Osinergmin

Organismo Supervisor de la Inversión en Energía y Minería

State of the Art/Breakthrough- Diesel Emission Curtailment Technology/Know-How

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20 AÑOS TRANSFORMANDO LA ENERGÍA EN CONFIANZA

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Context

- Mine Ventilation Key Challenges
- Diesel Emissions
- Particle Deposition
- Why it Matters?
- Solutions at Glance
- DEEP Research and Learning's
- Breakthrough DPF Technology
- Next Steps: Implementation of Solutions and Further Work

Mine Ventilation –Key Challenges

- Ventilation is the lifeblood of a mine
- Intake airways are arteries carrying oxygen to the working areas (for personnel and machinery)
- Exhaust airways are the veins conduct pollutants away to be expelled to atmosphere
- Without ventilation no underground facility requiring personnel (or machinery) to enter it can operate safely

Mine Ventilation

- “The slaughter of men, women and children that took place in the coal mines of Britain during the 18th & 19th centuries resulted in the theory and **art** of ventilation becoming the primary mining science
- The success of research in this area has produced tremendous improvements in underground mining conditions”

(Source: Malcolm McPherson ; Text-book- Subsurface Ventilation and Environmental Engineering)

Mine Ventilation

- Improvements in ventilation have also allowed the productivity of mines to be greatly improved
- Neither the first nor the latest powered machines could have been introduced underground without the adequate supply of air
- Ventilation engineers are caught up in a continuing cycle of systematic improvement

VENTILATION DESIGN CRITERIA

Design Criteria - Purpose

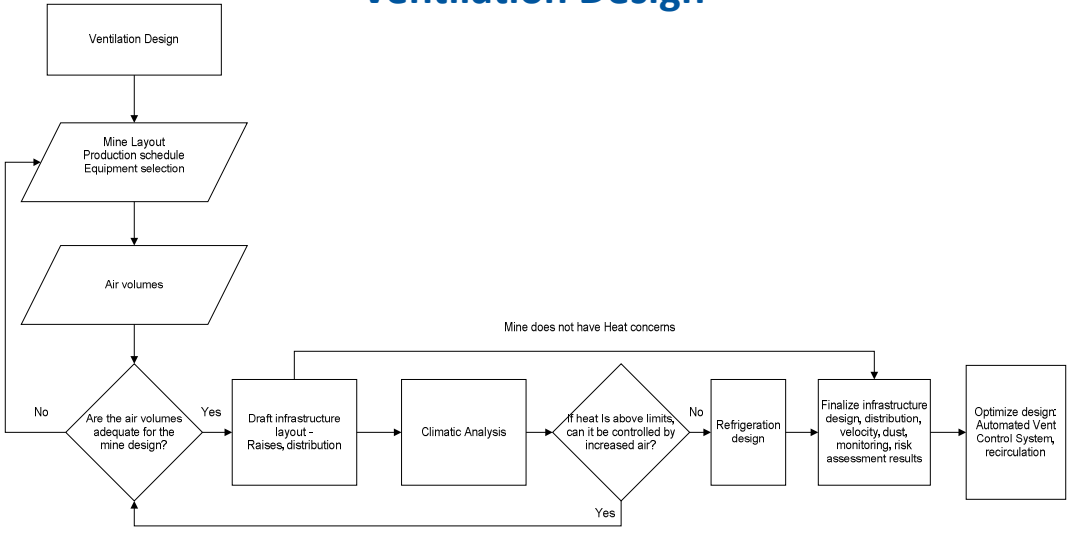
Why is it required?

- Structured approach to a design

What does it support?

- Safe work environment
- Fit-for-Purpose
- Robust
- Economic
- Flexible to meet the Life of Mine

Ventilation Design



Air Volume

Determining the air volume requires research

- Dependent on:
  - Mining method
  - Ore movement method
  - Mining depth
  - Ore body physical properties (silica, radon, asbestos)
  - Regulations

Critical first step and challenging

Mining Today in Canada
Challenges

The ventilation driving concerns :

- Depth
- Mechanization
- Power/energy operating costs
- Capital costs
- Health & Safety

Health and Safety

Provide a better environment for workers

- Cleaner equipment and processes (modern engines, exhaust treatment, fuel cells)
- More extensive monitoring (real-time, remote)
- Recognition of new substances … (DPM)
- Refinement/alteration of regulations …(Silica)
- Worker isolation … (remote control, cabs)

DPM: Diesel Particulate Matter

Path Forward

- **Ventilation "Building Code"**
  - Qualify current standards, Continue to find healthy, economical/sustainable ventilation solutions – global proven ventilation good practices,
- **Training/education of ventilation engineers**
  - Growth/maintenance of ventilation knowledge/competence in the mining industry – mentoring program
- **Rescue/egress**
  - Strategy that says a worker can get to safe place in emergency
- **Energy management**
  - Lakes for cooling, harnessing geothermal energy/collaboration
- **Curtailment of Diesel Emission**
  - Diesel is the workhorse of mining – spearhead research to limit diesel emissions

DIESEL EMISSIONS

Formation of Diesel Emissions

- Combustion time in internal combustion engine (ICE) is only milliseconds.
- Mixture of air and fuel can never be perfect'
- Combustion is > 99% complete ! Efficiency very high
- But this remaining 1 % is a concern

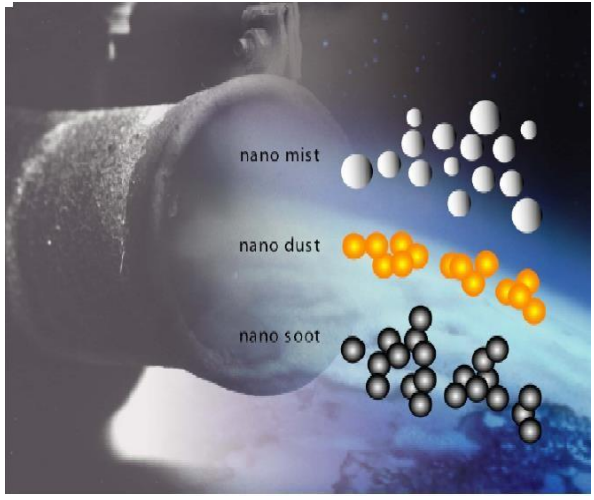

R1700G

Diesel Engine Emissions (*Dr. Markus Kasper , 2004*)

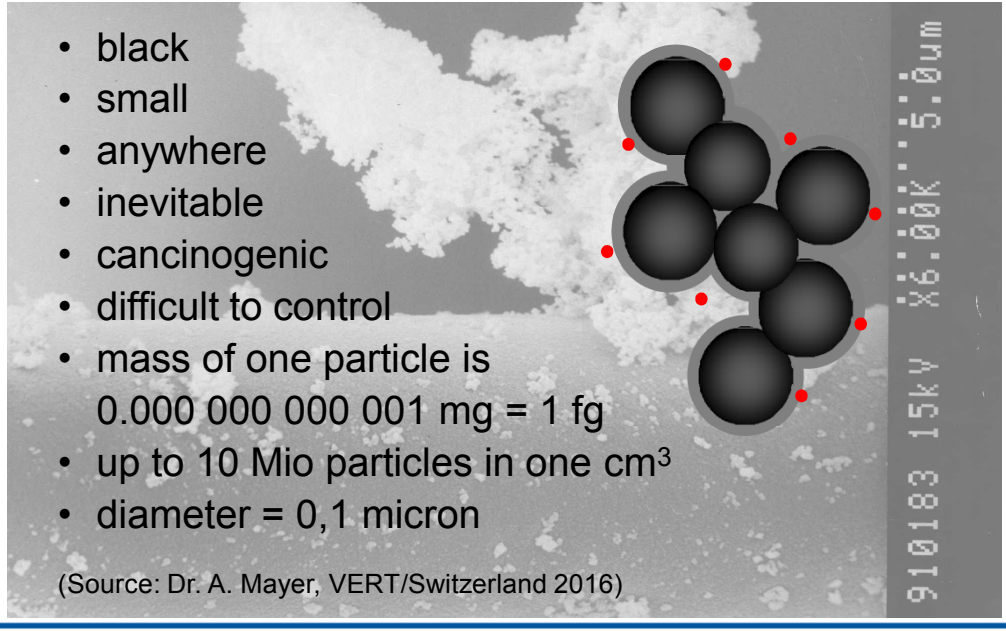
Soot Particles Ash Particles
Liquid Droplets

Gases:
CO, HC, NOx
PAH, Nitro-PAH

and many trace substances



Soot Particle

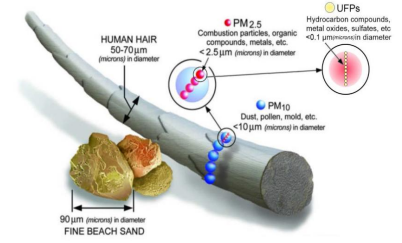


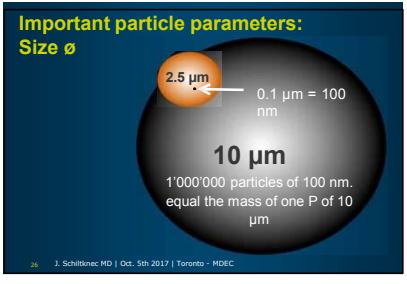
- black
- small
- anywhere
- inevitable
- cancinogenic
- difficult to control
- mass of one particle is
  0.000 000 000 001 mg = 1 fg
- up to 10 Mio particles in one cm^3
- diameter = 0,1 micron

(Source: Dr. A. Mayer, VERT/Switzerland 2016)

Diesel Particulate Matter/Soot

- Most of the mass is composed of carbonaceous agglomerates
- Particles are coated by PAH and “decorated” by metal oxides





Human hair is 50-70 μm in diameter

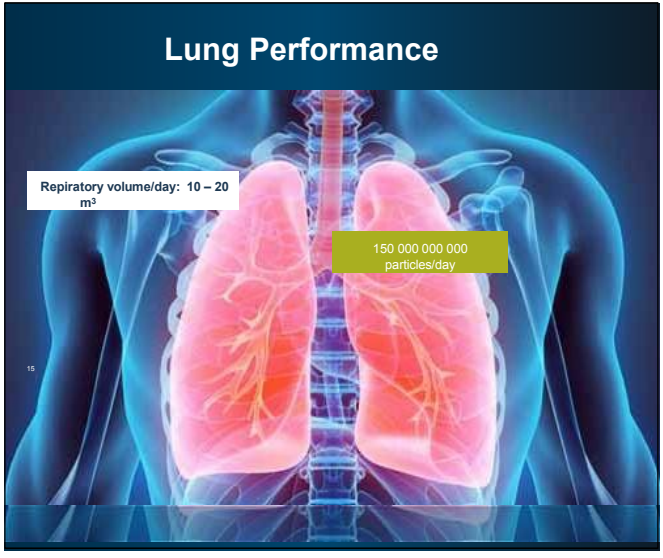
Typical size of Diesel Soot particle is 0.1 μm in diameter or 500 – 1000 times smaller than human hair

1 ,000,000 particles of 0.1 μm equals the mass of 1 Particle of 10 μm .

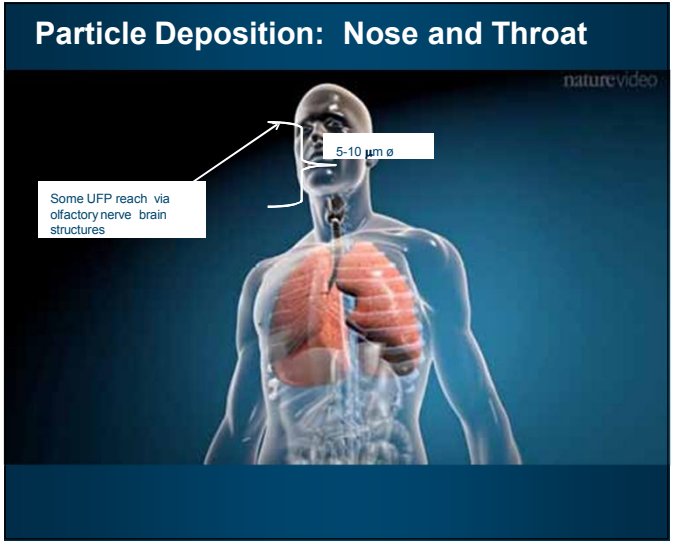
This demonstrate why size matters

Size Comparison of Various Classes of Particulate Matter
(Source: Dr Schiltknecht, MDEC, 2017)

Particle Deposition

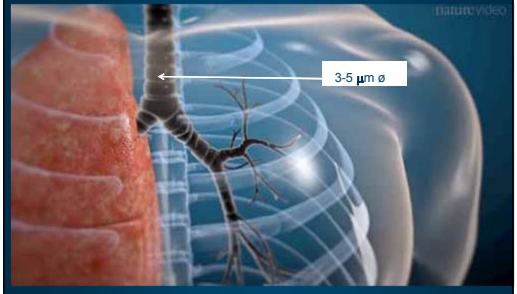


Daily , we inhale a total of 10-20 m3 of air, and together with this air, tens of trillions of suspended particles (Source : Nature video /Dr. J. Schiltknecht)



The deposition of particles occurs on different levels – nose and throat: 5-10 µm

Particle Deposition Trachea and major Bronchi



Particles of 3-5 µm reach trachea and major bronchi - **stick to the mucus pushed to the mouth and swallowed or expectorated.**

Particle Deposition: Bronchi and Bronchioles

Even smaller particles are captured and eliminated by the "mucociliary elevator".

So with this defense mechanism developed during evolution **the lungs were perfectly protected against solid particles** –

Until the industry began to produce smaller particles less than 1 µm resulting from technical combustion

Particle Deposition: Alveoli

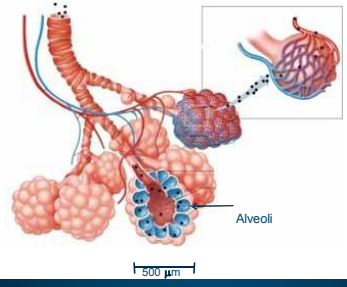
Source: nature video / Dr. J. Schlitknecht

The nanoparticles reach alveoli.

That is where the “drama begins”

Part of the nanoparticles **under 1 µm and smaller** translocate through the subtle respiratory membrane

Translocation into Blood Circulation



Source: McGraw-Hill / Dr. J. Schlitknecht 2015

The **black dots** symbolize the particles translocated into the **blood circulation.**

We have some 500 million of alveoli, their inner surface totals 150 square meter.

The network of arteries in the lungs has a total length of about 2000 km !

Cellular Uptake of Particles

- Solid particles smaller **than 0.5 µm reach the alveoli** – about 5% of them translocation into blood stream
- They infiltrate the bladder, the liver, the brain- all of our organs
- Small particles around 0.1 µm – the typical size of Diesel.
- Particles, may enter the cells....causing damage to the DNA
- This demonstrates why size matters....

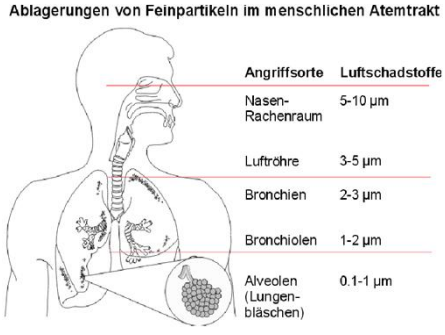
(Source: Prof. Peter Gehr, former head of the Institute for Anatomy, University of Berne Switzerland, "personal communication") and Dr. J. Schiltknecht MDEC 2017)

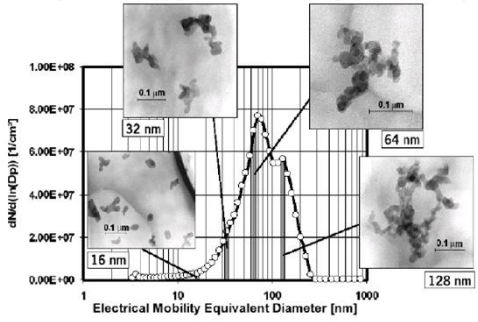
The Lung: An Open Door for Engine Emitted Particles (Dr. A. Mayer , 2017)

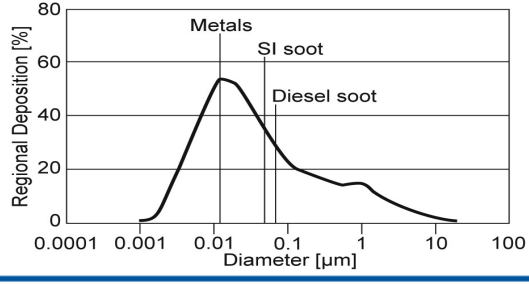
The most susceptible size range
of the Lungs is the strongest emission range of the Engines :
0.01- 0.3 µm (10 – 300nm)

There is no defense in the lung for diesel particles less than 0.5 µm (500nm)

Solution: Diesel Particulate Filter (DPF) catches all Particles even below 0.001 µm







Summary- Relevance of Particle Size

Airborne mass concentration ($\mu g/m^3$)	*Particle diameter (μm)*	*Particles/ml of air*	*Particle surface area (μm^2/ml air)*
10	2	1.2	24
10	0.5	153	120
10	0.02	2400000	3016

Table modified from data of G Oberdorster. The relevance of this lies in the fact that any monitor collecting all of these particles in these three different conditions would always give the same airborne mass concentration of 10 $\mu g/m^3$. However, the physical characteristics of the cloud are very different for particle number and surface area and both of these are properties that might have important impact on the lung.

Occup. Environ Med (2001)

WHY *Diesel Emitted Solid Elemental Carbon (EC)-Particles* Matter

Why it matters?

In March 2012 the NIOSH and NCI 20-year *'Diesel Exhaust in Mines Study report was published* (National Cancer Institute 2012)*:*

- It involved a cohort mortality study of 12,315 mineworkers at 8 US underground non-metal mines – *from which 198 had died by lung cancer*
- **it indicated** a strong link between the **level of exposure** and **risk of lung cancer** mortality.
- The **mortality rates** for those at higher exposures were **3 to 5** times greater compared to those at lowest exposures.

Classification of Diesel Exhaust

In June 2012 the IARC -International Agency for Research on Cancer (part of the WHO) classified **Diesel Engine Exhaust as carcinogenic** to humans (Group 1- just as Asbestos)

This landmark study was informed on the lung cancer risk for the underground (metal-)mine workers, but the findings suggest that the risk may extend to other workers exposed to diesel exhaust...

SOLUTIONS AT A GLANCE

Solutions

Modern Engine
ENGINE MAINTENANCE

→ Clean-burning engine, good fuel to air ratio → reduces particle mass, by reducing particle size, particle number unchanged.

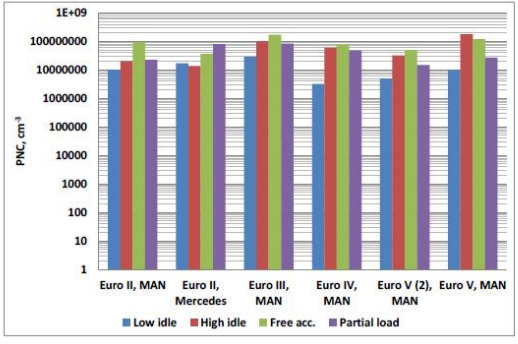
INCREASED VENTILATION

→ Increasing airflow, will lead to greater diesel exhaust dilution, but: → doubling flow requires eight times the power

DIESEL PARTICULATE FILTERS (DPF)

→ Reduction/Elimination of diesel soot from exhaust → filtration > 99.9%

Engine Combustion Development has so far not able to eliminate Particle Emissions



PM has been reduced but
PN was not changed,
particles are smaller
→ more toxicity

Modern engines emit 10 % of the total particulate mass emitted by engines build two decades ago. Although these low emission engine technologies hold considerable promise for **reducing the total mass of "soot",** - the laboratories studies (Switzerland) demonstrated **no reduction in the number** of small nuclei-mode particles 0.02–0.5 µm (20- 500 nm).(Source: Dr. A. Mayer 2007)

Ventilation and Maintenance Practices

Improvements in ventilation have permitted the productivity of mines to be enhanced. Neither the first powered machines, nor the latest heavy duty scoop tram or haulage truck equipment could have been employed without an adequate supply of air. **Good ventilation is indispensable but would not be feasible to eliminate all of the diesel particulate matter emissions by itself.**

VENTILATION PRACTICES

DEEP Research and Leanings

DEEP Program

DEEP (Diesel Emission Evaluation Program) focused on the importance of **good ventilation practices**, well planned **maintenance**, **filter technology**, use of **high quality fuels and lubricants** and measurement methods

Vale conducted long term study – 4 years over $2.5M evaluation of 9-nine state-of-the art DPF systems retrofitted to heavy and light duty underground mining vehicles

Develop Canadian expertise on the DPF technology and DPM measurement methodology.

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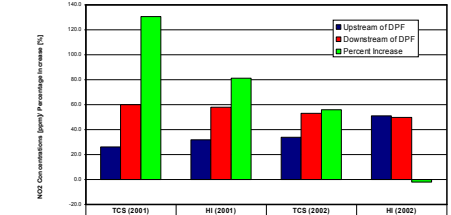
DEEP's Research - Results

- Both heavy duty and light duty underground vehicles **can be fitted with DPF systems**
- The systems can obtain a filtration efficiency of > 98%
- Several challenges were:
  - Ability to eliminate the operator involvement from the operation of the filter
    - » Plugging in for regeneration
    - » Changing filters mid-shift for cleaned filter
  - Generation of NO_2 in filters with platinum catalyst



	TCS (2001)	HI (2001)	TCS (2002)	HI (2002)
Upstream of DPF	26.0	32.0	34.0	51.0
Downstream of DPF	60.0	58.0	53.0	50.0
Percent Increase	130.8	81.3	55.9	-2.0

J. Stachulak, Bruce Conard;, Evaluation of Diesel Particulate Filter Systems at Stobie Mine, Final Report, Version 2, Sept 2012

Concluding Remarks - DEEP

- What is needed is a **DPF system** that works in a **fashion similar to an catalytic converter that does not require operators intervention under normal operating conditions**.

- In the wake of DEEP studies, Vale undertook **additional efforts in identifying products suitable for underground mining operations.**

J. Stachulak, Bruce Conard,, M. Gangal; 2009, Experience and Evaluation of Innovative Diesel Particulate Filter System at Vale-Inco, presented at the International Mine ventilation Congress, New Delhi India

BREAKTHROUGH DPF TECHNOLOGY

Breakthrough Post DEEP Projects -Light Duty Vehicles

Light duty vehicles were tested underground at Creighton Mine

HJS DPF system (SMF®-AR) installed on 33 kW Kubota and 60 kW locomotive

Ref. J. Stachulak and C. Allen ;A History of Diesel Emission Program at Vale Ontario Mines, MDEC, Toronto, Oct. 2015

Results

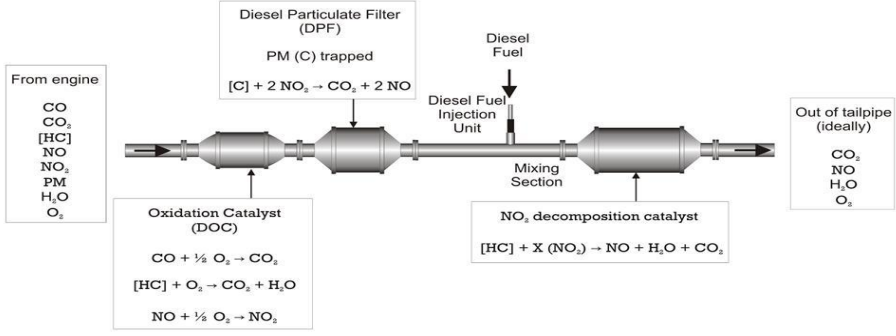
The system:

- **Removed** more than **98%** of DPM by particle number (PN)
- Regeneration **is automatic** and does not effect the operating cycle
- Tolerant of variations in engine operating conditions.
- Does not require **downtime during operation** (the spare unit was used at cleaning time)

– The implementation of the SMF-AR systems is currently underway at two Vale mines in Sudbury region, having acquired over 10,000 hours of operation over multiple vehicles.

Ref: J. Stachulak and C. Allen ;A History of Diesel Emission Program at Vale Ontario Mines, MDEC, Toronto, Oct. 2015

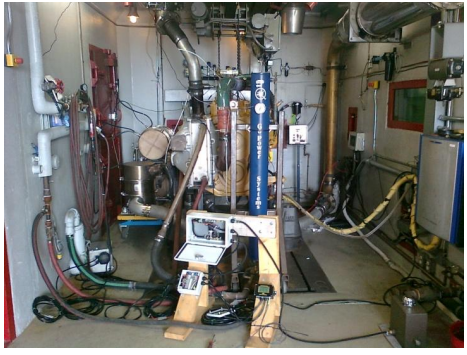
- Mining version JM CRT (DPF) system was selected for evaluation at Vale's Creighton, Totten and CC Mines
  - Bench testing was carried out at **CANMET's** Bells Corner Lab
  - JM DPF system was installed on a Caterpillar R1700 LHD - **263 kW Tier 3 engine**

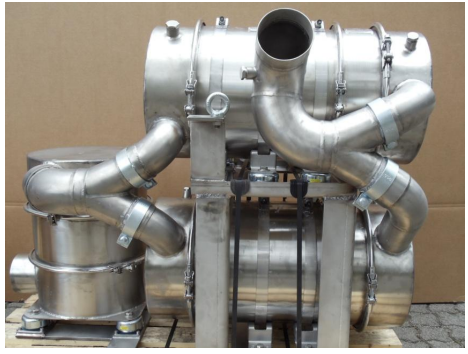


CRT – Continuous Regenerating Trap

JM/DPF - Bench Test at CANMET, Ottawa

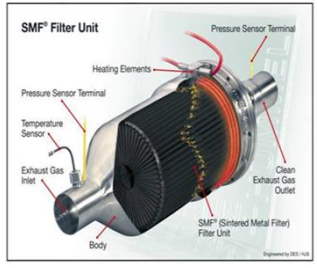
- The system was evaluated at steady-state and transient conditions
- Low HC-injection rates (max.190 ml/hour)





Diesel Emission Reduction Research (DERR) Project/s

- **Consortium of:**
  - Glencore Nickel
  - Glencore Copper
  - Vale Ontario
  - Vale Manitoba
  - KGHM
  - CAMIRO Mining Division



- 3 Projects under the DERR consortium were Diesel Particulate Filter **(DPF)** evaluation for Light Duty and Heavy Duty, as well as a DOC study regarding NO_2 emission.

Diesel Emission Reduction Research (DERR) Project Results

- Diesel Particulate Matter concentration and Particle number reduction +98%
- Operational acceptance
- No increase in NO_2 emissions
- The equipment prep for the filter system included removal of one of the fuel tanks to make room for the double canister
- The system operated without intervention from the operator

Diesel Emission Reduction Research (DERR) Project Results

- Low maintenance requirements. The project maintenance consisted of ECOM readings and data downloads
- Minor challenges consisted of:
    - fuel injection corrections,
    - exhaust re-direction,
    - sensor wiring changes
- The project is complete and the LHD is currently operating with the filter in normal conditions and part of the diesel fleet.

Ref. J. Stachulak and C. Allen ;A History of Diesel Emission Program at Vale Ontario Mines, MDEC, Toronto, Oct. 2015

Breakthrough/Results – 98% Elimination of Diesel Soot

- **The light duty applications** selected proved to be a practical solution.
  - Vale has 30 light duty DPF units operating on tractors,
  - locomotives and light duty trucks

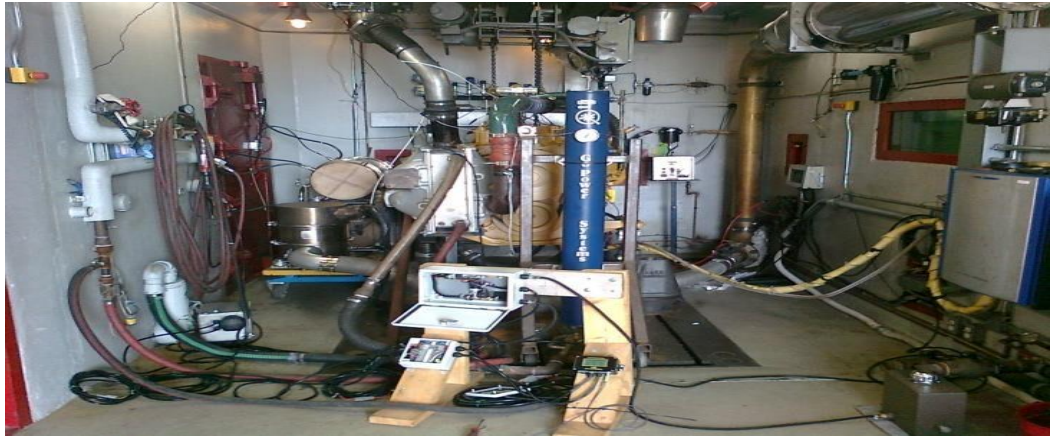
- **The heavy duty application**:
  - Unit successfully eliminated 98% , accumulated 2000 hrs The unit was removed and a spare unit re-installed within one shift
  - The LHD is currently in the normal production fleet

Ref. J. Stachulak and C. Allen ;A History of Diesel Emission Program at Vale Ontario Mines, MDEC, Toronto, Oct. 2015

NEXT STEPS

Recommendation – Path forward

- Consolidate the diesel curtailment breakthrough
- Implementation strategy is underway
- Research partners?? Canadian, International



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- Cheryl Allen, Principal Engineer – Vale
- Vale's Copper Cliff Mine Team
- Vale's Totten Mine Team
- Vale's Creighton Mine Team

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