

Evaluation of DPF system at Vale's Creighton Mine

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Abstract

Vale has been very active in evaluating new technologies to curtail diesel emission. The presentation discusses the selection, installation and evaluation of diesel particulate filters (DPFs) for reduction of particulate matter in underground mines.

Diesel exhaust emissions reduction in underground mines is a primary goal of occupational health air quality regulations. Emission control devices effectively reduce carbon monoxide, hydrocarbons and diesel particulate matter (DPM), and can be more cost effective than increasing fresh air ventilation to reduce contaminant concentrations. However, these devices must not increase emission of nitrogen dioxide or cause any safety concerns.

This presentation outlines "business as usual" operation of the MANN+HUMMEL SMF[®]-AR DPF system applied to light duty vehicles to reduce DPM emissions without increase of other toxic emissions. The DPF system uses a sintered metal filter element, a base metal (iron) fuel borne catalyst (FBC) with an on-board dosing system, an electric heater that uses on-board power, and a sensor-based control unit. The control unit uses sophisticated software to adjust fuel dosing rate and heater timing to ensure filter regeneration for differing engines and operating scenarios encountered by light duty vehicles.

1 Introduction

The Diesel Emissions Evaluation Program (DEEP), a research consortium formed by Canadian mining companies, labour unions, and provincial and federal government departments completed its work by mid-2006. This program, in which Vale participated with both direct funding and in kind contributions, investigated the ability of currently available technology to significantly reduce underground concentrations of diesel particulate matter (DPM) with high efficiency and low maintenance over a long-term period. While DEEP's testing showed that engine maintenance is a critical component for lowering DPM, it was clear that reduction of DPM to the very low target levels of 0.05 mg/m³ was not possible with maintenance alone. The best candidate technology for achieving low DPM levels was diesel particulate filter systems, DPF. Furthermore, successful deployment of such systems was highly dependent on removing them from their reliance on human intervention for their regeneration. The research continues within Vale to identify a reliable and rugged system.

2 Post-DEEP DPF testing

With the experience gained from the DEEP testing at Stobie mine, Vale Inco is well positioned to continue its evaluation of DPFs for the underground environment. (<http://www.deep.org/reports/stobiedpf.pdf>, 2006) A new testing program is now underway at Creighton Mine. Identical MANN+HUMMEL SMF[®]-AR DPF systems have been installed on two light duty vehicles. More than 50 manufacturers worldwide offer DPFs capable of filtering DPM, but this number is reduced significantly by application of several service and performance criteria. In selecting DPFs for testing, Vale Inco carefully considered each candidate DPF's expected reliability and the technical and operational viability under the duty cycle of the vehicle. (Stachulak 2006) Important also was reliability shown through experience elsewhere and the technical support provided by the DPF manufacturers.

Test results

SMF[®]-AR DPFs are installed on two light duty diesel vehicles at Vale Inco Creighton Mine. One system is on a locomotive equipped with a 60 kW Deutz F6L912W engine, and a second is on a forklift equipped with a 33kW Kubota V2203 RP engine.

2.1 Test Results locomotive after 1600 h of operation

Figure 1 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 interval 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 temperatures below 300 °C. The preponderance of exhaust temperatures for the locomotive is below 200 °C.

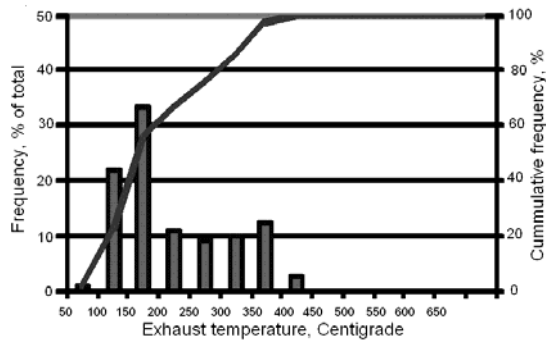


Figure 1 Temperature distribution for the locomotive with the 60 kW Deutz F6L912W engine

The exhaust backpressure distribution for the locomotive is shown in Figure 2.

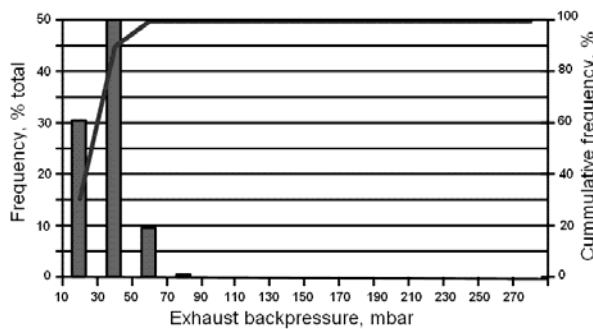


Figure 2 Exhaust backpressure distribution for the locomotive with the 60 kW Deutz F6L912W engine

The system alarm values were set at yellow ≥ 150 mbar and red ≥ 200 mbar. 96.80 % of time there was no alarm, 3.18 % of the time there was a yellow alarm, 0.02 % of the time a red alarm was indicated.

2.2 Test Results for the Forklift Truck after 1800 h of operation

Figure 3 shows the temperature profile of the forklift truck, Kubota V2203RP; 49 hp/36 kW @ 2600 engine, over a typical operation period.

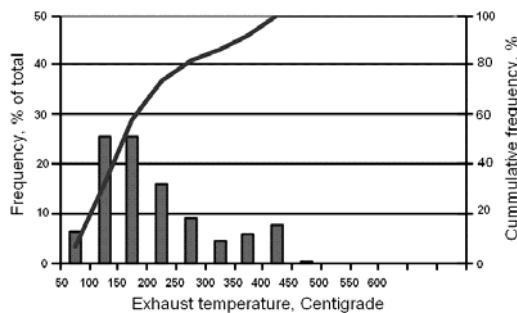


Figure 3 Exhaust temperature profile for the Kubota forklift truck with the 36 kW V2203RP engine

The exhaust temperature distribution of the Kubota forklift shows more occurrences of higher temperatures as evidenced by the taller bar between 400 and 450 °C and extension of the cumulative frequency line to the right.

The exhaust backpressure distribution for the forklift truck is shown in Figure 4. The pressure distribution is noticeably lower than that of the locomotive. Two circumstances are responsible for the lower backpressure. First, the engine is significantly cleaner thus produces less soot; the filter takes longer to load up. Second, the higher exhaust temperatures are sufficient to

allow the FBC to frequently or continuously auto-ignite the soot as it accumulates avoiding any significant accumulation that would increase backpressure. This behavior is characteristic of a passively regenerating DPF.

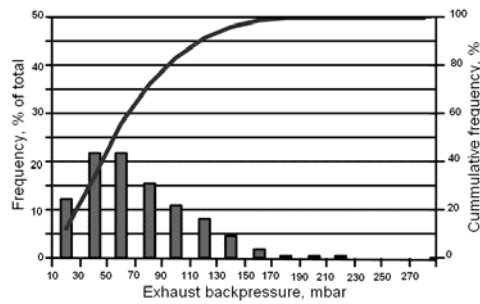


Figure 4 Exhaust backpressure profile for the Kubota forklift.

The alarm values for the forklift were set at yellow ≥ 150 mbar and red ≥ 200 mbar as they were for the locomotive. Over the full test period of 1759 operating hours no alarms occurred.

3 Summary

Tests of the two identical MANN+HUMMEL SMF[®]-AR DPFs on two quite different light duty diesel vehicles at Vale 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.

For the locomotive, which produces significant soot levels and has “lower” exhaust temperatures, the combination of the FBC and the as-needed autoactivation of the electric heater worked to ensure fully hands-off regeneration of the DPF with no effect on vehicle operation except for clean exhaust. The exhaust backpressure exhibits periods of slow rise followed by a rapid decrease to starting pressure after regeneration that is characteristic of active regeneration which typically takes about three minutes.

The forklift truck, which has inherently lower soot levels than the locomotive and somewhat higher exhaust temperatures, has accumulated some 1800h of operation, and maintains a very low average backpressure in the range of 28 mbar. In this case the FBC was sufficient to spontaneously combust the soot as it accumulated. The system behavior is characteristic of that of passive regeneration.

Both engines are equipped with the same diesel particulate filters and although the engines and vehicle operating cycles differed, the SMF[®]-AR DPF successfully self-adapted to these differing operating conditions. The ability of this system to adapt to a variety of engine types and operating conditions eliminates the need to tailor make a DPF system for a particular vehicle and eliminates the concern with the effects that a change in operating cycle would have on a tailor made DPF system.

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.

4 Acknowledgement

We would like to express our gratitude to Creighton Mine Team, MANN+HUMMEL GMBH, Germany and Vale. I would also like to acknowledge Dr. G. Schnakenberg previously NIOSH, USA, for his input.

5 References

<http://www.deep.org/reports/stobiedpf.pdf>, 2006. Evaluation of Diesel Particulate Filter Systems at Stobie Mine

Stachulak, J.S. 2006. Impact of Stobie Testing on Vale Inco’s Research Program, MDEC 2006



Evaluation of DPF Systems 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.

Diesel Emission Evaluation Program (DEEP)'s Work

- DEEP has also shown that reducing emissions of Diesel Particulate Matter (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.

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'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.

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

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.

VERT Criteria

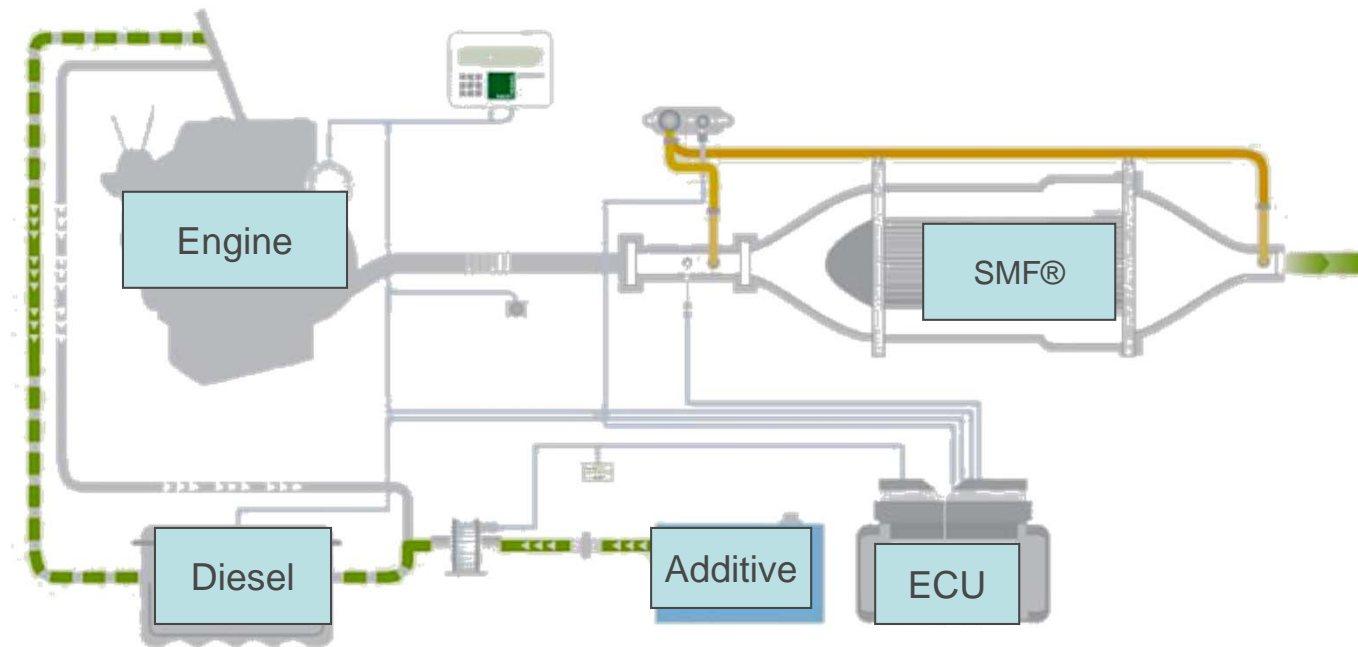
- Filtration of >95% (new and at 2000 hours service) and elemental carbon in the exhaust reduced by >90% when averaged over four operating conditions of the ISO 8178 test cycle.
- No increase in CO, chained hydrocarbons, NOx, dioxins, furans, poly-aromatic hydrocarbons and nitro-poly-aromatic hydrocarbons 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.

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.

Success through Fuel Borne Catalysts at Creighton Mine

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



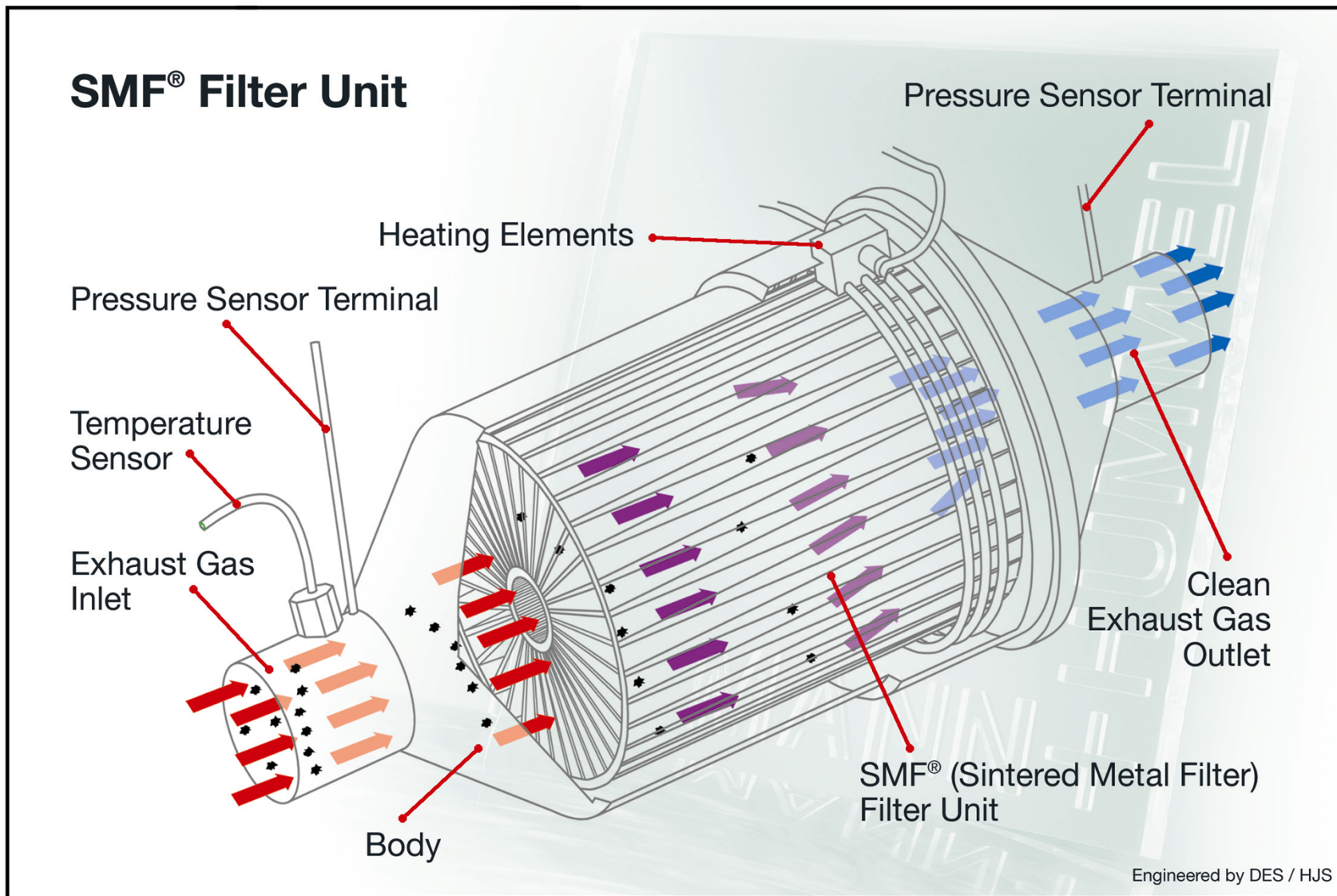
Observations at Creighton Mine

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, next slide 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

Observations at Creighton Mine

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

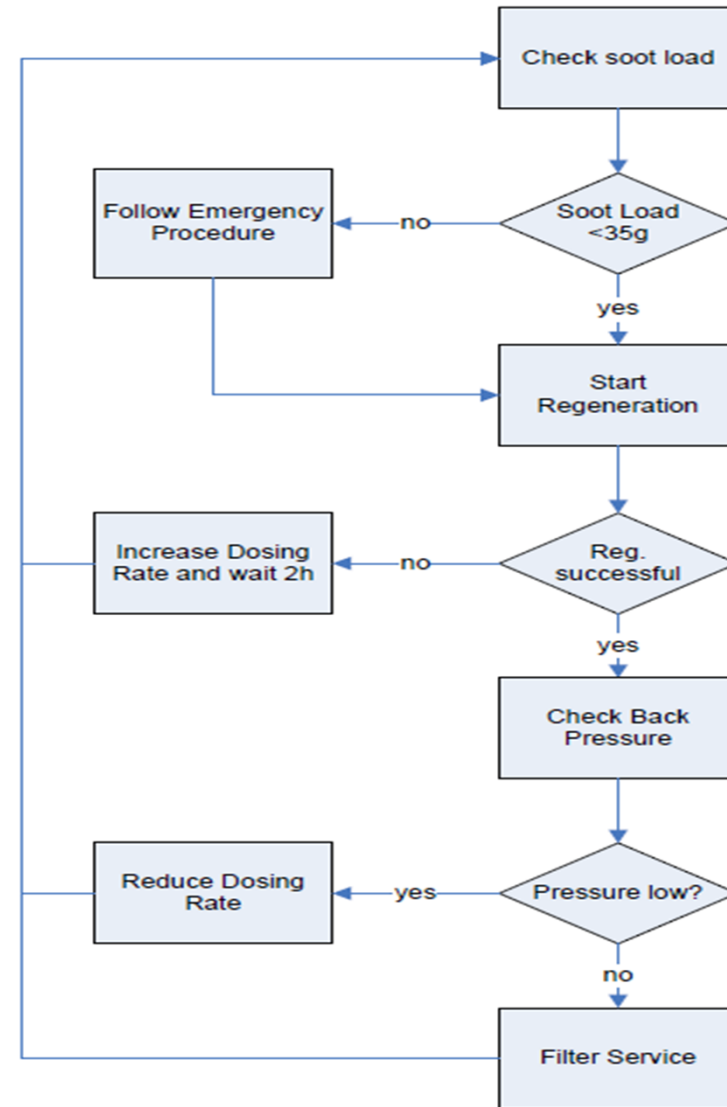


Observations at Creighton Mine

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

Smart Regeneration Technology

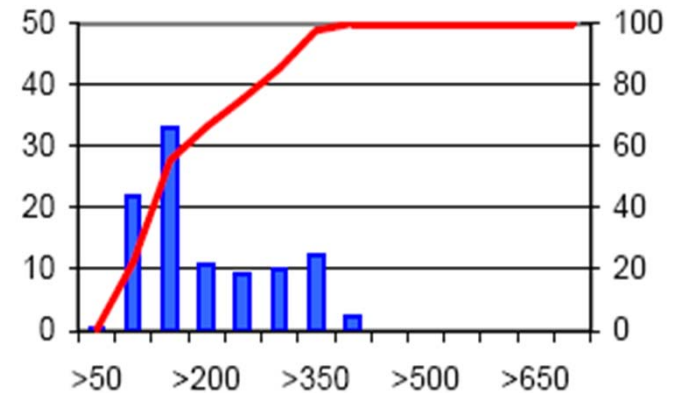
- Increase and decrease of dosing rate based on regeneration success
- Self learning software with statistical tools to detect best available regeneration timing (level 2: advanced)
- Automatic optimization for dosing rate in a defined window



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 interval 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

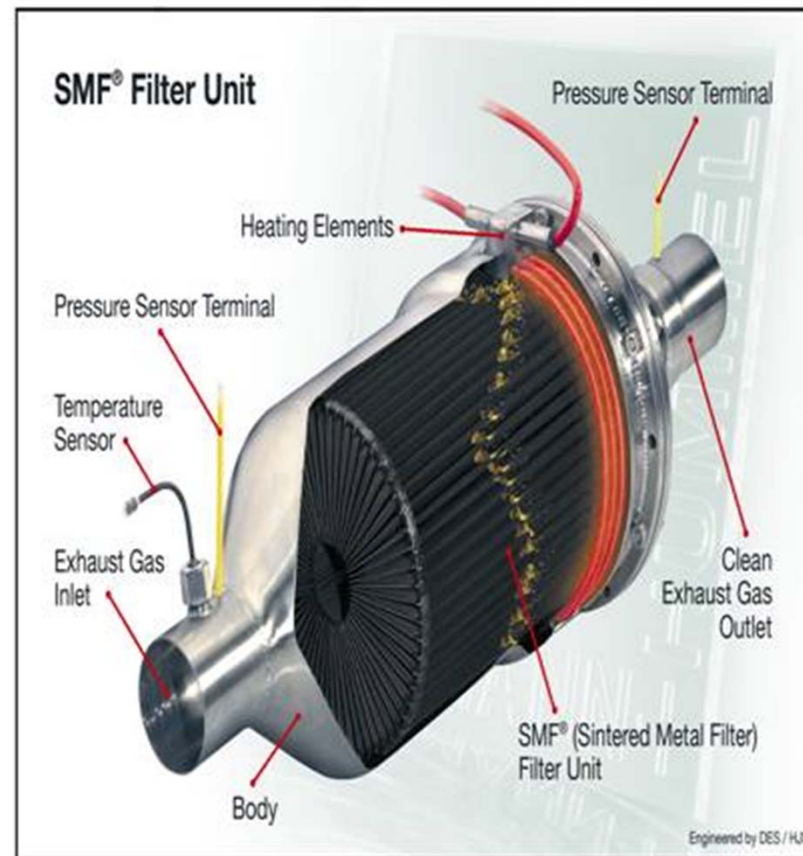


	Pressure [mbar]	Temp. 1 [°C]
Max. value	217	448
Min. value	0	50,5
Average	71	224
Standard dev.	37	89
95th percentile	141	387,7

Observations at Creighton Mine

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

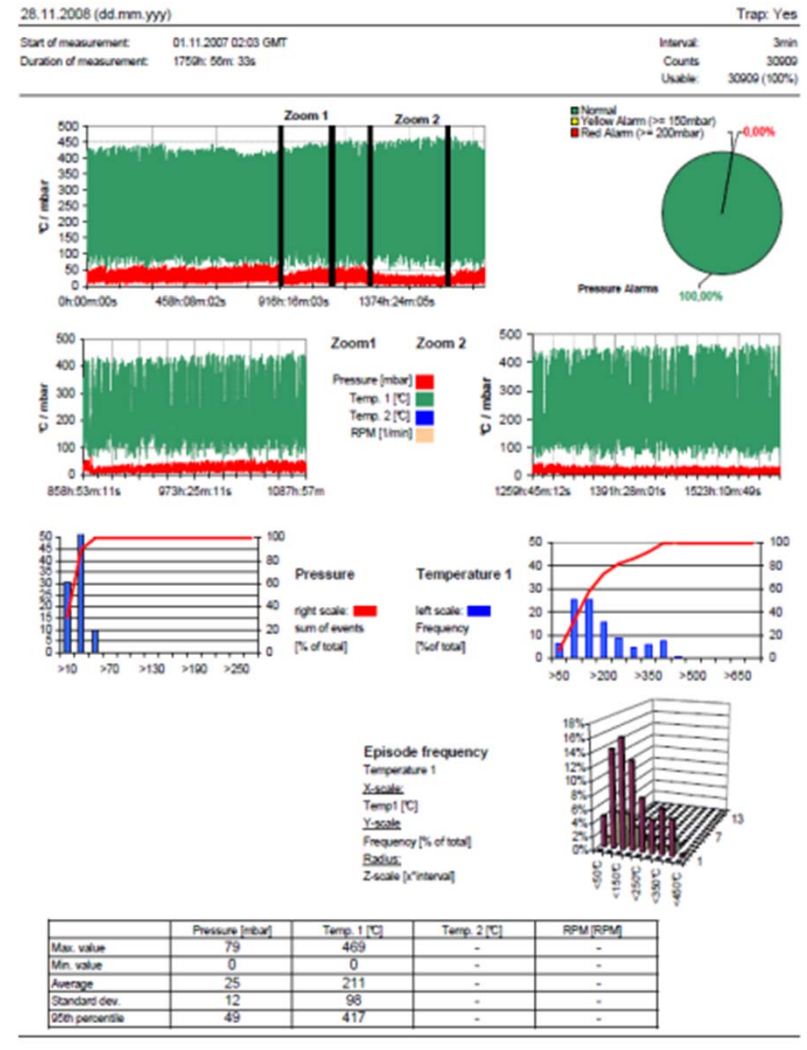
- During the process of active regeneration in the sintered metal filter, the diesel particulates are trapped until a specific volume of soot is deposited on the filter material.
- Then the diesel particulates are oxidized. The oxidation is made through heat radiated from the heating elements without 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.

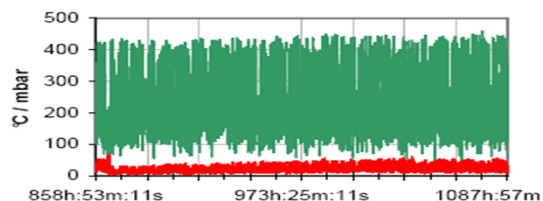
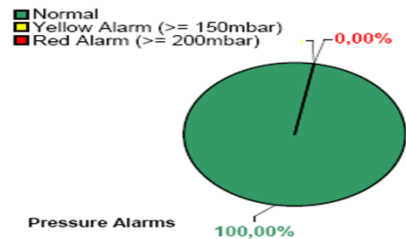
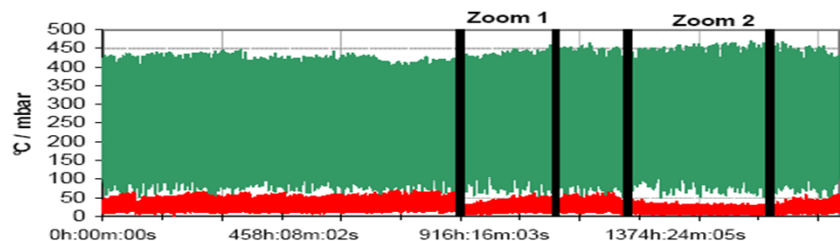


Observations at Creighton Mine

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

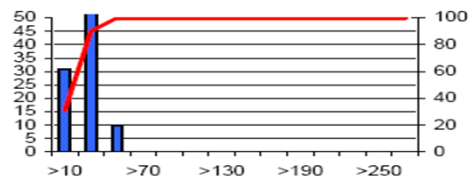
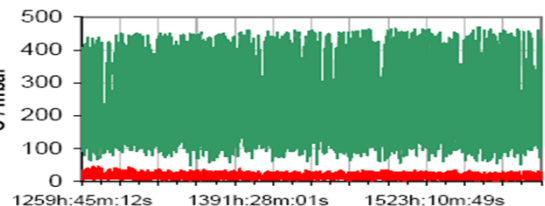
Start of measurement: 01.11.2007 02:03 GMT
 Duration of measurement: 1759h: 56m: 33s

Interval: 3min
 Counts: 30909
 Usable: 30909 (100%)



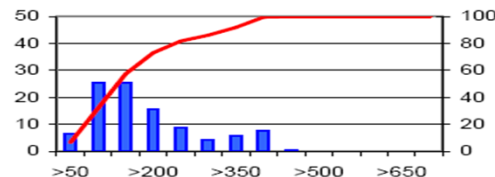
Zoom 1 Zoom 2

Pressure [mbar] ■
 Temp. 1 [°C] ■
 Temp. 2 [°C] ■
 RPM [1/min] ■

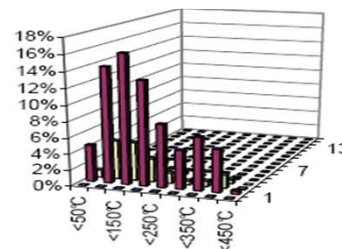


Pressure **Temperature 1**

right scale: ■ left scale: ■
 sum of events Frequency
 [% of total] [% of total]



Episode frequency
 Temperature 1
X-scale:
 Temp1 [°C]
Y-scale:
 Frequency [% of total]
Radius:
 Z-scale [x*interval]



	Pressure [mbar]	Temp. 1 [°C]	Temp. 2 [°C]	RPM [RPM]
Max. value	79	469	-	-
Min. value	0	0	-	-
Average	25	211	-	-
Standard dev.	12	98	-	-
95th percentile	49	417	-	-

Observations at Creighton Mine

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

- 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



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.

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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VALE