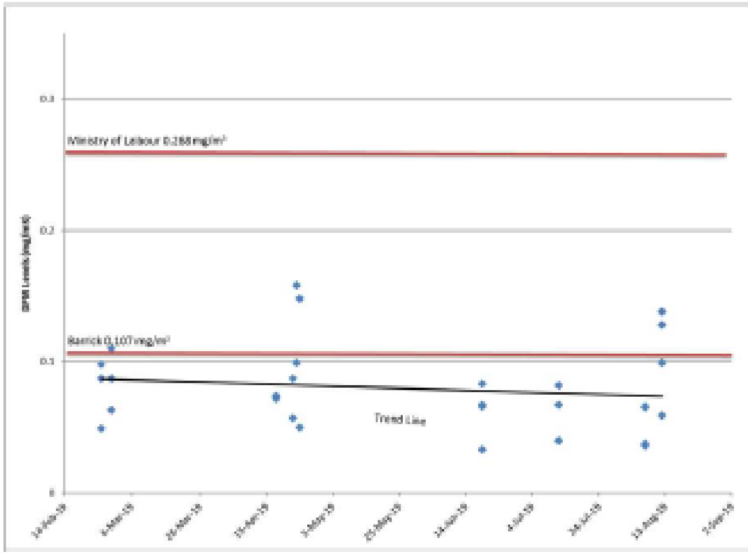
Personal Sampling 2019

BARRICK



- Sampling results remain consistently below the Barrick OEL even into the 3rd Quarter of 2019
- A handful of filters have already been replaced, but cleaning reports have suggested that many are starting to reach the end of their lifespan

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Lessons Learned

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- "What we wish we would have known…."

22

This is not just "Hannah's Problem"

BARRICK

- Multidisciplinary team effort
  - Maintenance department at all levels: supervision, planners, mechanics – they work on the equipment
  - Operations: supervisors, operators – they run the equipment
  - Trades: use your in-house expertise on installation of any additional items onto a piece of equipment. They work with this equipment and know how it can be manipulated
- Reach out to others!
  - Use your contacts, other sites within your company, subject matter experts etc. who have been dealing with DPM emissions at other sites
- Research
  - Get your head wrapped around the issue, understand what DPM is, what it is composed of
  - Understand the mechanics of an exhaust system, the fuel and how it all works together

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This is not just "Hannah's Problem"

BARRICK

- Sampling – a lot of sampling will need to be done to establish a baseline of the current levels of DPM seen. Likely more than you think initially
- With regards to diesel particulate filters (DPFs) and any other aftermarket installations – utilize the knowledge of the manufacturers – these are their products!
  - Bring them to site and underground, right to the equipment you will be working with, go through the set up with them
  - Initiate discussions regarding testing of their products, if they have any data from other customers that they can share
  - Have a list of items you want to discuss/request of them (such as wanting it to be "plug and play", minimal installation times, user friendly interfaces, etc.) and ask them what they can do to meet those points

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This is not just "Hannah's Problem"

BARRICK

- Training – SO MUCH TRAINING
  - Keep the operators in the loop through the process, include them in discussions with regards to what would be reasonable and logical to expect of them
  - Ensure they understand the role you need them to play and what they need to do – monitoring interfaces and knowing how to respond if/when warning lights start flashing (that DOES NOT include covering them with electrical tape)
- Emissions testing
  - Testing at both the inlet and outlet of the filters – this will help you to understand what your filters are doing – or not.
  - Track these levels on a regular schedule, e.g. monthly, or on a PM schedule, watch for changes over time with each piece of equipment
- More sampling!
  - Verification sampling after each step change

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Where are we now?

BARRICK

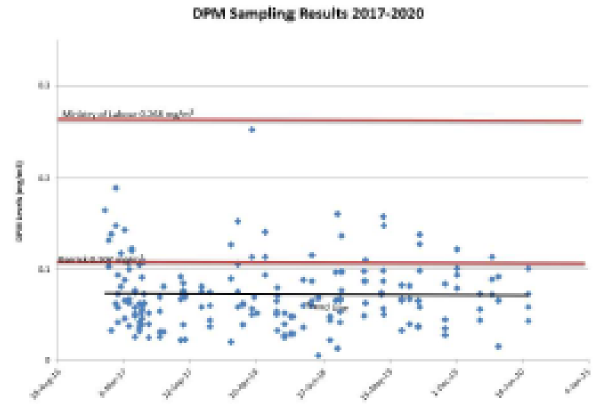
- In the process of upgrading parts of the UG fleet to equipment with Tier 4 Final engines (scoops and trucks)
- Purchase of battery powered equipment (Jumbos, bolters)
- Ventilation upgrades to increase flows in the busiest areas of the mine
- All new equipment coming with climate controlled cabs for operators

26

Where are we now?

BARRICK

- Continuing to monitor DPM levels UG



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APPENDIX B: Example 2 - Musselwhite Mine DPF Installation Project

Musselwhite Mine DPF Installation Project

Being Responsible

MDEC 2017

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Executive Summary

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- Goldcorp is one of the fastest growing, senior gold producers in the world.
- Goldcorp contributes significant economic and social benefits to the communities where we operate and the overall Ontario economy:
  - Produces more than 50% of Ontario's Gold.
  - Established collaboration agreements with all First Nations surrounding our three mining operations.
- Ontario is an important jurisdiction to Goldcorp – represents roughly 1/3 of a total 3 million ounces produced annually in the Americas.
- Goldcorp is currently engaged in an investment to expand the Musselwhite Mine production to extend the mine life and create jobs and associated economic benefits.

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The Challenge

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- Beginning in the fall of 2013 various areas of the mine had started to become affected by the high accumulation of diesel particulate.
- Initially our mechanical shops at 488 meter level had been affected. This had us reduce the shops scheduling to an 8 hour day reducing the throughput of machinery affecting our business partner's availability.
- Musselwhite also began to have other areas affected by the DPM which resulted in having other areas become "respiratory fit" mandatory. This affected the working environment and morale for many of our employees.
- We struggled with how we were going to deal with the problem as providing additional ventilation was challenging with the mine design, costly, and would not be available within and short time frame.

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The Solution

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- In 2013 a suggestion from the ventilation department was brought forward that there were DPM filters on the market that could help lower the levels in the mine.
- We started working with a manufacturer, Mammoth out of Australia in the fall of 2013. This involved testing the levels of DPM and also emissions to ensure we were not adding another problem such as N02 to our air quality. Testing of filters on the high volume contributors (haul trucks) was done for 3 months to help ensure quality of the product.
- The maintenance department investigated and spent the time working on the business case to ensure the investment would be beneficial and responsible. This was done by testing, documenting, planning, and bringing experts to site.
- We spent a lot of time with all of the Sites departments to ensure everyone had a voice in the problems and solutions. We held monthly DPM meetings to keep everyone informed. This helped to alleviate false information in work groups, clear any misconceptions and calm personnel issues with long lead times to get the product to site (1yr).

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- Prior to the filters being installed there was numerous attempts to improve the shop DPM test results, with different changes to the ventilation and by installing large circular ceiling fans on the back to help move air out of the shop.
- Initial testing at 488 Shop resulted in high readings of DPM above the set Ministry of Labour Occupational Exposure Limits (OEL) of 0.256mg/m3. The Goldcorp Industrial Hygiene action limit is set to 0.2 mg/m3 which is 80% of the OEL. Any areas within the mine that had exposure levels above the action limit was designated a “respiratory fit” mandatory area.
- The number of samples taken during this testing period was 37 (10.5hrs) from a March 2013-November 2013. A number of other controls were implemented related to changing mine ventilation and dust suppression which had little to no success. The decision was made to reduce the Shop Maintenance shift work hours to (8hrs) reducing the exposure of DPM on the workers (samples taken from Nov2013-Nov2014).

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- The trial filters were installed on a truck and scoop (cat AD45 and R2900G) for a trial period of one year prior to installing the Mammoth filters on the rest of the fleet (trucks and scoops).
- Once the filters arrived the maintenance team made a plan to execute the installation. This involved generating a "base line" before and after installs for future reference.
- The Mammoth filters were installed on all scoops and haulage trucks which significantly decreased the levels of DPM well below the Occupational Exposure Limit and the corporate Action Limit.
- The results after the changeover from Standard exhaust to Mammoth Filters was almost instantaneous. DPM results at 488 level shop came in below the MWM threshold acceptable levels in the first set of test results.
- Other mine levels that were restricted "respiratory fit" mandatory were also tested and were relieved of the restrictions within the first 2 weeks after installation. These were big wins to the mine site as they improved the health and morale of all workers underground.
- The results have been extremely positive and sustainable, but the filters are "maintenance intensive" and require a coordinated team effect along with investment to keep them performing.

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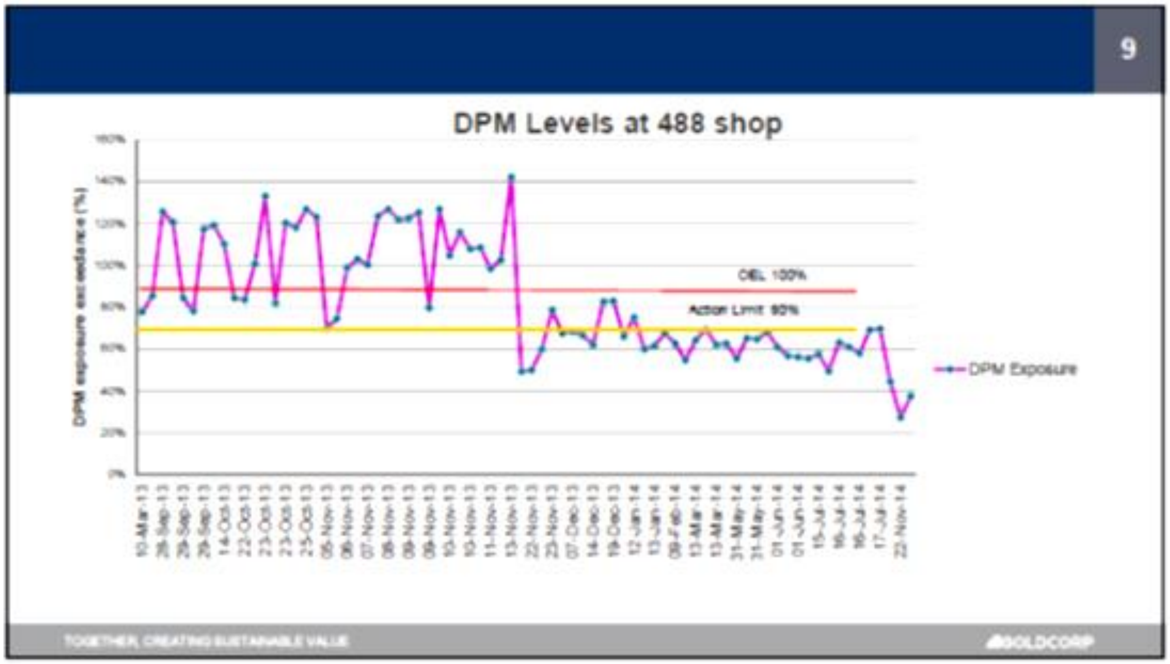
Goldcorp Musselwhite Mine - TWAs and Action Levels (July 2013)

(as per O. Regs. 833/90, 654/90 and 490/09 - shift adjusted by Brief and Scala Model)

Agent	TWA 8 hour	TWA 10.5 hour	TWA 12 hour	Action Level (80% of TWA) 8 hour	Action Level (80% of TWA) 10.5 hour	Action Level (80% of TWA) 12 hour
arsenic (As)	0.01 mg/m3	0.0064 mg/m3	0.005 mg/m3	0.008 mg/m3	0.0051 mg/m3	0.004 mg/m3
cadmium (Cd)	0.01 mg/m3	0.0064 mg/m3	0.005 mg/m3	0.008 mg/m3	0.0051 mg/m3	0.004 mg/m3
carbon disulphide	1 ppm	0.64 ppm	0.5 ppm	0.8 ppm	0.51 ppm	0.4 ppm
carbon monoxide (CO)	25 ppm	16 ppm	13 ppm	20 ppm	13 ppm	10 ppm
carbonyl sulphide	5 ppm	3.2 ppm	2.5 ppm	4 ppm	2.6 ppm	2 ppm
cobalt (Co)	0.02 mg/m3	0.013 mg/m3	0.01 mg/m3	0.016 mg/m3	0.01 mg/m3	0.008 mg/m3
copper (Cu) - dust	1 mg/m3	0.64 mg/m3	0.5 mg/m3	0.8 mg/m3	0.51 mg/m3	0.4 mg/m3
copper (Cu) - fume	0.2 mg/m3	0.13 mg/m3	0.1 mg/m3	0.16 mg/m3	0.1 mg/m3	0.08 mg/m3
dimethyl disulphide	0.5 ppm	0.32 ppm	0.25 ppm	0.4 ppm	0.26 ppm	0.2 ppm
dimethyl sulphide	10 ppm	6.4 ppm	5 ppm	8 ppm	5.1 ppm	4 ppm
DPM - elemental carbon	0.308 mg/m3	0.197 mg/m3	0.154 mg/m3	0.246 mg/m3	0.158 mg/m3	0.123 mg/m3
DPM - total carbon	0.4 mg/m3	0.256 mg/m3	0.2 mg/m3	0.32 mg/m3	0.2 mg/m3	0.16 mg/m3
ethyl mercaptan	0.5 ppm	0.32 ppm	0.25 ppm	0.4 ppm	0.26 ppm	0.2 ppm
hydrogen sulphide (H2S)	1 ppm	0.64 ppm	0.5 ppm	0.8 ppm	0.5 ppm	0.4 ppm
isocyanates	0.005 ppm	0.0032 ppm	0.0025 ppm	0.004 ppm	0.0026 ppm	002 ppm
lead (Pb)	0.05 mg/m3	0.032 mg/m3	0.025 mg/m3	0.04 mg/m3	0.026 mg/m3	0.02 mg/m3
manganese (Mn)	0.2 mg/m3	0.13 mg/m3	0.1 mg/m3	0.16 mg/m3	0.1 mg/m3	0.08 mg/m3
mercury (Hg)	0.025 mg/m3	0.016 mg/m3	0.013 mg/m3	0.02 mg/m3	0.013 mg/m3	0.01 mg/m3
methyl mercaptan	0.5 ppm	0.32 ppm	0.25 ppm	0.4 ppm	0.26 ppm	0.2 ppm
n-butyl mercaptan	0.5 ppm	0.32 ppm	0.25 ppm	0.4 ppm	0.26 ppm	0.2 ppm
nitric oxide (NO)	25 ppm	16 ppm	13 ppm	20 ppm	13 ppm	10 ppm
nitrogen dioxide (NO2)	0.2 ppm	0.13 ppm	0.1 ppm	0.16 ppm	0.1 ppm	0.08 ppm
respirable dust/fume	3 mg/m3	1.9 mg/m3	1.5 mg/m3	2.4 mg/m3	1.5 mg/m3	1.2 mg/m3
silica - cristobalite	0.05 mg/m3	0.032 mg/m3	0.025 mg/m3	0.04 mg/m3	0.026 mg/m3	0.02 mg/m3
silica - quartz	0.1 mg/m3	0.064 mg/m3	0.05 mg/m3	0.08 mg/m3	0.051 mg/m3	0.04 mg/m3
silica - tripoli	0.1 mg/m3	0.064 mg/m3	0.05 mg/m3	0.08 mg/m3	0.051 mg/m3	0.04 mg/m3
silver (Ag) - dust/fume	0.1 mg/m3	0.064 mg/m3	0.05 mg/m3	0.08 mg/m3	0.051 mg/m3	0.04 mg/m3
styrene	35 ppm	22 ppm	18 ppm	28 ppm	18 ppm	14 ppm
sulphur dioxide (SO2)	2 ppm	1.3 ppm	1 ppm	1.6 ppm	1 ppm	0.8 ppm
tungsten (W) - metal	5 mg/m3	3.2 mg/m3	2.5 mg/m3	4 mg/m3	2.6 mg/m3	2 mg/m3

S6P1 - 4


9
DPM Levels at 488 shop
OEL 100%
DPM Exposure
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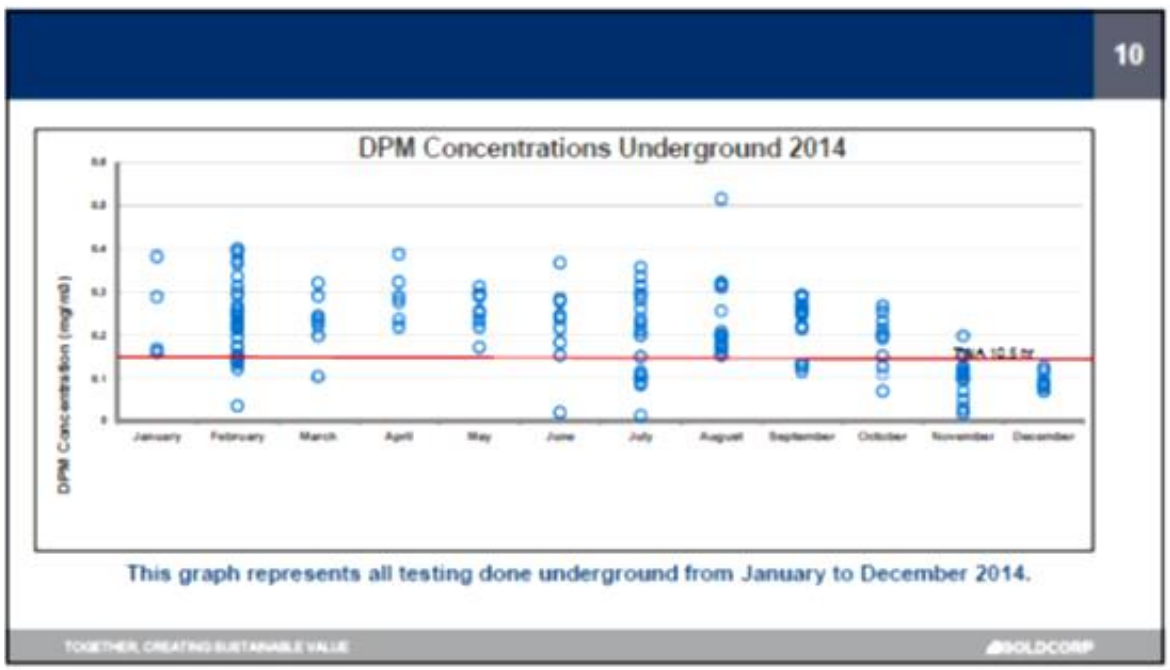
10
DPM Concentrations Underground 2014
January
February
March
April
May
June
July
August
September
October
November
December
This graph represents all testing done underground from January to December 2014.
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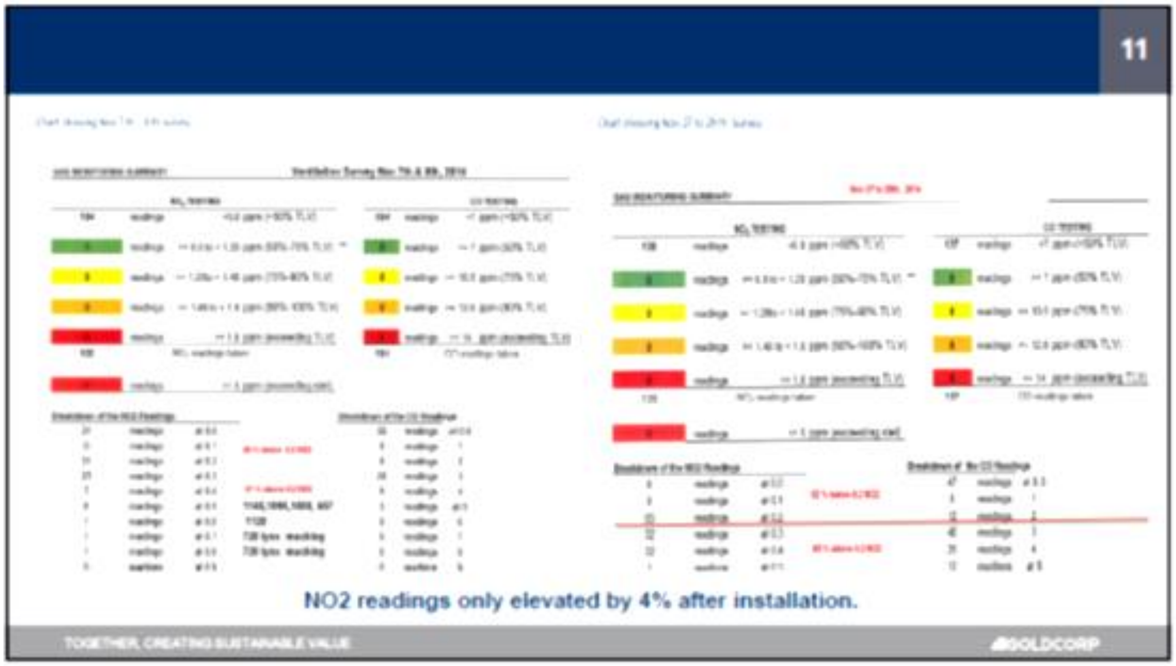
S6P1 - 5


11
NO2 readings only elevated by 4% after installation.
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12
DPF SNAPSHOT
The passive regeneration ZERO filter is a very efficient cleaning system of diesel exhaust. This DPF removes up to 99% of diesel particulates. The system consists of an oxidation catalyst upstream of the wall flow filter substrate. The highly durable ZERO filter is available to suit most heavy diesel equipment.
WALL FLOW FILTER
DIESEL OXIDATION CATALYST
EMISSION REDUCTIONS
CO
HC
PM
Zero
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Visual

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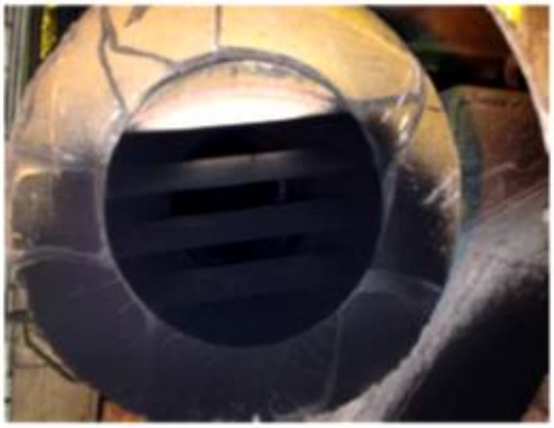
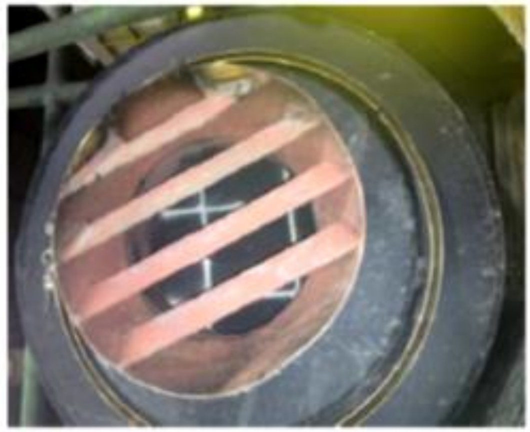
Original OEM



Mammoth Filter



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- **MWM has purchased and now are using FSX filter cleaning system.**
- **This helped us to lower the cost of cleaning and shipping of filters.**
- **This has also helped us to ensure we are tracking and protecting our investments.**

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Additional equipment Improvements

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- We are currently working with Mammoth on new designs for different applications.
- Boom trucks have been one of the higher contributors of DPM but are very hard to eliminate because of the nature of the machine, running up and down the ramp and extended idling in cold weather on surface.
- We are currently trying heat blankets to help the filters regenerate.
- We currently have 2 Boom trucks with Stratus 8.1 DPF Systems. Initial results show improved results.

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2 year trend (2016 – 2017)

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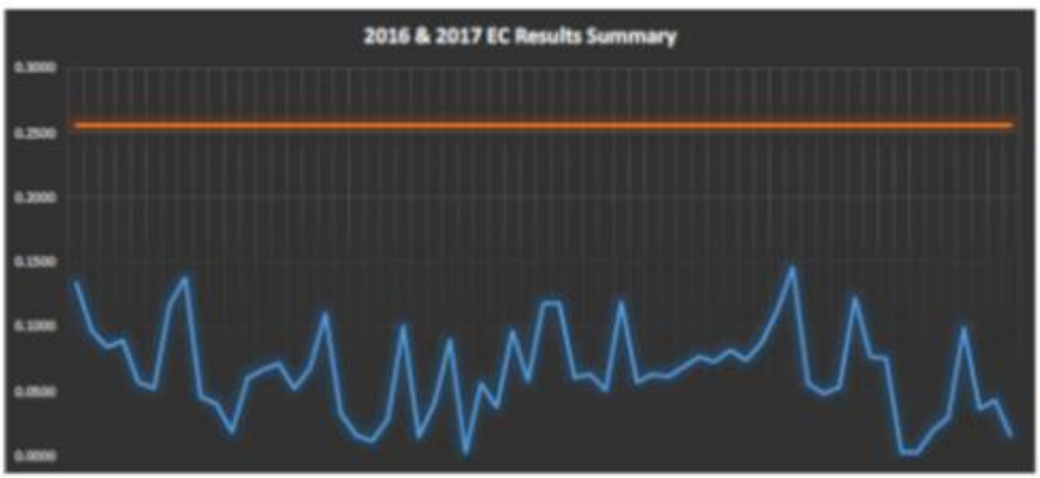

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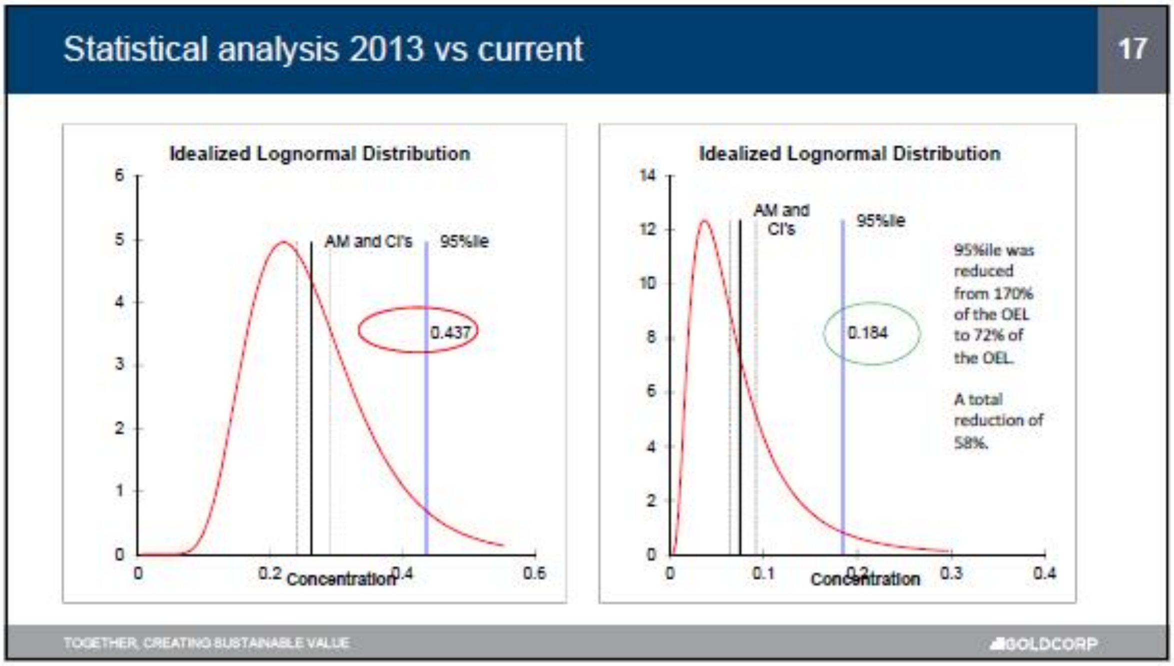

Statistical analysis 2013 vs current
17
Idealized Lognormal Distribution
AM and CI's
95%ile
0.437
Concentration
Idealized Lognormal Distribution
AM and CI's
95%ile
0.184
95%ile was reduced from 170% of the OEL to 72% of the OEL.
A total reduction of 58%.
Concentration
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THANK YOU
QUESTIONS
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Additional resource material

Auxiliary Ventilation: Good Installation and Maintenance Practices for Miners

Free training resources on diesel emission hazards for all industries: Participant training manual and Leader presentation

Hazard alert: Diesel fuel tank vent systems and risk of flash fires

Infographic: Health effects of diesel exhaust in mines

Infographic: Proper use of respirators in mines and mining plants

Occupational Diseases in the Ontario Mining Industry: An update from the Occupational Cancer Research Centre

Ontario Ministry of Labour Diesel Survey of Mines and Mine Contractors

Ventilation Assessment for Underground Mines