Successful application of DPF System at Vale's Creighton Mine

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Introduction

- Vale employs over 800 diesel-powered units at its Ontario mining operations in the Sudbury basin.
- While the use of alternative power (e.g., electricity, fuel cells) is being explored, Vale's Ontario Operations and most other Canadian deep-rock mining companies realize that diesel engines will continue to be a very important component of a working fleet of vehicles for many years to come.
- In view of this, it is imperative to lessen diesels' undesirable features such as noxious substances in its exhaust.

DEEP's Work

- DEEP has also shown that reducing emissions of DPM from the tailpipes of diesel vehicles is not a simple task:

  a) Older diesel engines, particularly heavy-duty engines, are the primary generators of DPM. Newer engines, which are electronically controlled, are better, but many of these engines cannot reliably meet the proposed DPM levels.

  b) Engine maintenance is an essential component to having diesels perform while limiting deleterious emissions, but maintenance will not by itself be able to reach very low DPM specifications.

- Alternative fuels, such as biodiesel, can assist in lowering DPM emissions, but will achieve no more than 30-50% reduction.

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DEEP's Work

- The best technology for achieving dramatic reductions in DPM emissions is diesel particulate filter systems.

- Extensive tests were conducted under the auspices of DEEP at Vale Inco's Stobie mine from 2000-2006.

- While many of the DPF's tested there showed good performance for extended periods of time, the main challenge remaining to be overcome in implementing DPF system technology on underground vehicles is to eliminate the human parameter from their operation.

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Mining Industry Role

- Because of underground mining's reliance on diesel equipment in its operations, Vale needs to be involved in finding reliable DPF systems for use in retrofitting ageing equipment and in supplying DPM control for new equipment.
- It would be challenging for mining companies to leave DPM control completely in the hands of engine or vehicle manufacturers, because the successful use of a DPM control strategy ultimately is the responsibility of the mining company and problems with improperly designed systems would directly impact mining productivity.

Post-DEEP Vale Ontario Operations Testing

- With the experience gained from the DEEP testing at Stobie Mine, Vale is well positioned and committed to continue its evaluation of DPF's for the underground environment.
- More than 50 manufacturers worldwide offer DPF's capable of filtering DPM, but this number was reduced significantly by application of several service and performance criteria.
- In selecting units for testing, consideration was given to the expected DPF reliability, along with its technical and operational viability under the duty cycle of the vehicle. The technical support of the DPF manufacturer and the experience attained elsewhere in a particular DPF's use was also considered.

Criteria for Initial Selections of DPF's

- Regeneration of DPF's was known to be a critical aspect of having a system work successfully over a long-term period of time.
- The probability of success of each regeneration system depended on the method used for regeneration. The factors needed for success therefore were varied for each kind of system. Critical success factors of various regeneration methods are shown below:

Regeneration method	Implementation complexity	Fuel quality	Secondary Emissions (NO_2)	Regeneration Rate	Duty Cycle	Power supply	Additive dosage	Cost	Dependability	Operating logistics
Diesel burner	x							x		
Continuous Regeneration		x	x	x	x					
Fuel-Borne Cat.	x						x			
Catalytic coating				x	x					
Electric offboard						x			x	x
Burner standstill									x	x

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The Strategy for Selecting DPF's for the Creighton Project

- The experience gained during extensive testing of many systems at Stobie Mine and Brunswick Mine during the DEEP project
- NIOSH, USA experience, discussion and feed-back
- Communication and lessons learned at Kali und Salz, mines, Germany and LKAB mines, Sweden
- The experience gained during extensive testing of many systems in Europe by VERT.

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VERT Criteria

- Filtration of >95% (new and at 2000 hours service) and elemental carbon in the exhaust reduced by >90% when averaged over four operating conditions of the ISO 8178 test cycle.
- No increase in CO, chained hydrocarbons, NOx, dioxins, furans, poly-aromatic hydrocarbons and nitro-poly-aromatic hydrocarbons during DPF operation and/or regeneration.
- Opacity of exhaust of 5% during free acceleration.
- At maximum exhaust flow at rpm limit, the backpressures to be maintained
  - For new filter: <50 mbar
  - For operating filter: maximum range of 100-125 mbar.

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VERT Criteria

- For fuel additives, dosing should be automatic with interrupt if filter ruptures.
- Muffling capacity is to be equivalent to muffler that is being replaced by the DPF.
- The life expectancy of the DPF is >5000 hours. Useable hours until ash cleaning was expected to be > 2000 hours
- Labeling of serial number and manufacturing data must be clearly visible and legible even after prolonged use. Also, flow direction through the filter must be indicated by an arrow and reverse mounting should be prevented by design.

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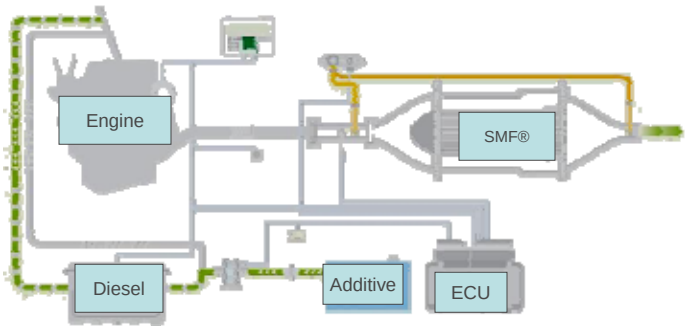
Success through Fuel Borne Catalysts at Creighton Mine

Functionality of FBC based DPF-Systems
FBC-Additive automatically dosed in diesel fuel (22–28 ppm)



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Observations at Creighton Mine
MANN+ HUMMEL SMF®–AR DPF for Light Duty Vehicles

- It is an active system installed on 2 light duty vehicles, namely: a locomotive equipped with a Deutz F6L912W, 60 kW engine, and a Forklift equipped with a Kubota V2203 RP 33 kW engine.
- This SMF®-AR system, Figure 2 consists of diesel particulate filter with sinter metal technology and a fully automatic regeneration unit equipped with fuel additive.
- The regeneration takes place during operation; the control unit automatically initiates the regeneration process

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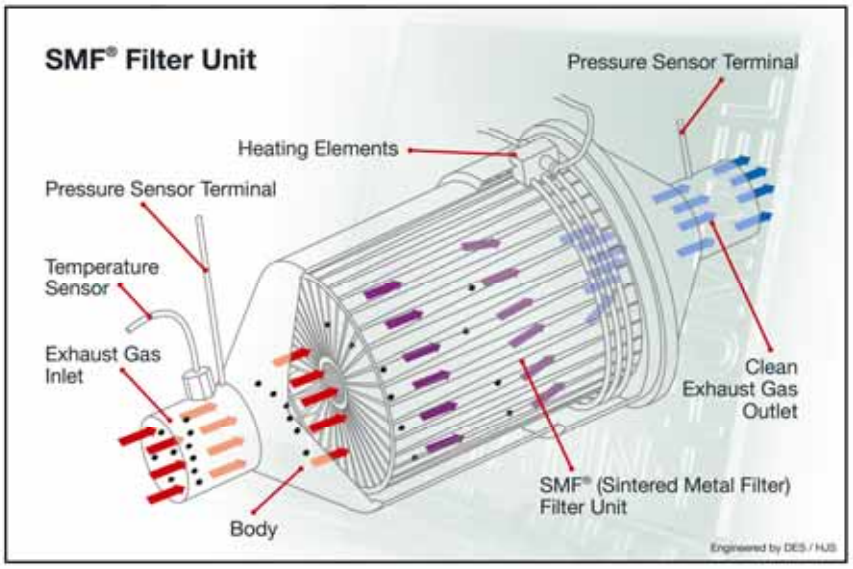
Observations at Creighton Mine

MANN+ HUMMEL SMF®–AR DPF for Light Duty Vehicles



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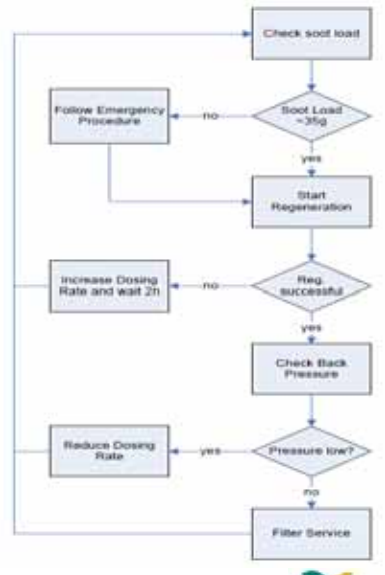
Observations at Creighton Mine

MANN+ HUMMEL SMF®–AR DPF for Light Duty Vehicles

Smart Regeneration Technology

- Increase and decrease of dosing rate based on regeneration success
- Self learning software with statistical tools to detect best available regeneration timing (level 2: advanced)
- Automatic optimization for dosing rate in a defined window



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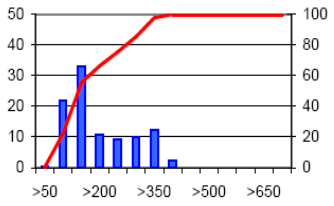
Observations at Creighton Mine
MANN+ HUMMEL SMF®–AR DPF for Light Duty Vehicles

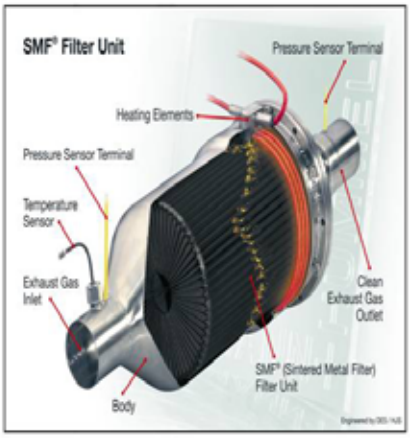
- The 60 kW locomotive has accumulated some 1580 operating hours at an average backpressure of 71 mbar.
- The Figure on the right shows the exhaust temperature distribution of the locomotive over a representative time period of operation.
  - Each vertical bar represents the number of temperature samples (as a percent of total samples) in the temperature interva indicated on the abscissa. For example, about 33% of the temperature samples were between 150 and 200 °C.
  - The solid line is the cumulative or total number of samples that were less than the indicated temperatures and ranges from 0 to 100%. For example 80% of the samples had temperature below 300 C



	Pressure [mbar]	Temp. 1 [°C]
Max. value	217	448
Min. value	0	50,5
Average	71	224
Standard dev.	37	89
95th percentile	141	387,7

Observations at Creighton Mine
MANN+ HUMMEL SMF®–AR DPF for Light Duty Vehicles

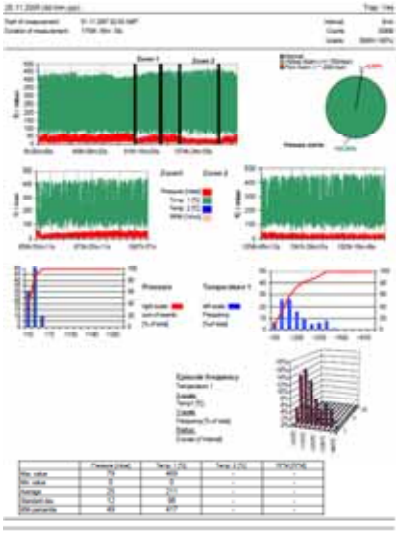
- During the process of active regeneration in the sintered metal filter, the diesel particulates are trapped until a specific volume of soot is deposited on the filter material.
- Then the diesel particulates are oxidized. The oxidation is made through heat radiated from the heating elements without physical contact.
- Even under extreme conditions the fully-automatic oxidation of the layer of diesel particulates can take place within a heating period of just 2 minutes. During the process the machine continues operation.



Observations at Creighton Mine

MANN+ HUMMEL SMF®–AR DPF for Light Duty Vehicles

- The Forklift has accumulated some 1800 hours of operation and maintained a very low average backpressure in the range of 25 mbar.
- Both engines are equipped with the same diesel particulate filters. The difference between them is that on one hand that the engine of the Locomotive produces more soot.
- Therefore the backpressure rises up faster but on the other hand the reached temperature is lower than in the Forklift.



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Observations at Creighton Mine

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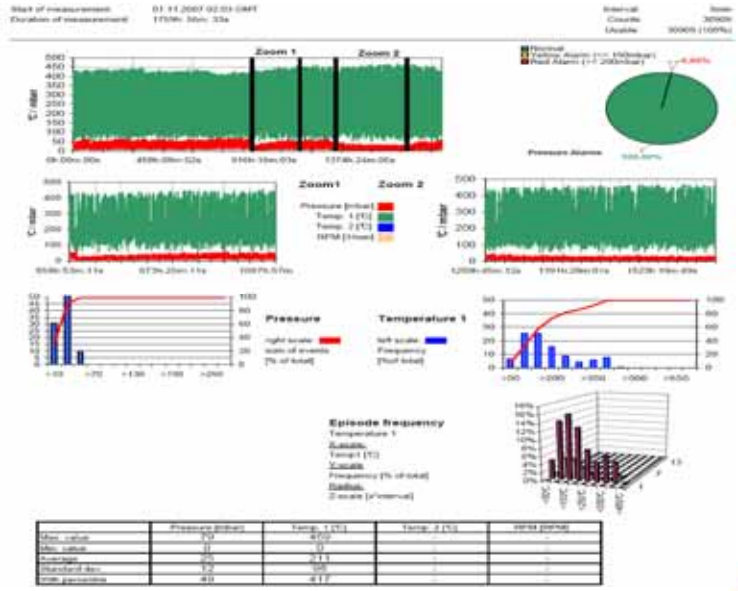

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Observations at Creighton Mine

MANN+ HUMMEL SMF®–AR DPF for Light Duty Vehicles

- This results that the temperature of the Forklift is high enough for passive regeneration.
- The diesel particulate filters work in both different operating modes very well, if needed the active electrical regeneration takes place, if not the system regenerates passively (without electrical heating).
- The main benefits of the system are no downtime during operation, compact design and long service interval

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Summary

- Tests of the two identical MANN+HUMMEL SMF®–AR DPF's on two quite different light duty diesel vehicles at Vale's Creighton Mine demonstrated that this system can successfully address soot emissions control for light duty vehicles with differing soot emission levels, exhaust temperatures and duty cycles.
- The SMF®-AR DPF system is capable of adapting to and thus 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 against cost.
- Other than the obvious benefits of clean exhaust and no downtime during operation, the system is compact, demonstrably robust, and has long (500 – 800 h) service intervals.

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Conclusion

- The MANN+HUMMEL SMF®-AR DPF system, consisting of a pleated sintered metal particulate filter surrounded for part of its length by an electric heating element, a controllable FBC dosing system, and a control unit with self-adaptive control software was tested at Vale's Creighton Mine.
- The advanced technology of the system is applicable in the mining industry and fulfills the expectations of diesel particle filtration for light duty vehicles. In particular
- it is effective in exhaust soot reduction, regenerates automatically with no effect on operating cycle, is tolerant of engine variations and of changing operating cycles, is compact, robust and uses on-board vehicle electric power.

Acknowledgement

- I would also like to acknowledge our colleagues at:
  - Creighton Mine team
  - NIOSH, USA
  - MANN+HUMMEL GMBH, Germany
  - Kali und Salz, Mines Germany
  - LKAB, Sweden

Thank you!

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