

Presentation Outline

- The Issue
- Contributions to Diesel Emission Evaluation Program (DEEP) and results
- Continuation of independent work
- Diesel Emission Reduction Research (DERR) Project
- Conclusion



1 Hist



The Issue

- Regulation changes were proposed in 1995. Adoption would reduce diesel emissions significantly, but have a major impact to the use of diesel engines in the mining industry.
- The solutions for controlling emissions were not well understood and it was necessary to develop Canadian expertise regarding diesel emissions.
- Solutions for reliably measuring low levels of emissions were also required.
- DEEP focused on the importance of good ventilation practices, well planned maintenance, filter technology, use of high quality fuels and lubricants and measurement methods.



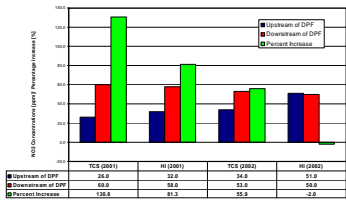
Vale Project within DEEP – Diesel Particulate Filter Evaluations Contribution

- Vale relies heavily on diesel powered mobile equipment, therefore was willing to be involved in the project. Stobie Mine was selected to evaluate 9 Diesel Particulate Filters
- Over a 4 year period, DPFs were evaluated for both light and heavy duty equipment
- Before any trials began, it was necessary to:
 - establish a selection criteria, for underground mines, that could eventually guide the end user
 - work with manufacturers to understand the data necessary for selecting an appropriate filter
- Emphasis of the trials was to understand the technical practicality of a DPF system used in a mining environment and ensure other hazardous emissions were not generated.



Vale Project within DEEP – Diesel Particulate Filter Evaluations 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 a cleaned filter
 - Generation of NO₂ in filters with platinum catalyst



Review

(Red - challenge, Yellow - wear other team, Green - OK)

Item	Issue	Impact	Root Cause	Action	Responsible	Status	Start Date	End Date
DPF	DPF 101	Challenge	DPF 101	DPF 101	DPF 101	Open		
DPF	DPF 102	Challenge	DPF 102	DPF 102	DPF 102	Open		
DPF	DPF 103	Challenge	DPF 103	DPF 103	DPF 103	Open		
DPF	DPF 104	Challenge	DPF 104	DPF 104	DPF 104	Open		
DPF	DPF 105	Challenge	DPF 105	DPF 105	DPF 105	Open		
DPF	DPF 106	Challenge	DPF 106	DPF 106	DPF 106	Open		
DPF	DPF 107	Challenge	DPF 107	DPF 107	DPF 107	Open		
DPF	DPF 108	Challenge	DPF 108	DPF 108	DPF 108	Open		
DPF	DPF 109	Challenge	DPF 109	DPF 109	DPF 109	Open		
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DPF	DPF 111	Challenge	DPF 111	DPF 111	DPF 111	Open		
DPF	DPF 112	Challenge	DPF 112	DPF 112	DPF 112	Open		
DPF	DPF 113	Challenge	DPF 113	DPF 113	DPF 113	Open		
DPF	DPF 114	Challenge	DPF 114	DPF 114	DPF 114	Open		
DPF	DPF 115	Challenge	DPF 115	DPF 115	DPF 115	Open		
DPF	DPF 116	Challenge	DPF 116	DPF 116	DPF 116	Open		
DPF	DPF 117	Challenge	DPF 117	DPF 117	DPF 117	Open		
DPF	DPF 118	Challenge	DPF 118	DPF 118	DPF 118	Open		
DPF	DPF 119	Challenge	DPF 119	DPF 119	DPF 119	Open		
DPF	DPF 120	Challenge	DPF 120	DPF 120	DPF 120	Open		



Vale projects continued post DEEP

- Light duty vehicles were tested underground at Creighton Mine
- Mann+Hummel/HJS DPF system (SMF®-AR) installed on 33 kw Kubota and 60 kw locomotive



Vale projects continued post DEEP Light Duty Results

- The Kubota forklift has accumulated more than 5000 hours of operation and maintained a very low average backpressure in the range of 25 mbar.
- The locomotive has accumulated some 6000 operating hours at an average backpressure of 71 mbar.
- The DPF system requires periodic ash cleaning:
 - Forklift – 800 hours
 - Locomotive – 500 hours
- DPF system is capable of adapting to working in different operating modes:
 - if needed the active electrical regeneration takes place;
 - if not the system regenerates passively (without electrical heating). In all cases the dosage of the FBC is moderated to optimize performance
- The system:
 - removed more than 98% of DPM
 - regeneration is automatic and does not effect an 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's mines in Sudbury region.

6 History of diesel emission projects at Vale



Vale projects continued post DEEP

- Heavy duty vehicle tested underground at Creighton
 - DPF – Johnson Matthey Mining CRT system – single unit
 - Caterpillar R1700 LHD tier 3 C11 263 kw engine
 - Experienced high back pressure that exceeded recommended value by manufacturer
 - DPF system went back to supplier for modifications
 - Re-designed parallel system fuel injection mapping (NO2 neutral) took place at CANMET
- Re-designed system (MCRT) was tested at Totten in a surface application
 - Load rock from ground stock pile (~ 200,000 tons , 1200 hrs of operation), haul rock to dump site located 100 to 1000 feet away and dump into caved area
 - Further modifications were made before next underground trial at Copper Cliff Mine



7 History of diesel emission projects at Vale



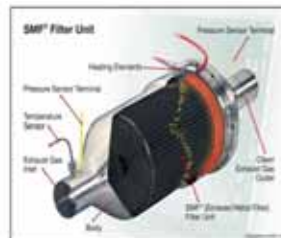
**Vale projects continued post DEEP
Filter Bench Test**

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



Diesel Emission Reduction Research (DERR) Project

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

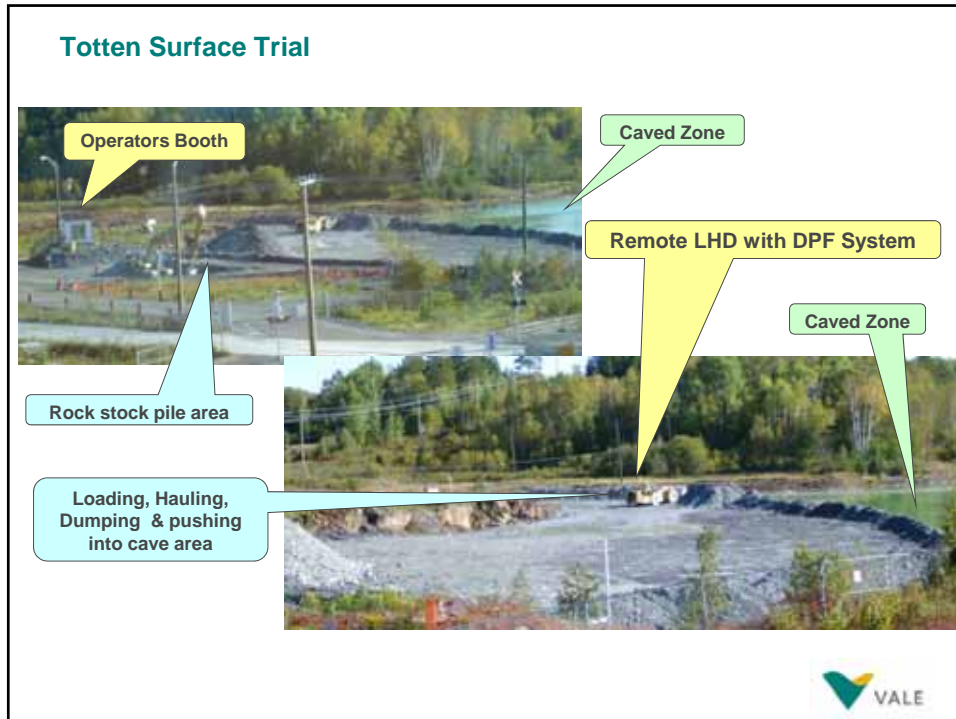


- 3 Projects under the DERR consortium were DPF trials for Light Duty and Heavy Duty, as well as a DOC study regarding NO₂ emission.



9 History of diesel emission projects at Vale





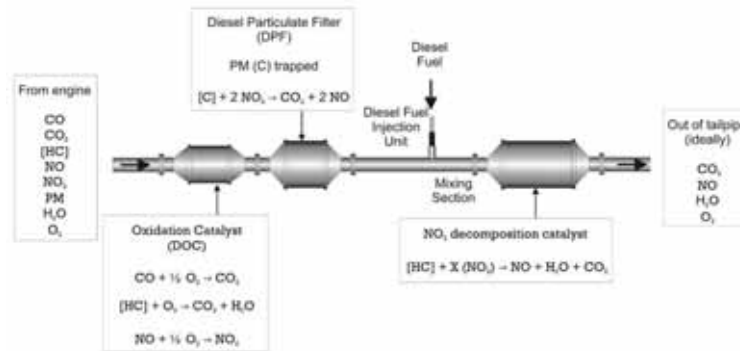
**Diesel Emissions Reduction Research (DERR) Project
Field evaluation at Totten Mine**

- Over-all the system operated very well with little maintenance issues and associated down time
- DPF regeneration did not require operator's involvement
- However, the idle time had to be reduced below 20 minutes/hour to avoid problems with DPF regeneration
- After 630 hours of operation vibration loosened the components of the DPF system and corrections were made immediately to get the scoop running.
- DPF system eventually accumulated 1200 hours



Diesel Emissions Reduction Research (DERR) Project – Heavy Duty Filter - Low NO₂

- Heavy Duty DPF system selected for trial was a JM CRT mining version (NO₂ neutral) based on results from the Totten trial
 - Improvements in design by JM in conjunction with U of Minnesota, NIOSH
 - Bench tested the new filter at CANMET's Bells Corner Lab
 - Install the M-CRT system on a Caterpillar R1700 LHD underground at Copper Cliff Mine



Diesel Emission Reduction Research (DERR) Project Copper Cliff Underground Trial

- Mining-CRT was installed on a Caterpillar Elphinstone R1700 LHD with C11 263 kW Hp tier 3 engine in April of 2014
- The system was optimized for NO₂ reduction with on-line, real time emission data using a SEMTECH analyzer (Sensors Inc, USA)
- Regular emission tests were completed weekly through the project to determine gaseous and soot emissions.



Diesel Emission Reduction Research (DERR) Project Trial Results

- The system was able to:
 - effectively reduce DPM concentrations and particle number count (+98%)
 - Operational acceptance
 - No increase in NO₂ 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
- 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.

14 History of diesel emission projects at Vale



Diesel Emission Reduction Research (DERR) Project DOC Study

- DOCs have been used to control CO and hydrocarbons. DPM and NO₂ have recently become the pollutant of most concern in Canada. Changes to NO₂ exposure have dropped 90% from 3.0ppm to 0.2 ppm.
- Emission testing over the past years has indicated that a majority of the tested DOCs increase NO₂ emissions.
- The evaluation was done in two stages. The first stage looked at 10 units with the second stage currently reviewing 17 additional units including new NO₂ neutral DOCs.
- Temperature of the gas through the DOC is the factor that effects the emission
- The first stage of testing commonly used DOCs in Vale mines showed:
 - temperatures below 225°C had DOC out NO₂ emissions similar to those from engine out
 - Temperatures above 250°C had DOC out NO₂ emissions greater than engine out
- DOCs should be tested under actual operating conditions to determine the emission trends from the particular application.

15 History of diesel emission projects at Vale



Diesel Emission Studies Conclusion

- The light duty applications selected proved to be a practical solution.
 - Vale has 30 light duty DPF units operating on Kubotas, locomotives and Toyotas
- The heavy duty application:
 - Accumulated 2000 hrs before being removed for analysis
 - The unit was removed and a spare unit re-installed within one shift
 - The original unit is currently out for cleaning and a system analysis
 - The LHD is currently in the normal production fleet
 - Vale has a combination of DPF styles installed on 5 pieces of heavy duty equipment.
- The second stage of the DOC testing is still in progress.
 - The first stage showed that most DOCs currently being used by Vale are producing NO₂ at levels higher than that of the engine out levels.
 - As DOCs need to be replaced, consideration is given to using NO₂ neutral units as required.

