**Diesel Emissions and Control Technologies**
**in Underground Metal and Nonmetal Mines**
**February 27, 2003**
**Cincinnati, Ohio**

# Edited Notes

Disclaimer: These notes are the result of the heroic effort of Lewis Wade, NIOSH, who volunteered to capture the comments, questions and answers of the workshop. Taken in long hand, these notes are not to be construed as a verbatim transcript of the proceedings. That being the case, these notes have been extensively edited to enhance clarity and technical accuracy so as to provide a usefully accurate document for your reference. – Editors.

**Welcome and Introduction** **Lewis Wade, NIOSH**

**Opening Remarks** **Ed Thimons, NIOSH**

We are not here to look at legal aspects [of the rule on exposure of underground miners to diesel particulate matter (DPM)], health effects [of diesel particulate matter], questions of OC (organic carbon) versus EC (elemental carbon) [as surrogate for DPM and] TC (total carbon), and issues of sampling. We are here to look at engineering controls and the effectiveness of engineering controls, specifically diesel particulate filters (DPF).

***Update on MSHA Metal/Nonmetal Rule*** **Bill Pomroy, MSHA**

Questions and Answers:

Q: With regard to slide # 4, maintenance and engineering controls do not apply if contractor presence is infrequent, short duration, and irregular (e.g. for delivery trucks). Define short duration?
A: For example, if the Caterpillar dealer comes and leaves in the same day, that would be short duration.

***Overview of Control Technologies Available to the Underground Mining Industry*** **Aleksandar Bugarski, NIOSH**

Questions and Answers:

Q: Does the "per cubic meter" [concentrations of DPM you mentioned] apply to the exhaust gas or mine air?
A: Mine air.

Q: Do both active and passive regenerations depend upon heat?
A: Yes. [With passive regeneration, the heat comes from the engine exhaust during normal equipment operation; in the active regeneration process, the heat comes from electric heaters while the engine is off. -- Editor]

Q: With regard to the use of DOC's [diesel oxidation catalysts] you might see a 20 to 30 percent reduction in total carbon; what about elemental carbon?
A: You won't see a significant reduction in elemental carbon. The reductions in carbon monoxide and especially hydrocarbons emissions will improve air quality. I recommend using both DOC's and DPF's in combination.

Q: With active regeneration, should there be heat sensors associated with the engine?
A: No. The engine is not running during the active regeneration process. The DPF systems designed for on-board electrical regeneration have electric heating elements integrated in the system. The air required for the process can be provided by an on-board compressor or from an external source of compressed air. The heating elements are put through a programmed cycle while a small flow (about 8 cfm) of air is passed through the system. A valve in the exhaust pipe, located upstream of the filter, prevents air from flowing toward the engine. Thermal safety features are incorporated into the regenerating systems.

Q: Your slides, number 29 and 33, speak to the problems associated with active regeneration systems. Do you think active regeneration systems are practical?
A: Yes they are. Their practicality strongly depends on the application. For example, for light duty vehicles, active regeneration might be the only viable option [because of the low exhaust temperatures generated by light duty vehicles and space limitations]. In some cases, where providing regeneration stations at several locations in a mine is not an option, off-board regeneration systems with removable filter units are the viable solution. In these cases, the regeneration would be accomplished elsewhere, e.g. in maintenance shops. Obviously, active regeneration is not as convenient as passive regeneration. You have to consider each case individually.

Q: Is active regeneration practical for large engines in the 600 to 700 horsepower range?
A: In a case of large displacement engines, one can possibly consider using multiple smaller filter units placed in parallel. This would make handling the units and the whole process of off-board regeneration physically possible.

Q: What happens to the PAH compounds that are absorbed on the soot during regeneration?
A: As the DPF temperature is gradually increased during the regeneration process, the PAH compounds and other hydrocarbons vaporize and evolve first. Eventually, as the temperature increases, most of the hydrocarbons and soot will be oxidized to CO and $CO_2$. Although only a low volume of air flows through the filter during regeneration, it is still recommended that the regeneration process be performed in a well-ventilated location.

Q: What is the average aromatic content of diesel fuel?
A: There are specific tests to determine the actual aromatic content (ASTM D1319), but generally the aromatic content of regular diesel fuel is between 20 and 35 %. The reformulated fuels with aromatic content of 10 or even 1 percent are available.

Q: In several instances when you referred to active versus passive regeneration, you mentioned that operator attitudes or different mind-sets within the mining industry need to be considered. Would you clarify and expand upon that?
A: You cannot neglect diesel particulate filters; they require some baby-sitting. You have to watch out for the attitude "we can get one more shift out of this" in the case when that obviously violates the standard operating procedure. Many people in the industry are bonus oriented, and they might not want to take the time to take the appropriate action to regenerate the filters. This could wind up being a problem in the end, as they will experience greater problems. A real example is trying to stretch filter life between regeneration sessions from an anticipated 12 hours to 36 hours. The DPFs are not "plug-and-play" devices, and unfortunately they cannot be installed and forgotten. The operator needs to adhere to the operating procedures and perform the requisite preventive maintenance on both the engines and the filters.

Q: What will be the impact of the new low (15 ppm) sulfur fuel on DPM?
A: There have been studies in the US and Europe that showed significant reductions in DPM emissions [by definition DPM includes the sulfates and associated water] with the use of the ultra lower sulfur fuels. The CRT DPF system by Johnson Matthey, for example, requires fuel with less than 30 ppm sulfur [this system is not recommended for use in underground mines because of its tendency to increase $NO_2$ emissions]. The use of lower sulfur fuels does not significantly affect total carbon emissions. [Editor's note: Use of ultra-low sulfur fuel is always beneficial since it reduces the emission of toxic sulfur oxides, reduces the poisoning of some catalyst systems including DOCs whose catalysts are formulated to compensate for fuel sulfur by using more active catalysts. Due to tax incentives, on-highway fuel with sulfur content of less than 10 ppm is available in Europe. Currently, diesel fuel sold in California has less than 100 ppm sulfur.]

**Diesel Particulate Filters (DPFs) in Underground Mining**

***DEEP-Sponsored Long-Term Evaluation Of The DPF's At Noranda's Brunswick Mining And Smelting Mine***

**Sean McGinn, McGinn Integration, Inc**

Additional comments not included on the slides:

1. [When addressing DPM emissions and exposure of underground miners to DPM] you should first consider maintenance, then engineering controls.
2. Data logging [of exhaust temperatures and engine backpressure] is crucial for success; it does not have to be elaborate and expensive, but you have to do it. It is the

duty cycle of the equipment targeted for a DPF that defines your DPF selection, and temperature logging allows you to recognize the duty cycle.

3. In order to make a passive DPF system application successful, the idling time of the targeted piece of equipment must be minimized. The less the idling time, the better chance of success. This was not the case with the haul trucks at this particular mine, since they were operated in idle mode for 32% of the time. The scoop trams, however, idled only about 22% of the time.
4. Concerning the ECS Octel System, that vehicle/engine was operated below peak load for a long period of time. When finally the vehicle was put under a high load, the DPF system went into an uncontrolled regeneration and experienced temperatures they thought were in the range of 3000°C. [Editor: Such a high temperature (white hot) is not likely, but they were probably in excess of 1000°C and were sufficient enough to melt the metal substrate of the DOC following the DPF element]. This happened twice during the study.
5. You need to watch for obvious flaws such as exhaust leaks, and perform interim visual inspections of the DPF element and of the full system.
6. The Bacharach/Bosch smoke test is a great tool especially for mechanics to use for assuring DPF filter element integrity. [Any discoloration approaching 1 indicates a marginal filtration performance for cordierite or silicon carbide DPFs.]
7. DPF system that used a precious metal catalyst, a platinum group metal, for example, exhibits an increase in $NO_2$ emissions [owing to catalytic conversion of NO to $NO_2$]. Elevated $NO_2$ tailpipe emissions was not a concern for the Brunswick Mine, since their ample ventilation [at least 100 cfm/hp] was sufficient to dilute the $NO_2$ to levels below those that would cause concern. In their opinion, improvements in filter efficiency [passive regeneration and the reduction of ambient DPM] outweighed the increase in $NO_2$ emissions. You have to be mindful of the potential problem as it relates to platinum group metal catalysts.
8. One of the greatest problems concerning the introduction of this technology is getting the operators to accept it. It is as simple as plugging in an active DPF unit at the end of the shift so that it can be regenerated. This often turns out to be a problem; there is a need for the miners to change their attitude so they can become acclimated to this new technology.

Questions and Answers:

Q: When you refer to different levels of $mg/m^3$ [in the isolated zone tests] are you referring to personal breathing zone tests?
A: No, I was referring to area sampling, although the on-vehicle sampling during the isozone tests did collect samples from the operator's immediate breathing zone.

Comments by the presenter: Regarding the data on the slides on page 15, the presenter stressed that the air entering the isozone was fresh, uncontaminated air, and that there was only one vehicle operating in each of isolated zone tests. Concerning the data presented in figure 15B, it represents how far you can get [how low a DPM level can be achieved] by applying this technology. With regard to the DCL System, it was difficult to get the operators to plug it in, and the presenter felt that represented a management failure that

has to be overcome. Concerning the ECS Octel System, when the DPFs worked they worked well, but there was evidence of failure on both the original and the replacement system. These are the units that experienced uncontrolled regeneration. With regard to the future, they [Brunswick Mines] will be purchasing ECS CatTraps for all new [Wagner] ST8B Scoops. They know that these DPFs work for Brunswick's [LHD] applications and duty cycles. However, one would need to determine if a selected DPF matches his targeted application.

Q: What is the life of the mine?
A: Four years.

Q: What was the size, volume, of the ECS CatTrap?
A: They were twin 12 inches by 12 (or 14) inches units.

Q: What was the back pressure for the DCL System?
A: For the DCL System there seemed to be a plateau of back pressure of about approximately 50 to 60 inches water gage. [100 mbars = 40.2" water gage.] For the ECS CatTrap System it continued to climb until the problem occurred [this may be for the ECS Octel which eventually failed; we recall that the ECS CatTrap worked well on the ST8B scoop – Editors], and for the Oberland Mangold System there was a plateau of about 40 inches water gage.

Q: Do you favor passive regeneration systems over active regeneration systems?
A: Yes, because of ease of maintenance.

Q: Are active regeneration systems practical?
A: Yes, but you have to resolve the engineering issues specific to their application in your mine. They offer the potential for better filtration, but you do have to plug the units in at the end of the shift. The presenter doesn't see this as a practicality issue but instead as a management issue.

Q: What does mode 4 refer to on your slides?
A: Mode 4 referred to idle mode on each of the slides.

Q: Do you sample for emissions before and after the filter was installed?
A: Yes. [No, not literally; emissions are sampled at every PM (250 hours) upstream and downstream of the filter.]

Q: When looking at the $NO_2$ issue, was data taken before and after filter application?
A: Yes. [No, not literally; emissions are sampled at every PM (250 hours) upstream and downstream of the filter.]

Comment: Clean Air DPF systems that use a platinum-cerium based fuel borne catalysts have been installed on locomotives in a Jim Walters coal mines (30 units). The same system is also being installed on machines at an IMC Global operation (1 or 2 units). MSHA commented that the data from these tests will be available on their website. They

are working on resolving the $NO_2$ issue [in general, but so far the lab data indicates that the small $NO_2$ increase for Clean Air systems will not increase the ventilation requirements for any engine with which it is used.]

Q: Did you use the same 6 duty cycles [engine loadings] for all of the vehicles for the particulate matter testing?
A: Yes, except for the gathering the smoke spot samples for NIOSH 5040 carbon analysis; the test mode for that was always torque converter stall.

Q: What were the costs of the systems?
A: The range of costs for the systems studied was between CAN$15,000 and CAN$30,000. It was hard to determine the actual additional costs of the labor associated with active regeneration of the systems but the presenter felt that they were insignificant.

Q: Was there enough time to regenerate between shifts?
A: Since the mine operates 2 shifts per day, each 10-½ hours, the regeneration time was not an issue.

Q: What is the federal DPM standard in Canada?
A: There is no federal standard in Canada, but the provincial standard in Quebec is 0.6 $mg/m^3$ of total carbon. For the other provinces in Canada, it is 1.5 $mg/m^3$, [measured as respirable combustible dust, RCD].

Q: How many samples were taken during the isolated zone tests?
A: There were 15 samples per vehicle over a 4-hour time frame, [5 at each of the sampling locations: upstream of the vehicle tram path, on-vehicle, and downstream of the vehicle tram path].

Q: How were the personal samples taken?
A: The ambient samples were obtained using a sampling train consisting of a Dorr-Oliver cyclone, a filter cassette containing a pre-cleaned tissue quartz filter, and a Gillian flow controlled sampling pump. There was no sub-micron size selecting impactor (e.g., an SKC diesel sampler or its aluminum prototype predecessor) in the sampling train.

Q: Was the NIOSH 5040 method used to do the analysis?
A: Yes. CANMET laboratories in Sudbury, ON, CA performed the analysis.

Q: Were the results taken over the 4-hour interval scaled to an 8-hour shift?
A: Yes. [The question does not make sense. The actual average carbon concentrations for the duration of the test period were obtained by using standard formulae and were not converted to equivalent full shift exposures as would be done if they were MSHA compliance samples.]

Q: Did you ever clean the filters from ash?

A: Yes. The ECS CatTrap Systems were taken out of service after 1000 hours and sent back to ECS for a thorough cleaning. For cleaning the other systems, mine personnel used compressed air at the mine site.

Q: Why would you have to send the ECS CatTrap Systems back? Shouldn't all of the soot been burned off during the regeneration?
A: Generally not all of the soot was burned off during the regeneration, and it was necessary to return the DPF system to the manufacturer for a good thorough cleaning using the manufacture's equipment. [Additionally, the non-combustible ash from lube oil and fuel additives accumulates over time and must be removed. ECS now offers a "CombiClean" system that performs a full regeneration and ash removal at a mine site. Other DPF manufacturers may also provide the equipment or methods that can be used by mine personnel for safe removal of un-combusted soot and ash from a DPF.]

Q: Was all of the testing in the isolated zone done in the main entry?
A: No. [Well yes, actually: There was a need to turn the equipment around so a sealed side entry at each end of the zone was used for a 3-point turning. All of the vehicle emissions were swept into the main airflow that was being sampled at the downstream end of the isozone.]

Q: Are you convinced your employees do not need to use respirators if DPF's are used?
A: Yes, I am convinced the employees do not need to use respirators when the DPF's are used.

Q: Was the ACGIH TLV [for diesel particulate matter] withdrawn? [The ACGIH only proposed a TLV for diesel particulate matter.]
A: Yes. It was commented by an audience member that [it was rumored that] they did not want to get sued.

Q: What was the cost of fuel catalysts?
A: The cost was negligible being only 2 or 3 cents Canadian per liter.

Q: What was the price of the diesel fuel?
A: Approximately 77 cents Canadian per liter.

***DEEP-Sponsored Long-Term Evaluation Of The DPFs At INCO's Stobie Mine***

**Joseph Stachulak**
**INCO, Ltd.**

Questions and Answers:

Q: Were the hours shown for the filters hours to failure?
A: No, they were total hours on the equipment to time of the report.

Q: Was the fire you mentioned related to the trap?
A: No. It was not directly linked to the trap.

Comment: It is necessary to make cultural changes although it appears that it is quite difficult to get people to make those changes. They need to understand importance of the process of plugging in the active systems at the end of the shift. The presenter was sure this was something that could be accomplished.

***DPFs in U. S. Underground Coal Mines*** **Steve Forbush**
**Canyon Fuels, Inc.**

Comments: Referring to slide 6 that shows 2 modifications: The first modification was referring to adjustments to the timing of the engine on a trial-and-error basis, and the second modification referred to further refinements until correct settings are established. For both Mod 1 and Mod 2, a different torque converter was used than in the cases shown as MSHA and OEM settings. Steve suggested that the metal and nonmetal industry should follow the model of the coal industry. He said there is too much work for any single mine to evaluate all of the different filter systems. He suggested the metal/nonmetal industry break up the work of DPF feasibility testing to several mines and shares the results. He credited NIOSH for assisting in the work, and he credited the Utah Mining Association and Colorado Mining Association for facilitating the division of evaluations between companies and making the information available to everyone. Dr. Schnakenberg pointed out the existence of the NIOSH list server where such information could be easily reported.

The issue of mine worthiness centers on how well the systems are capable of surviving in the mine environment and whether or not one can actually afford to purchase them. Once you get above 100 horsepower engines, the price of a DPF gets high and in some cases not affordable. You have to do your planning and thinking specific to your operations and conditions and just because one system works well under one set of conditions there is no reason to assume it will work well under different conditions. It is not a "one size fits all." The company decided not to use platinum-based systems but to use base metal systems. The company will likely go with active systems rather than with passive systems because of the $NO_2$ issue.

Questions and Answers:

Q: Is it true that active systems are application specific?
A: Yes, you certainly have to consider the logistic. You have to change people's minds in term of the need to do the things necessary for the proper operation of the systems. [Although exhaust temperatures are important for selecting a DPF, they are of little value after the installation of an a*ctive* DPF system, which function only as a soot collector. Also, because passive systems absolutely *must* have exhaust temperatures meet or exceed their specific regeneration temperature, they are also application (duty cycle) specific. -- Editors]

Comment: They [a coal mine] recently tried a DST "paper" filter system with a stated filter life of 100 hours, and they were only able to get 8 hours from the filters. They

called in the manufacturer who sent personnel to the site and found some problems with the engines. They are now achieving up to 20 hours on the "paper" filters. You need to make the suppliers earn their money by bringing them in to work on specific problems. Disposable "paper" filters and wet systems have caused them problems.

Comment: They are considering a Donaldson "paper" filter that is supposed to work up to exhaust temperatures of 1200 degree F. Currently the results have been mixed but they are continuing to explore the technology. [Donaldson's designation for this prototype filter has a "DYN" in the part number. Contact MSHA to check for filter performance data. Further in-mine testing of this filter is planned by the western coal industry. – Editors]

Q: Robert Wheeler of Microfresh questioned the presenter regarding his comments on performance of Microfresh filters during evaluations in Utah coalmine. He wanted clarification that the results are specific to the application. The filters have been working very successfully for 8 years at BHP mines in Australia.
A: The presenter was only speaking to specific applications at the test mines and was not referring to other mines or other applications. The presenter agreed that the Microfresh filter would not burn. The presenter pointed out that there was problem with excessive back pressure with the Microfresh system and that the Australians tolerate higher levels of engine back pressure than their counterparts in the U.S. [for the same engine used in the US mines].

Comment: Regarding the higher back pressures reported during the studies conducted at the Canadian mines, these levels were only tolerated during the testing and would not be permitted during normal mining operations.

Q: Were measurements taken during regeneration of active filters?
A: Yes. We measured very high levels of CO (5000 to 6000 ppm) at the tail pipe but we could not detect any significant concentrations of CO just 2 feet away from it. One needs to be mindful of the issue but it did not represent a problem for them. [The low ambient concentrations can be explained by the relatively low volume flow through the DPF during regeneration of about 10 cfm or less.]

**Emissions Assisted Maintenance**

***Maintenance of Heavy-Duty Underground Mining Diesel-Powered Equipment***

**Sean McGinn, McGinn Integration, Inc.**

Comments:
1. Relative to slide 3B, at first glance it looks nicely arranged and fine but what you really see is oil and air filters sitting out of the boxes and wraps in dusty underground shop, collecting dirt. Therefore it is not a situation conducive to proper storage and handling of filters.
2. Relative to his figure 5A, you need to pressurize the air intake system and use soap and water to check for leaks.

3. You should not do anything to modify the system [engine (valves, timing, injectors, etc.), air intake, cooling, DOC, etc.] unless you base your decision on something that was measured.

Questions and Answers:

Q: Two of the tools you talked about, what are the costs?
A: The Detroit Diesel Diagnostic Link [gives you access to data stored in the engine management system] costs about CAN $1000. The IR temperature gun [used for surface temperature measurements, e.g. of cooling system] costs a couple of hundred dollars.

Q: What kind of improvements can you expect in the reduction of DPM using maintenance alone?
A: You can expect to receive up to a 60% improvement. I've seen evidence of up to a 90% reduction in CO from maintenance alone. [Editor's note: This obviously depends on how bad the system/engine is before maintenance is performed.]

Q: Does a well-maintained system pay for itself?
A: Yes, in terms of engine longevity, fuel savings and in many other ways. [And the reduced DPM and gaseous emissions benefit the workers.]

Q: Do you have any rough numbers of the cost savings that you would realize in going from old to new technology engines?
A: No. There are stories that would say when people have a chance to upgrade to a new engine they are so locked into the old engine they simply order the old engine. That seems to be something that happens often within the mining industry.

Comment: The representative of unidentified mine offered testimony related to the issue. The mine was running Caterpillar 980's and wanted to upgrade to vehicles with new engines. Caterpillar rejected to provide the new engines for such modification stating that vehicles required too many modifications to accept the new engines. A number of participants reinforced this by saying they had similar experiences with [re-powering] the Caterpillar 988 [with a cleaner Caterpillar engine]. The point here was that although low emitting engines are available on the market, it is difficult to get manufacturers to modify engines and vehicles for mining applications. The Detroit Diesel representative stated that they had successfully re-powered a significant number of mining vehicles with modern electronically controlled engines.

***Maintenance Of Heavy-Duty Diesel-Powered Equipment Using Emissions Data*** — **Steve Forbush, Canyon Fuels Co.**

Comments:
1. The Fed's forced them [Canyon Fuel Co.] into maintenance program in 1997 by introducing the diesel regulations [Coal mine regulations, 30 CFR Part 7, 1996]. The

only way they could comply with the new regulations was to get serious about the maintenance program for their equipment.

2. An initial assessment of their baseline in 1997 showed a fleet average of 1597 ppm of CO. Although they had to be below 2500 ppm CO in order to meet the regulations, from the safety perspective of their company, they felt that they had to do better. They set the target to meet manufacturers' specifications for all their equipment at any given time. They went even further by setting the standard that even if a piece of equipment does meet manufacturers' specifications, but a drop of 20% in system performance is observed, that piece of the equipment would be immediately taken out of service and serviced.
3. Relative to slide 11, the engine cannot be considered alone. One has to consider the combination of the vehicle, the torque converter, the transmission, the engine – all of these components make up a system. You have to do all of your work, including maintenance and emissions, with the entire system in mind.
4. Relative to slide 14, various engine emission contour maps laid one on top of the other allowed the presenter to find the "sweet spot" where CO and $NO_x$ emissions are the lowest while power output and rpm of the engine is acceptable. This is what drove the presenter to develop the processes he is presenting and allowed him to do the fine-tuning of the diesel equipment operated at his mines.

Questions and Answers:

Q: You spoke on several occasions of needing 100% management buy-in. How do you get it?
A: It wasn't hard for him since he serves three mines while working for a company that considers health and safety as a value. For example, he has no problem taking a piece of equipment that hauls shields during long wall moves out of service once it's emissions are 20% over baseline although that is the most critical piece of equipment in the mine. If they see that kind of rise in emissions they will take that piece of equipment out of service immediately. This speaks to the commitment of the 3 mines he works with regarding the value of health and safety.

Q: You mentioned ventilation change as a means of realizing better performance in coal mines, what do you mean?
A: He wasn't referring only to coal mines but was referring to a way to meet the 400 $\mu g/m^3$ [total carbon (TC)] standard that the metal nonmetal industry is facing. In the presenter's opinion, with the appropriate ventilation and well-maintained engines, the majority of mines should be able to meet the 400 $\mu g/m^3$ TC standard.

Comment:
1. One of the best tools that can be used by the industry to realize improvements is operator training. It's tougher to get a meaningful training experience and change the operators' behavior than it is to change the maintenance staff, and that's really where you are going to see the improvements. The maintenance staff is much easier to instruct and to cause them to behave in a certain way. The operators are out there, spread all over the place, and it is difficult to get them trained to understand the importance of their role in

terms of the operation and maintenance of the equipment. For the most part we have good people working in the mines, and it's really a matter of providing those people with the education they need to do the job right.

Q: When you spoke of doing full load tests, what was the time frame and the duration of those tests?
A: You run those tests until you stabilize CO levels.

Q: How have you been able to quantify savings versus costs for the maintenance programs that you recommend?
A: The presenter offered that he can not speak directly to costs, overall. He can say that before the maintenance program, he was routinely having engines rebuilt after 3000 hours and now, with the maintenance program in place, they are looking at 12000 hours. He also sees fuel consumption from 1997 dropping from a level of 23000 gallons per month to 13000 gallons per month. He admits there has been some downsizing, but he also feels a large percentage of that drop is based upon the economies of using well-maintained engines. The presenter shared an observation of a competitor who is able to use only 2 vehicles during long wall moves to keep CO concentrations under 25 ppm [which is 50% of the TLV] while the presenter's mines are able to use 6 vehicles under same conditions.

***A Strategy for Deployment of Diesel Particulate Filters (DPFs) -- An Overview of the NIOSH-MSHA DPF Selection Guide***

**George Schnakenberg, NIOSH-Pittsburgh Research Laboratory**

Questions and Answers:

Q: With regard to onboard active regeneration, how much compressed air do you need and where do you get it from?
A: Generally you need between 4 and 12 cfm, and some of the DPF units that accomplish on-board active regeneration have a compressor on board of the vehicle to supply the compressed air. [The other source of compressed air might be filtered and regulated shop air]

Comment:
1. The time to actively regenerate DPF that is using a cordierite ceramic media is on the order of 8 hours; and for a silicon carbide DPFs, it is on the order of 1 to 2 hours.

Q: What is involved during cleaning a filter from ash, and is ash considered a hazardous waste?
A: The presenter wasn't sure, but he didn't think ash was considered a hazardous waste. In follow up discussion it was decided EPA would be an arbiter for that question. A participant offered the data that New York City has begun using filters on buses and New York State has determined that the ash involving from cleaning process for those filters is not considered a hazardous waste. The presenter suggested that ash involving

from cleaning process can be collected into bags, or it can be blown out of the filter with compressed air in well controlled environment such as properly ventilated hood. The presenter offered the opinion that the filters can be cleaned from the ash or by DPF manufacturers or by mine personnel on the sites where equipment, expertise and conditions are present. An ECS representative suggested that it is not necessary to send DPFs back to manufacturers for cleaning, but he does not recommend using water for the cleaning of the filters, since water can cause damage to the filter. He further offered that his company could provide a station that can be used to accomplish a thorough cleaning of the filters from soot and ash. He said that the cleaning of DPF at such a station would take about 8 hours.

Q: Had NIOSH done any research regarding biodiesel fuels?
A: No but the presenter was aware of research that was done at INCO through the DEEP project [see www.deep.org for a report], and he was aware of work that was done in Kentucky at a stone mine in cooperation with MSHA. NIOSH has also done some sampling that indicates there might be some benefit. The presenter suggested that the impacts of biodiesel on the emissions should be evaluated as part of the Stillwater isolated zone study.

Comment: The representative of the stone mine in Kentucky offered his testimony regarding the previous question. The mine in cooperation with MSHA had run tests using B50 (blend of 50% regular diesel and 50% biodiesel) and B20 (blend of 80% regular diesel and 20% biodiesel) yellow grease biodiesel. MSHA will publish the results of those trials in April. He also suggested that at this point the preliminary results indicate "dramatic" improvements [measured as a reduction in total or elemental carbon].

Q: Does biodiesel attack gaskets?
A: No, they have not experienced any problems with hoses or gaskets [The duration of the test was not sufficient to justify bringing conclusions on this issue]. They did have some problems with fuel filters when they were using the B50 fuel. They had only been using biodiesel fuel for 2 weeks. A representative from Griffin biodiesel stated that biodiesel is a mild solvent and will dissolve rubber gaskets, hoses, etc. Thus there may be a problem at 70% biodiesel-fuel blends, but no deterioration had been observed with the 20% and 50% blends used in the recent underground mine tests. If there is a long-term concern, the rubber [neoprene] parts should be replaced with viton.

Comment:
Mike Roach of Clean Air Systems, offered his experience as a DPF manufacturer. They have been conducting field trials with a passive system using a lightly catalyzed filter with fuel additive [cerium and platinum based]. The system requires an exhaust temperature of 335 degrees C in excess of 30% of the time. [Based on their survey of the exhaust temperatures for mining equipment] they believe that this DPF system should work [i.e., passively regenerate] for up to 80% of the engines out there. He said that since the filter element receives only lightly catalyzed treatment, it does not increase significantly $NO_2$ emissions above baseline levels.

George Saseen of MSHA, stated that MSHA is seeking permission to put the exhaust temperature traces for such DPF systems installed on mining equipment on their web site. George also suggested that MSHA has seen some increase in $NO_2$ emissions related to the use of particle traps lightly catalyzed with platinum. The observed increase was not significant to warrant a change in ventilation [the ventilation rate obtained during engine certification]. In fact he offered that increase is comparable to that of a diesel oxidation catalyst.

Q: Regarding the German standard of 300 $\mu g/m^3$ [as elemental carbon] and what was the basis behind that standard and is it a proper standard?
A: They were referred to the dieselnet web site [www.dieselnet.com] for discussion of this topic. George said that the 300 micrograms standard in Germany was set as a technically achievable standard for mining, and it was not set as a health based standard. For other industries, the standard is set at 100 $\mu g/m^3$, elemental carbon.

Q: Did the Germans have difficulty in realizing compliance with the 300 microgram standard?
A: Joe Stachulak answered that he did not know for a fact but would check and provide an answer back to the group. Joe offered that INCO had used biodiesel in their isolated zone test and had seen a 20% reduction in DPM. He also offered that the mix used in their test was 56% biodiesel and 44% D2 diesel fuel. [see www.deep.org for the report.]

Comment:
1. Biodiesel is a mild solvent and can attack rubber hoses and gaskets.
2. George Schnakenberg offered that one should consider following a lightly catalyzed particulate filter with an oxidation catalyst to reduce hydrocarbons and CO.
3. George also cautioned that when you hear people talk of DPM reductions [as a result of using such and such], you have to realize that [the DPM] includes water, ash, etc and may not result in a similar reduction of total carbon or elemental carbon as measured by NIOSH 5040.
4. MSHA has best practices on their web site.

Comment by Jim Angel of MSHA: MSHA has the NIOSH M/NM Filter Selection Guide along with a number of Best Practices on filter use on the MSHA web site at: http://www.msha.gov/nioshmnmfilterselectionguide/dpmfilterguide.htm .

Q: Mark Ellis of MSHA, asked Skinner [Steve Forbush] for clarification of the different test situations he had referred to, the OEM, the MSHA and the mod 1, mod 2.
A: OEM was the original equipment manufacturers (how it came set up from the show room floor), MSHA setting was the OEM setting with engine derated using the general rule of thumb of reducing fuel supply to the engine by 3% per each 1000 ft of elevation after 1000 ft above sea level for naturally aspirated engines. With regard to mod 1, he had made the first estimate of the retardation of 1.0 degree in timing and he refined that in mod 2 to a retardation of 0.15 degree.

Q: What is MSHA's attitude toward the work Skinner is doing ?
A: George Saseen of MSHA responded: Under part 7, MSHA approves fueling, timing, injection settings and such there is some tolerance in the numbers that MSHA approves. Certainly MSHA would have no problems with a fuel setting slightly below the value for which the engine was approved. There are also tolerances with regard to timing, and it was Saseen's opinion that Skinner's work was well within those tolerances.

Q: Regarding this whiz-bang Rentar unit, this is a catalyst device that is inserted into the fuel line and claims to reduce emissions.
A: MSHA has done testing of the device at a Kentucky limestone mine and results are to follow. There has also been testing at a Utah coal mine, and the results have yet to be published.

Comment:
1. Skinner offered the opinion that it is wise for the mines to work together on these issues. Not everyone has to test all things. He reiterated the example of the partnership that the coal industry formed under leadership of the Utah Mining Association and the Colorado Mining Association to deal with the issues related to implementation of DPFs in mines.
2. George Schnakenberg commented that it is the best to test Rentar and similar systems and devices in the lab first. However, MSHA has limited resources and ability to do lab testing, and NIOSH does not have that ability yet. George offered the thought that maybe the industry should pool resources, buy some test time in a commercial test cells and test some of these devices.

Q: Does anyone in the United States do the kind of maintenance that Sean talked about being done in Canada?
A: Sean McGinn of McGinn Integration responded that at Noranda's Falconbridge mine, the unions have taken up the cause of emission-based maintenance and are insisting upon that in their contracts. At this stage, this is a corporate wide commitment. He also offered that IMC Potash has also adopted this philosophy.

Q: (To Sean McGinn) What cost is added for the implementation of the emission-based maintenance program?
A: For each of the shops, the cost was a bit less than CAN $30,000 or US$ 20,000. The large portion would be the training costs – there we're talking about 100 mechanics, and it required 3 days overtime for each mechanic. Since the mechanics were so busy that they couldn't spare the time during regular work shifts, the mine paid them to do the training on overtime. He said this was a cost of hundreds of thousands of dollars.

Comment by Jozef Stachulak, INCO.
1. INCO is preparing engine-specific preventative maintenance schedules. PM is required on all systems associated with their engines every 250 operating hours.
2. George Saseen of MSHA commented following: In coal there is a requirement for doing emissions measurements over repeatable engine load tests [these tests are done at a torque stall condition] on a weekly basis. The objective is to determine the need

for maintenance. $CO_2$ is looked at [as an indication of sufficient engine load] as well as CO for the tune of the engine. CO levels at the 200 to 300 ppm range are common, with a 1000 ppm CO being an indication of some problem [the exact levels are engine-dependent]. He thought that this approach [weekly emissions testing for CO emissions] might also be a viable option for the metal and nonmetal industry.

3. Sean McGinn made the comment that Falconbridge is considering a specific preventative maintenance routine for engines. This would be a complete routine every 250 hours and would cover all 6 engine systems. He felt that such a routine would not take more than 1 hour to accomplish.

Q: Does Falconbridge expect a return on their investment and what would that return be?
A: They expect the return in terms of cleaner engines, lower emissions. The actual cost benefits are difficult to quantify but that was something they were trying to estimate.

Comment:

1. Drew Wilson of ECOM America: They [ECOM America] have asked their customers for such [cost benefit] information regarding their monitoring systems and they get some information. Some of the benefits are tangible but the majority of them are intangible. They think that the use of such emissions monitoring systems results in cleaner air, and they also think it is cool because it is high tech kind of stuff. One customer said they have seen a reduction of 7.5% in fuel consumption or about 20000 gallons in a year; there is less down time, and there is less catastrophic failure. It takes 100% management buy-in to implement this kind of program.
2. George Saseen of MSHA: A technology that has been considered by some mines is PuriNOx™, a water-fuel emulsion from Lubrizol. It has been tested in the salt mines, and results have been presented at the most recent MDEC meeting [MDEC 2002, Markam, Ontario, October 28-31, 2002] .

Q: What effects does shock and vibration have on filters given the brittle nature of the filter material.
A: John Stekar of Catalytic Exhaust Products: The procedure is to use a mechanical means to isolate the filter from the machine. The technology was developed for on-road vehicles. There is very limited breakage experience on filters that results from shock and vibration. The breakage more often comes from the vehicle hitting a bump in the road.
A: Jozef Stachulak of INCO: They have not experienced any breakage resulting from shock and vibrations on the systems installed at INCO..

Q: Are there provisions for equipping the 50 or 75 ton haul trucks with engineering controls.
A: (various) The CAT 3516's with 2300 hp engines have been equipped with filters and there are filter systems on locomotives as well. There is no expectation that filtering of large diesels would be particularly difficult.

Comment (on shock and vibration):

1. Satish Viswanathan of Johnson Matthey: You can allow the filter to vibrate with the engine or the chassis, but it cannot be left to vibrate with both. [The recommendation

is to fasten the DPF rigidly to the vehicle chassis and use flexible pipe between the DPF and engine.

Q: Mark Ellis of MSHA: How long does it take to install and debug this type of equipment?
A: Hicham Agha of Emission Control Products, Engelhard: It doesn't take long and it depends on how much homework you do. The more upfront work you do with the manufacturer, the less time is spent on the actual installation and debugging.

Q: Mike Roach of Clean Air Systems was asked how they accomplished the dosing of the fuel additives.
A: The fuel additive was added during fueling of the vehicle. The fuel is pumped using a rotary vane pump, which in turn also pumps in a proportional amount of additive. If a vehicle does not use an additive, then you do not use the additive dispensing system. The cost was approximately 8 to 10 cents a gallon for the fuel additive.

Q: Can the manufacturers deliver all the filters that will be necessary to be delivered by July 19, 2003?
A: It depends upon when the orders are placed. They need lead times and lead times range from a couple of weeks for the equipment that is available off shelf; otherwise it may take 6 or 8 weeks. They really felt the industry needed to work with the manufacturers as quickly as possible to define their needs so they would have enough time for ordering, delivering, installing and debugging prior to the July 19th, 2003 deadline.

Q: How much work has been done with PuriNOx and biodiesel in combination with filters?
A: George Schnakenberg of NIOSH: Why would you want to use filters in combination with the biodiesel? For example if the filters are 99.9% effective wouldn't you just use regular diesel fuel? [The case in question uses PuriNOx fleet-wide. Thus the entire mine gains the benefit of DPM reduction. In the instance when additional reduction is needed, a DPF can be used. However, one needs to be aware that PuriNOx reduces exhaust temperatures, and an active DPF system may be required. Profiling exhaust temperatures while using PuriNOx is mandatory. A similar statement holds for using biodiesel for the whole underground fleet. – Editor]

Comment to answer: While there have been a number of individual engineering controls discussed, you shouldn't lose sight of the fact that there are very effective combinations of such controls. An example is PuriNOx used with a diesel oxidation catalyst. The mining industry has a great deal of flexibility in combining controls. Combining controls might be effective way to go.
Comment: One should be very leery thinking you can take information such as temperature profiles developed on one piece of equipment and apply it to a similar piece of equipment in a different location. It is always best to gather that kind of information for each individual piece of equipment operating in the situation in which the DPF will be applied.

Q: There was some confusion regarding the DPF efficiencies presented on the MSHA website. MSHA states an 85% efficiency for a cordierite filter and an 87% efficiency for a silicon carbide filter. But today, the speakers have been talking about 99% efficiency for these filters.
A: George Saseen of MSHA: The 99% would normally be referring to elemental carbon while the 85% and 87% would be referring to the whole DPM [where a significant fraction could be sulfate and associated water].

Q: To the engine manufacturers, what kind of solution are you going to strive for?
A: George Hedge of Detroit Diesel: They are looking for engines to get as clean as possible and to make them ready to work in combination with filter systems.

A: Dana Getman of Getman Corporation: They are focusing on powering the vehicles with whatever engines their customers want.

Discussion raised: The coal rule requires that certain technologies be installed. That being the case, why are we having all this discussion about monitoring this and monitoring that since it didn't matter what the monitoring levels were since the rule required you to install certain technologies? MSHA responded that they are prepared to work with the industry to explore other technologies that might produce an acceptable result in terms of particulate loading, so there would be provisions to approve alternate technologies based upon their effectiveness. MSHA offered that Skinner is leading the effort in working with MSHA to explore the alternatives.

Q: Question was asked of the Engine Manufacturers Association, particularly Detroit Diesel representative: do you agree with the Engine Manufacturers Association [comment to the MSHA proposed rule in which they recommend not to use filters based upon their study of their suitability for use in off-highway equipment]? "Don't use filters?"
A: George Hedge of Detroit Diesel: They do not support that position. They would work with the mining industry to produce systems that work in the mining application including the use of filters. He was also not aware of the EMA position and could not confirm that position.

Comment: (Ed Thimons):
NIOSH stands ready to work with the folks in the metal and nonmetal industry to develop case studies that can be the basis for the information sharing that Skinner had referred to earlier.

Q: Regarding the fire [resulting from a turbo charger destruction] in Canada, are there anticipated regulations by MSHA to deal with such situations?
A: George Saseen of MSHA: In coal regulations, part 75 has an equipment specification that is about isolating hot surfaces.
Bill Pomroy of MSHA offered the opinion that he did not expect to see MSHA engaged in new rule making regarding fires on the metal and nonmetal side.

Mark Ellis of MSHA offered that MSHA has a broad array of regulations on the books that deal with issues such as fire suppression, etc. And these rules stand ready to be applied to situations regarding diesel technology and the application of diesel technology.