Reducing the effect of underground diesel emissions

New Diesel Particulate Matter (DPM) regulations in the USA require better management of mobile equipment and underground mine ventilation systems. As always, tightening regulations in America can be a wake up call for other mining countries. The latest DPM Permitted Exposure Limit (PEL) in the US, as of May 20 last year, is 160 µg/m^3

Nett Technologies, a major manufacturer of diesel exhaust purifiers explains that DPM "is the most apparent and troublesome of all diesel emissions. [It] is a complex aggregate of solid and liquid material. Its origin is carbonaceous particles generated in the engine cylinder during combustion which subsequently combine with several other exhaust components.

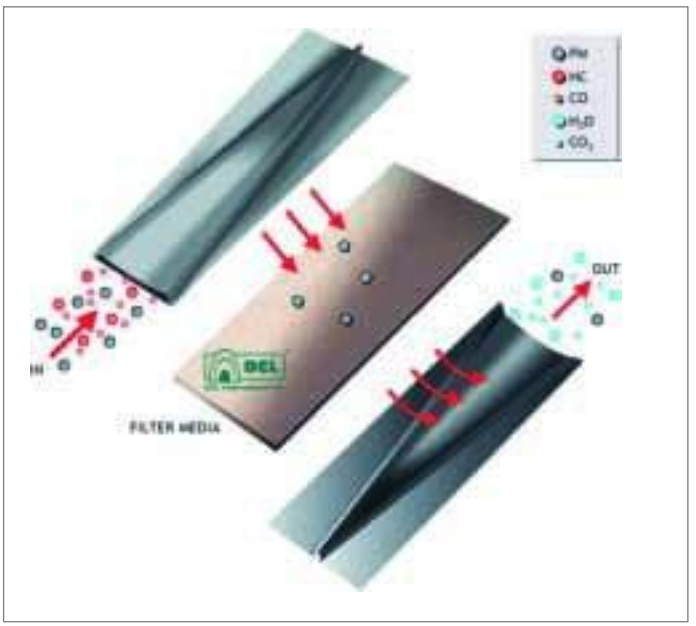
"DPM is divided into three fractions:

- Carbon - dry carbon particles, commonly known as soot
- Soluble Organic Fraction (SOF) - heavy hydrocarbons adsorbed and condensed on the carbon particles
- Sulphate - hydrated sulphuric acid.

"DPM, because of its sub-micron particle size, is almost totally respirable. It is known to increase the risk of heart and respiratory diseases and has been classified by several government agencies as 'human carcinogen' or 'probable human carcinogen'.

"Conversion of DPM is an important function of the modern diesel oxidation catalyst. The conversion of SOF may reach and exceed 80%. Catalysts for heavy-duty applications incorporate sulphate suppressants to maximise their particulate matter performance. The resulting total conversion of DPM depends on the engine, exhaust gas temperature, fuel, and duty cycle. Conversions between 20 and 50% are typically observed. Low sulphur fuel is recommended for use with catalytic converters. It will minimise the irritating sulphur dioxide emissions and enhance the catalyst DPM performance."

Mines are, obviously, finding their way to comply with these DPM restrictions. Stillwater Mining Co in the USA has been an industry leader in its approach to DPM compliance and its experiences are well worth examining. Vic Christensen, Maintenance Manager, explains[1] that the mine has developed a DPM Attenuation Plan which continues to evolve based on the exploration and testing of new technologies.



DCL's MINE-X Flow-Through Filter provides effective removal of DPM and lower back pressure than conventional wall-flow particulate filters

Stillwater has tested many technologies and developed an integrated approach to reducing DPM exposure that embraces:

- Ventilation and engine upgrades
- Emissions-based maintenance
- Exhaust treatments
- Biodiesel blends
- Administrative controls
- Reduce/replace diesel-powered mining techniques.

Changes to the ventilation circuit design to increase dilution "did not get us where we wanted to be in production areas," Christensen explains.

Stillwater has more than 330 items of diesel equipment, all with Caterpillar, Cummins or Deutz engines. About one third of them have electronic controls:

- 85 Electronic engines (32 are Tier 3)
- 39 Electronic governors.

Electronic engines are not available for the complete underground fleet and the cost of total replacement would be prohibitive. Current practice is to replace properly running Tier 1 or 2 engines with Tier 3 only as part of normal replacement at the end of life or if they have high ventilation rate requirements.

However, Chistensen observes that "electronic controls improve emissions, but don't solve DPM. Will Tier 4 engines cure DPM?"

He notes that "electronic controls and emissions-based maintenance enhance DPM reduction techniques. Properly maintained engine systems reduce DPM and keep other gaseous emissions in check." They also "allow other treatments to work to reduce DPM."

Exhaust treatments

Stillwater then placed greater emphasis on exhaust treatments as a means to reduce DPM, aware that properly tuned engines will better support exhaust treatments.

The haulage fleet of trucks and locos (featuring the mine's greatest percentage of electronic controls) was the first group of machines selected for Diesel Particulate Filters (DPFs) because of the larger power, high duty cycle and low quantity. They were considered the "perfect application for passive DPFs. Four 20-t Brookville locos and 23 10-t haul trucks were equipped with catalysed DPFs.

DCL Mine-X BM Plus® DPFs (two-Stage units; base metal with Palladium catalyst in front) were installed on four Caterpillar AD30 trucks. This provided an "excellent duty cycle" with exhaust gas temperatures of over 480°C, offering low NO_2 production as well as DPM regeneration. Field measurements showed no detectable NO_2 behind two operating trucks (at 298 kW each).

Stillwater tested two different active on-board DPFs on the LHDs. A R1300 was equipped with a Rypos unit. 2007 MSHA & Environment Canada testing had suggested greater than 90% DPM reduction, with NO_2 reduction. This gave "excellent emissions results – DPM, CO, and NO_2 reduction."

Caterpillar allows Mann+Hummel to work with its dealership network to provide off highway solutions like Mann+Hummel's SMF-AR technology for low exhaust temperature applications. Mann+Hummel filters at Stillwater have provided good DPM and NO_2 reduction, but no CO conversion, Christensen explains. It "requires additive tank for catalyst to 'dose' fuel in the fuel tank to assist regeneration."

Enerteck's EnerBurn® (MSHA/EPA approved), is a diesel fuel specific combustion catalyst, delivered to the engine via the diesel fuel, to improve the combustion rate of the fuel.

The Mann+Hummel/Enerteck package is currently operating on an R1300 and an MTI LT-270. The mine has committed to a number for the LT-270s.

Dwaine Reese of Enerteck told IM that EnerBurn's primary benefit is an improvement in fuel efficiency (8-14%) and that the decrease in DPM production can be as much as 40-50%. He cautions that it is not an immediate effect and that the product needs time to build up a catalytic coating and then it will start working. He also says engine

life is often increased by 40-60% through the use of Enerburn, and there have been even higher achievements. Engine power can increase by 4-5%.

Other benefits are impressive and include the reduction of NOx emissions, by 12% on average. Exhaust smoke should be reduced by 50 to 75%, and in some applications a total reduction of exhaust smokes to the point where only the heat signature is visible. Oil life is prolonged, increasing oil change intervals by some 75-100%, thereby reducing annual oil consumption by 40-50%.

Reese explains that using Enerburn allows the Mann+Hummel filters to regenerate much faster. Regeneration times of usually an hour can be cut to one minute. Furthermore if temperatures are high enough, passive regeneration is possible.

The utility fleet and drill jumbos were the third group of machines Stillwater addressed – about 196 units with a wide range of duty cycles at lower power. Of eight "medium" duty cycle equipments, five delivery vehicles with a dedicated number of operators have DCL Titan™ active, off-board, catalysed DPFs that operate in passive mode. Three motor graders (Cat 120Gs with 3126B engines) have Nett® passive DPF with NO_2 suppressent which is MHSA compliant and uses proprietary wash coat catalyst (precious and base metals) to control NO_2 emissions.

The majority of the remaining fleets have Flow Through Filters (FTFs) using metal substrates (124 units). The next step (if required) is active, on-board DPFs.

From DCL, Mark Ahrendt, Sales Manager, Export Dept, considers that "new, advanced and/or improved catalytic technology claims are published and promoted regularly, claiming vast reductions in toxic gases and substances. While these may or may not prove themselves over time and testing," he recommends mining operations also "refer to the well-established VERT testing and certification procedures for air quality in underground work places.

"VERT protocols were originally established by the occupational health and safety authorities of Austria, Switzerland and Germany to ensure functional and beneficial systems be utilised for the removal of harmful diesel emissions in underground environments. VERT is an acronym for *Verminderung der Emissionen Realer Dieselmotoren im Tunnelbau*, which in plain English means Reduction of Diesel-emissions in tunnelling. VERT tested and approved technologies must furthermore meet a multitude of criteria, including substantial reduction in particulate matter, and only minimal increase in secondary emissions (i.e. CO, HC, NO_2), as well as stringent durability requirements." (www.akpf.org/about.html)

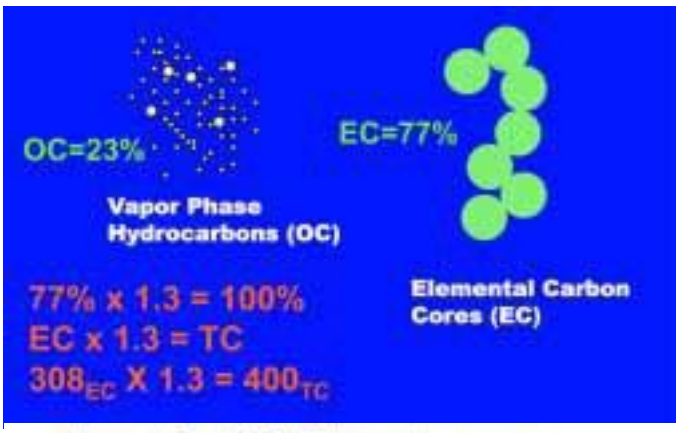
Turning to NO_2 concerns, Christensen observes that "application of catalysed treatments should increase NO_2." He also noted that "active filters seemed to be the only solution," but are not yet proven in underground mining. The Rypos removed measurable NO_2, and had great smoke dot numbers. The Mann & Hummel reduced NO_2, and also had great smoke dot numbers. So in late 2007 Stillwater turned to Nett DPFs with NO_2 suppressing catalyst. This reduced NO_2 by 50% to 80% instead of increasing it by 200% to 500%.

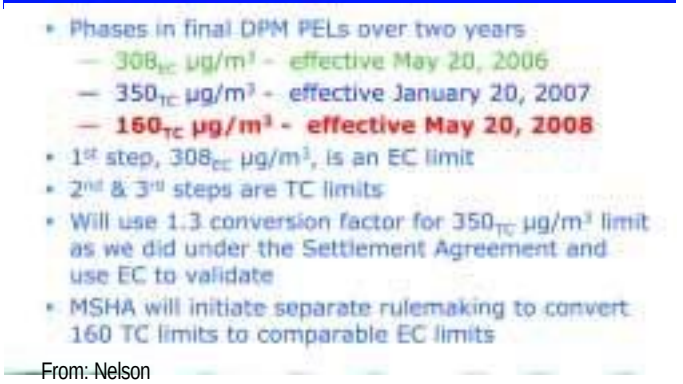
He also says the industry "needs FTFs with NO_2 reducing technology. DPFs [too] must have NO_2 reducing technologies and should be 'fit and forget.' [It is] time for manufacturers to address low duty cycle equipment."

Donaldson notes that compliance with recent diesel engine emissions regulations has significantly increased the use of DPFs. DPFs capture ash and soot generated during the combustion cycle and oxidise only the soot through a regeneration process, leaving the ash behind. So, DPFs require periodic cleaning to remove ash. Donaldson has taken proven Pulse-Jet technology from the dust collection business and applied it to diesel engine emission reduction products. This DPF Cleaning System is a proven two-stage cleaning system incorporating a DPF Pulse Cleaner and DPF Thermal Regenerator.

Biodiesel

"Biodiesel is the only alternative fuel providing a DPM reduction," Christensen says. In late spring 2008, the mine increased its blend to B70. It is currently winter testing with additive to determine CFPP (Cold Filter Plugging Point), etc.





From: Nelson

Biodiesel can be an answer. It integrates straight into a mine's existing petroleum infrastructure – "pour and go", as Richard Nelson of Kansas State University and the US National Biodiesel Board[2] describes it. With a high Cetane* number (>50 versus 42), there is no problem with firing up the engines. It offers high lubricity — 2% blend biodiesel increases lubricity by up to 65%. The BTU Content of B100 (100% biodiesel) is just 8% less than #2 diesel, and it contains virtually zero sulphur.

There are, however, cold flow concerns. Doe Run (***IM***, December 2008) is using B98, but that high proportion of biodiesel would, with today's technology, not likely work any much further north.

The emission reductions can be impressive, as this table shows:

	B100	B20	B2
Total unburned hydrocarbons	-67%	-20%	-2.2%
Carbon Monoxide	-48%	-12%	-1.3%
Particulate Matter	-47%	-12%	-1.3%
NOX	+10%	+/-2%	+0.2%

From: Nelson

Nelson says that several OEMs have indicated they will be more likely to issue B20 support to their customers once the new AS™ B6-B20 specifications become official.

John Sander, Head of Research & Development, Lubrication Engineers Inc. (L.E.), explains that "in order to meet the recent 2007 EPA requirements for lower emissions, engine builders began to produce newly designed engines for on-road vehicles. Alone, even these new engines could not meet the new stricter requirements. It was also necessary for the refiners to produce a new diesel fuel - Ultra Low Sulphur Diesel (ULSD). The new EPA standards require that on-road diesel contains no more than a maximum allowable level of 15 ppm of sulphur as compared to the previous figure of 500 ppm! Use of higher sulphur diesel will be allowed in off-road equipment in mines until 2010. Removing sulphur is beneficial to the engine's emission reduction systems but not to fuel pumps. Sulphur acts as a naturally occurring lubricant, so its removal means the fuel will not provide adequate fuel system lubrication. Fortunately for users, the new laws also

require refiners to therefore add a lubricity additive to the diesel fuel - but only to meet minimum requirements. Further fuel additisation will therefore be required by many mines for their diesel fuels once they are required to use ULSD also."

A variety of high-performance diesel fuel supplements are now available to help mines further reduce the DPM emissions of their equipment. In early 2007, L.E. introduced a way to protect the fuel systems in both old and new diesel engines and upgraded its popular BTU+ Diesel Fuel supplements to make them ULSD compliant. What this means is that they do not contain more than 15 ppm S and thus result in no additional SO_2 emissions when the fuel is burned. But they do contain a new and improved additive system which includes a very effective lubricity additive. L.E.'s chemists worked on this upgrade for nearly a year before introducing the new formula *2410 BTU+ Total Treat and 2420 BTU+ Power Supplement & Cleaner* that are needed by ULSD users. Furthermore, both 2410 & 2420 can still be used in off-road applications, whether they are using higher sulphur diesel or ULSD.

In certain field applications, BTU+ has been proven to provide up to a 13% reduction in hydrocarbon emissions, 16% reduction in CO, and approximately 5% reduction in DPM. It can also be used with biodiesel to assist in the controlling of deposits, cleaning of injectors, improving fuel oxidation stability. LE 2410 BTU+ Total Treat can also be used to improve the cold flow properties of biodiesel blends up to B20.

The engine builder

Cummins says underground haul trucks powered by its engines have demonstrated productivity increases of up to 20%, "achieved by higher capacities and faster operating cycle times. Equally impressive productivity results can also be seen with recent Cummins installations in LHDs and other types of equipment."

"Several of the world's largest manufacturers of underground mining equipment are based in Europe and Cummins power has proved increasingly attractive to them by offering more responsive performance, rugged dependability and unrivalled worldwide service support," said Manfred Duering, General Manager of Cummins Underground Mining Business. "Cummins now powers around a third of all European-built haul trucks and LHDs for underground hard rock and permissible coal mining. We anticipate Cummins engine availability in this highly specialised equipment to increase as demand for more productive equipment continues to grow," added Duering.

Cummins QSK19 powers some of the largest underground haul trucks in the 50-to 60-t payload class with ratings from 485 to 567 kW. Fast engine response with smooth power delivery makes easier work of long, steep access ramps. In terms of uptime availability and life-to-overhaul, the 19-litre engine achieves exceptional results while working under the most severe duty cycles, Cummins reports.

Some of the latest LHDs and haul trucks are using Cummins 11-litre QSM, which comes with a reputation for heavy-duty performance and durability. Extending from 216 to 298 kW, the QSM offers deep reserves of torque to enable faster operation for haul trucks up to 30-t capacity. For LHD applications the QSM enables a high breakout force and over 14-t capacity. The 8.9-litre QSL provides high power density with space-efficient packaging in the popular 20-t capacity haul truck class and LHD vehicles in the 10-t capacity range. A high-pressure common rail fuel system enables optimised fuel-efficiency across the rpm range, reducing cost per tonne. The QSL features a peak power boost capability which responds to very heavy work demands. For example, the QSL rated 261 kW at 2,100 rpm comes with a useful peak power capability of 276 kW at a lower 1,900 rpm.

Cummins six-cylinder 6.7-litre and four-cylinder 4.5-litre QSB engines offer a good power match for smaller-sized, low-profile trucks and LHDs operating in confined work areas. Both the QSB6.7 and QSB4.5 offer compact installation envelopes with the flexibility of a broad power range from 82 to 205 kW. While economical to operate, the QSB brings the premium performance of full-authority electronics in common with the larger QSL, QSM and QSK19. ***IM***