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## Evaluation of Diesel Particulate Filter Systems at Stobie Mine

### About the Project

Diesel particulate filters (DPF) have been identified by the DEEP program as the most promising technology to reduce miner's exposure to diesel particulate matter (DPM). The objective of the Stobie Mine Diesel Particulate Filter Study was to investigate the long term effectiveness of DPF systems on a variety of underground vehicles operated under harsh physical environments.

The Stobie Mine study was the final DEEP project. It was conducted at Inco's Stobie Mine in Sudbury, ON from April 2000 to December 2004. The final report—authored by Bruce Conard—was submitted to DEEP in March 2006.

The study was conducted by a team of Stobie Mine personnel led by Joe Stachulak, with the participation of Andreas Mayer, NIOSH, and CANMET.

### Vehicles and DPF Systems

Five heavy duty load-haul-dump (LHD) scooptrams were selected as representing the primary heavy-duty workhorse in underground mining. One of these units had a dual exhaust Deutz engine, and four had Detroit Diesel DDEC 60 engines. Four Kubota tractors were selected, which were representative of light-duty vehicles used for transporting mine personnel. DPF systems on light-duty underground vehicles had not been studied anywhere at the time the Stobie project was started.

The duty cycles of the candidate vehicles were monitored for six months prior to selecting the DPFs for testing. Temperature sensors were installed in the exhaust manifolds, and signals were recorded by dataloggers mounted on the vehicles. The data obtained for each vehicle were analyzed to judge whether the engine exhaust temperature was sufficiently high to oxidize the soot captured in the filter and sustain *passive* DPF regeneration, or else if *active* DPF systems were needed, where the captured soot would be burned by supplying additional heat.

Surprisingly, the results showed that heavy-duty vehicles did not routinely achieve high enough exhaust temperatures to fully regenerate passive filters. Hence, both passive and active DPF systems were required for the LHDs. Data on light-duty vehicles clearly showed the need for active regeneration. The final choice of filter systems is shown in the following table.

Supplier	DPF System
<i>Heavy-duty Vehicles</i>	
Engelhard	Catalyzed cordierite; passive
ECS/Unikat Combifilter	SiC; on-board electric heater (2 units)
Johnson Matthey	SiC; fuel borne catalyst and electric heaters
ArvinMeritor	Cordierite; fuel burner
Oberland-Mangold	Knitted glass fiber; fuel borne catalyst; passive
<i>Light-Duty Vehicles</i>	
ECS/Unikat Combifilter	SiC; on-board electric heater
DCL	SiC; off-board electric heater
ECS/3M	Ceramic fibers; on-board electric heater

### Project Methodology

Periodic tests were conducted every 250 hours of vehicle operation for heavy-duty machines and monthly for light-duty vehicles. During these tests, a portable ECOM emission analyzer was used to determine exhaust concentrations of NO, NO<sub>2</sub>, CO, CO<sub>2</sub> and O<sub>2</sub>, and to measure Bacharach smoke numbers upstream and downstream of the DPF.

Three more extensive testing periods were conducted during the summers of 2001, 2002, and 2004. These tests—performed under three reproducible steady-state engine operating conditions—involved the measurement of gas concentrations and smoke numbers upstream and downstream of the filters, particulate concentrations using a photoelectric aerosol analyzer, particle size distribution using a

Scanning Mobility Particle Sizer, and exhaust opacity.

In addition to exhaust gas measurements, industrial hygiene (ambient air) measurements were performed in the vicinity of selected test vehicles before and after DPF installation. Samples were collected for RCD analysis, and elemental carbon analysis at three different locations relative to the vehicle. The results showed a reduction in elemental carbon exposures when filters were used, but the quality and quantity of data were insufficient to make quantitative conclusions.

### DPF Specific Results

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#### Engelhard Catalyzed Filter (LHD Vehicle)

This passively regenerated filter was operated with no apparent problems over a period of 2221 hours, with soot filtration efficiency in excess of 98%. The system was removed when the engine's turbocharger failed and caused an oil fire. It was not clear if the filter played a role in the turbocharger failure. Increased NO<sub>2</sub> emissions were noted downstream of the filter, but the average tailpipe NO<sub>2</sub> remained at about 6% of the total NO<sub>x</sub> (43 ppm).

#### ECS/Unikat Combifilter (LHD)

The Combifilter system utilized two silicon carbide (SiC) filters connected in parallel, sized to hold soot collected over two working shifts. Each filter included an electric heater. Once the target soot load had been reached, the filter had to be regenerated by connecting to an off-board regeneration station, which supplied electricity and regeneration air to the filter.

Two of the Combifilter systems were tested. The first system developed cracks in the SiC honeycomb after 940 hours, which were attributed to the active regeneration not being routinely conducted. After more intensive education of the workers, a replacement filter worked well, yielding 93-99.8% reductions in DPM emissions over the ISO 8178 8-mode test.

#### Johnson Matthey (LHD)

Two identical filters were fitted on both sides of the dual exhaust from the Deutz engine. The filters were regenerated by a combination of passive and active regeneration. The passive regeneration was facilitated by the use of the cerium-based EOLYS fuel additive. An active regeneration backup was provided through electric heaters which had to be connected to a

shore regeneration station providing the electric power and air.

Filtration efficiencies remained high, ranging from 84 to 99%, however, the pressure drop levels were high, indicating that active regeneration was often not properly conducted by the operators. After 2057 hours, one of the SiC honeycombs separated from its shell, causing a leak of unfiltered exhaust.

#### ArvinMeritor (LHD)

This automated, fuel burner regenerated system encountered problems with the control software, as well as soot breakthrough. The testing was terminated after 116 hours.

#### Oberland-Mangold (LHD)

This fuel additive regenerated system showed low soot filtration efficiency from the beginning of the test, and was deemed to have failed.

#### ECS/Unikat Combifilter (Tractor Vehicle)

This filter system achieved 577 hours of operation over nearly three years, with excellent soot filtration efficiencies of over 99%.

#### DCL Titan (Tractor)

Two filters were used: one in service on vehicle, while the other was being regenerated using an off-board heater. The filter system was successfully operated for nearly three years, achieving 864 hours of operation and soot filtration efficiencies of about 99%.

#### ECS/3M (Tractor)

The system was operated for 453 hours, with filtration efficiencies from 77 to 94%.

### Conclusions

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The project concluded that both heavy- and light-duty mining vehicles could be retrofitted with DPFs. However, most of the filter systems required a significant amount of maintenance and attention from the vehicle operators to function properly.

Matching the vehicle and its duty cycle with the appropriate DPF system was essential for the successful DPF operation.

Communication with the vehicle operators and proper dashboard signals were deemed very important; if operators are not attentive to DPF alerts and high backpressure alarms, serious harm could be done to the engine.