Evaluation of a continuously regenerating DPF system

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Content

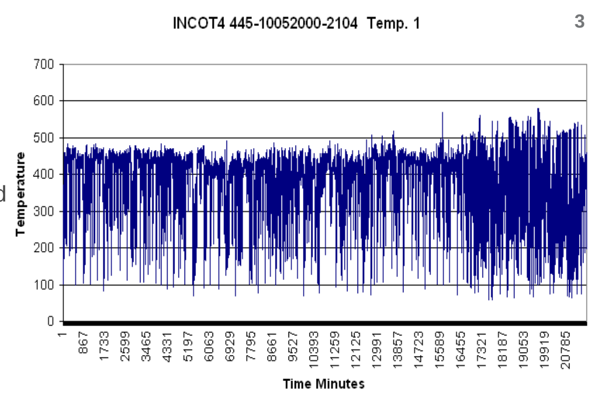
- Review of previous DPF studies and results
- Continuation of DPF studies by Vale
- Evaluation of Johnson Matthey (JM) Continuously Regenerating Trap (CRT) optimized for underground mining applications:
  - Underground evaluation at Creighton Mine
  - Laboratory evaluation at CANMET,Ottawa
  - Surface evaluation at Totten Mine
  - Underground evaluation at Copper Cliff Mine
- Summary

Introduction to DPF Technology

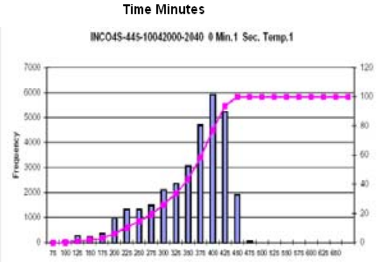
- Modern DPF technologies were shown in laboratory studies to provide filtration efficiency above **95%** with respect to **mass** and **number of solid carbonaceous particles.**
- The challenge is the periodic **cleaning** of such filters by combustion of the deposited DPM (regeneration).
- Unassisted DPM combustion for regeneration requires prolonged exhaust temperatures in excess of **600 ºC** – which is not attainable under the typical mine vehicle operating conditions.

DPF Regeneration

- Typical exhaust temperature trend for LHD powered by DDEC 60 engine- accumulated over 592 hours of operation.
- The average temperature was **341 ºC.**
- Therefore, "auto-regeneration" of uncatalyzed DPF could not take place.

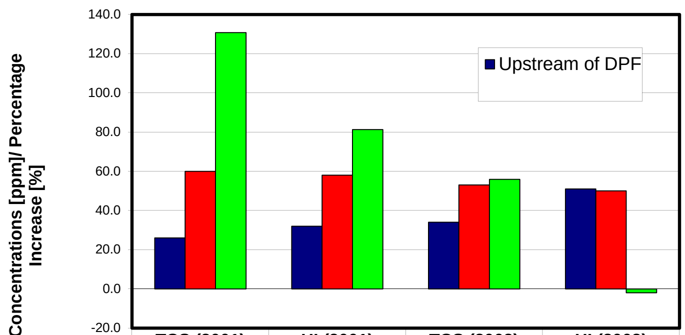


Vehicle #	Description	Accum. Hours	Mean Temp.	Max Temp.
			ºC	ºC
735	haulage truck	27.3	233	477
820	LHD	183.3	313	498
362	LHD	453.2	366	465
445	LHD	592.1	**341**	468



Due to adverse effect on NO_2 emissions not all DPFs are suitable for underground applications

- Pt-catalyzed DPF system on #362 promoted NO to NO_2 conversion



	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

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DEEP Evaluation at Vale's Stobie Mine

- Vale evaluated **nine state-of-the-art DPF systems** retrofitted to heavy-duty and light-duty underground mining vehicles used in normal production cycle.
- The specific objectives were:
  - Determine the ability of selected DPF systems to reduce DPM **without increasing emissions of other noxious substances**
  - Develop Canadian expertise on the DPF technology and DPM measurement methodology.

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Findings of DEEP DPF Evaluation Program

- The evaluated systems were found to be **very effective +**95% in removing DPM.
- One of the key challenges in implementing active DPF system was the need for **extensive human involvement** in their operation**.**
- The "business as usual" DPF system would need to work in a fashion similar to a catalytic converter that does not require operator intervention under normal operating conditions.
- After the DEEP program was completed, Vale **undertook** additional efforts in identifying products that fit their requirements for underground mining operations.

Vale Evaluations- DPF System for Light-Duty Vehicles

• Vale initiated a DPF evaluation program at Creighton, and Coleman mines.

•As a result, several light-duty vehicles at both Mines are currently equipped with HJS DPF system.

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Vale Evaluations- DPF System for Heavy-Duty Vehicles

Johnson Matthey (JM) Continuously Regenerating Trap (CRT) Retrofit for underground mining heavy-duty applications

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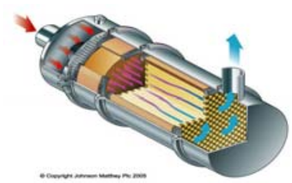
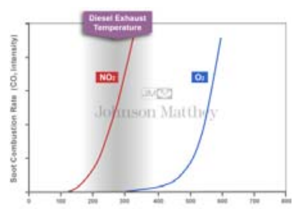
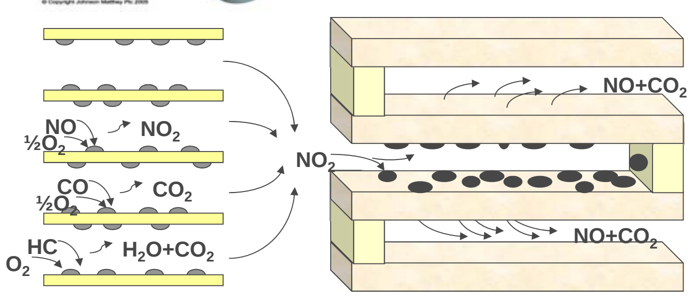
JM/Heavy Duty DPF Background

Principle of CRT Operation







Flow Through Catalyst Wall Flow Filter

Principle of CRT® Operation

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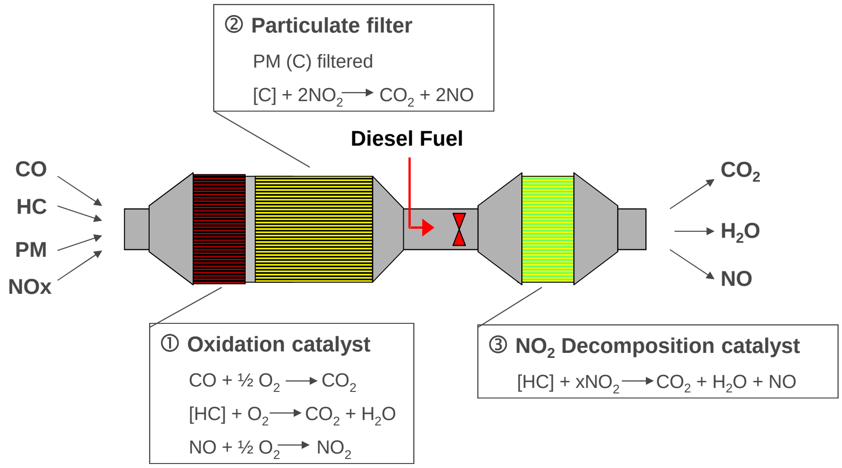
Johnson Matthey Low NO_2 "Mining" CRT System



- CRT system designed to oxidize soot using NO_2 generated in the oxidation catalyst.
- The NO_2 slip is controlled via reaction of NO_2 with injected fuel over decomposition catalyst.

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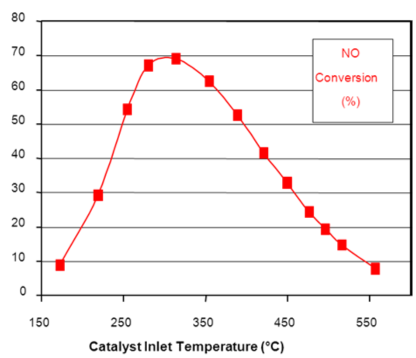
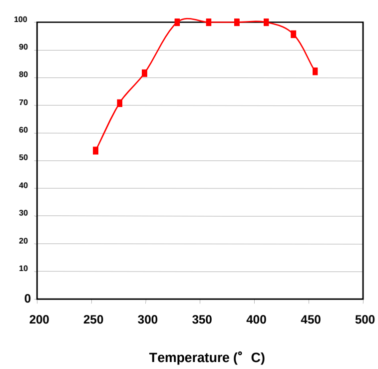
Continuous regeneration occurs at low exhaust temperatures (T_{40} = 220 ºC). The decomposition of NO_2 takes place at temperatures higher than 200 ºC.



Oxidation of NO to NO_2 over oxidation catalyst



Decomposition of NO_2 to NO over decomposition catalyst

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Four Phases of Field and Laboratory Evaluation of the Heavy-Duty DPF

- Phase 1: Initial field trial at Vale’s Creighton Mine
    - Completed
- Phase 2: Bench testing of the system at CANMET’s diesel laboratory in Ottawa, Canada
    - Completed
- Phase 3: Field evaluation on surface operation at Vale's Totten Mine Project, Sudbury, Canada
    - Completed
- Phase 4: Field evaluation at Vale's Copper Cliff Mine, Sudbury, Canada
    - In Progress

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Test Vehicle – LHD

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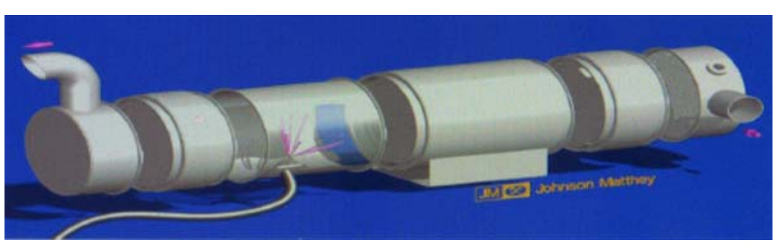
Test Vehicle - LHD

Machine manufacturer	Caterpillar
Machine type	Scoop tram R1700G
Engine manufacturer	Caterpillar
Engine type	C11
Engine certification	EPA TIER 3
Engine power	263 kW
Engine speed	1800 RPM
Engine displacement	11.1 Litres
Number of cylinders	6, in-line
Aspiration	Turbo charged and aftercooled
Exhaust gas volume	3.143 m^3/hour / 1500 kg/h
Exhaust gas temperature	460-470 ° C
Fuel	Diesel fuel, max.15 ppm Sulphur

Underground Evaluation at Vale's Creighton Mine

- Prototype JM system was installed on LHD, Caterpillar R1700G powered by ACERT Tier III engine
- The objective was to test the system in an underground operation
- The system quickly proved to be undersized for the application
- Maximum engine backpressure exceeded manufacturer recommended value.
- JM redesigned the system to alleviate the engine backpressure problem



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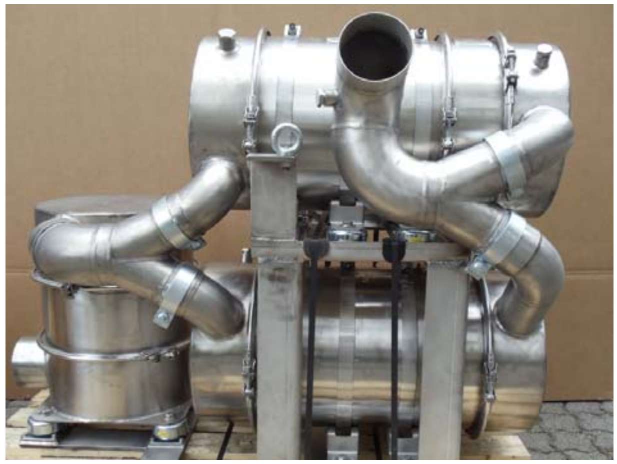
Redesign system used two parallel DOC/DPF elements

Inlet (engine out)



Discharge
to tailpipe

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Laboratory evaluation at CANMET Diesel Research Lab at Bell’s Corner

- Redesigned system was tested over steady and transient condition
- Low HC injection rates (max 190 ml/hr)

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The laboratory results were encouraging and supported field evaluations

Results

- Outstanding DPM reduction – 98 % in particle number
- For all test conditions DPF-out NO_2 and HC emissions were lower than corresponding engine-out NO_2 and HC emissions

Field evaluation at surface operation at Vale's Totten Mine Project

- LHD equipped with JM MCRT system was operated remotely at the surface areas of Totten Mine
  - Load rock from ground stock pile (~ 200,000 tons)
  - Haul rock to dump sites located 100 to 1000 feet away
  - Dump rock into cave area

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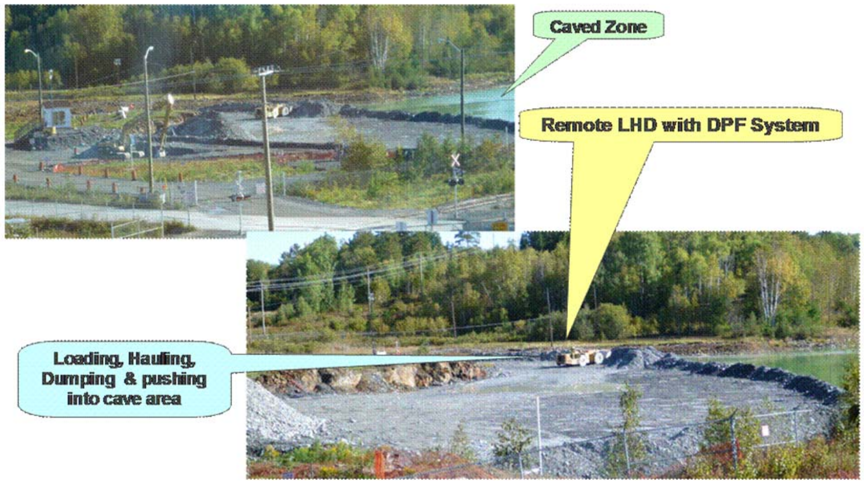
Surface Evaluation at Vale Totten Mine



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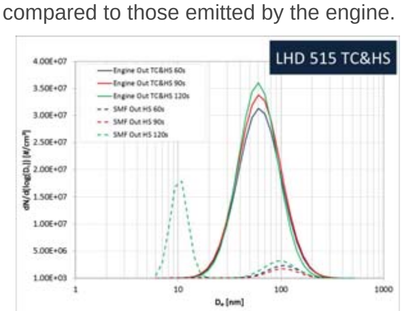
Effects of the system on aerosol and gaseous emissions from JM system installed on #515 were evaluated by NIOSH.

JM MCRT system was very effective in reducing the number and surface area concentrations of aerosols emitted by tested engine.

With exception of the case of TC&HS conditions, the concentrations of aerosols emitted from the system were almost negligible compared to those emitted by the engine.



Operating Conditions	Average Efficiency [%]
TC&HS max	96.2
TC&HS min	68.3
HI	96.8
LI	76.4

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Field evaluation at Totten Mine was successfully completed.

- Over-all the system operated very well with little maintenance issues and associated down time
- DPF system accumulated 1200 hours
- DPF regeneration did not require operator's involvement
- Idle time had to be reduced below 20 minutes/hour to avoid problems with DPF regeneration
- After 630 hours of operation, a DPF system quality issue emerged and was corrected by manufactuer

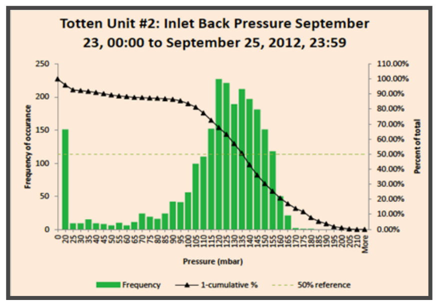
Underground Evaluation at Copper Cliff Mine

•Cab fabricated in Tasmania and flown to Sudbury,

•Installed at Toromont shops mid-2013

Copper Cliff Mine

- DPF modified by JM/Germany shipped and installed.
- Backpressure issues corrected by removing abrupt pipe changes, 5 in. (12.7cm) to 6 in. (15 cm)
- Pressure sensor relocated



Evaluation at Copper Cliff Mine

The system was optimized using results of extensive testing conducted by JM, NIOSH, Sensors Inc

Real time on-board SEMTEC DS analyzer was used to optimize fuel injection.

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Evaluation at Copper Cliff Mine

•Cautious introduction operated on – day shift only for first 520 hours by trained operators

•Weekly meetings with JM/Germany, Toromont, NIOSH, Mine maintenance and operations

•Performance of the system is verified weekly using ECOM measurements

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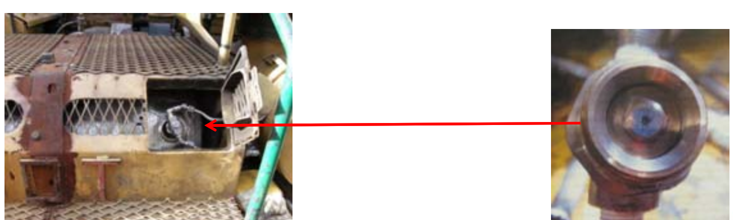
Evaluation at Copper Cliff Mine

- Issue with plugging of the fuel/air nozzle in NO2 decomposition catalyst
- Fuel nozzle was modified to extend hours between cleaning intervals
- The average idling between 20 and 30% will need to be reduced below 20% to avoid challenges with DPF regeneration
- Exhaust discharge modifications were made to reduce entrainment of road dust



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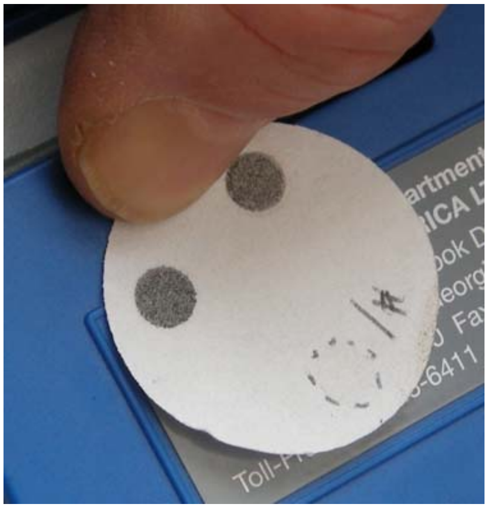
Bacharach = 9 in / 0 out !!

Very positive qualitative, visual results



Summary of the CCMine Test

- Began test in April 2014
- The DPF was optimized using the results of 2 weeks of real time measurements of gaseous emissions using Sensors Inc.SEMTECH DS portable emissions system
- Excellent filtration performance of DPF (JM graph) and NO_2 reduction
- Step-by-step implementation
- Operator engagement
- Frequent meetings
- Solid involvement of supplier/ service agent
- High tech instrumentation for initial calibration
- Weekly inspection, monitoring, downloads

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Next Steps

- Completion of underground trials
- Report with recommendations

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Copper Cliff Mine Underground JM/DPF Evaluation
Core Team members

- Robert MacDonald, CC Mine Manager
- Kevin Hinds, CC Mine Mobile Superintendent
- Steve Merley, CC Mine Superintendent
- Kevin Watson, CC Mine Mobile Planner
- Gilles Dupuis, Scoop Operator, CC Mine
- Brian Kutschke, CC Mine Local 6500 Worker Representative, JHSC Co-Chair
- Ryan Valin, CC Mine JHSC Member
- Shannon Wicklander, CC Mine Occupational Health Representative
- Cheryl Allen, Principal Engineer - Ventilation, Vale
- Simon Nickson, Chief Mine Engineer, Vale
- Joe Stachulak, DERR Principal Investigator, MIRARCO
- Peter Werth, Product Manager,Johnson Matthey,Germany
- Manuel Aguiar, Field Technician, Toromont
- Brent Rubeli, Project Engineer, Diesel Research, CANMET
- Dr Aleksandar Bugarski, Senior Scientist NIOSH, USA
- Dr Mahe Gangal, Head of Diesel Lab, CANMET
- Peter Golde, Managing Director, CAMIRO

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