Controlling Diesel Emissions in Underground Mining within an Evolving Regulatory Structure in Canada and the United States of America

Sean McGinn

Consultant
McGinn Integration Inc., Montreal, Quebec, Canada

Abstract

Since the mid-1990's the reduction and control of diesel emissions in underground mining has received considerable focus in Canada and the United States. In May 1995 the American Conference of Governmental Industrial Hygienists (ACGIH) proposed a TLV of 0.15 mg/m^3 for diesel exhaust [ACGIH 1995] particulate matter concentrations. This proposed TLV served as a catalyst to the mining industry in terms of mining regulators looking at proposing significantly lower regulated limits for DPM and mining operators seeking technology and solutions that would allow them to achieve these reductions.

In 1996 the Diesel Emissions Evaluation Program (DEEP) was formed [Majewski et al 2006] from this catalyst to address the concerns. DEEP was a consortium formed between industry, government, regulatory, labour, research and manufacturing sectors in mining. The project mandate of DEEP was divided into three main project focus areas, measurement methodology, emissions reduction technologies, and measurement use and management. Since the completion of the DEEP research projects there has been a continued thrust towards lower regulated limits for DPM particularly in the U.S., and technologies that allow mine operators to achieve them.

This paper will discuss the changing landscape of emissions regulations in Canada and the U.S. and what mine operators are doing to achieve compliance. The projects that tested concepts for emissions reduction technologies in DEEP have since moved beyond to more innovative methods and technological advancements and the new challenges that come with them. Engine technology has seen many changes in recent years to achieve compliance within global regulations such as U.S. EPA Tier II and III and creates questions for mining operators in terms of how to choose the best technology for the application. Emissions control technology such as the latest developments in diesel particulate filter (DPF) systems offer some of the best possibilities for DPM reduction but often confront users with as many challenges as there are opportunities. In the end the most important emissions reduction technology remains maintenance at the source of the problem. Mine maintenance departments are presented with ever more complex problems to deal with in terms of keeping new and more advanced technology diesel engines and emission control systems operating efficiently and reliably. To achieve this they are looking towards spending considerable effort in learning the use of new diagnostic tools and better techniques sustaining the balance between the cleanest possible technology and mine production and profitability.

Background

The use of diesel powered equipment in underground mining has grown steadily since being widely introduced in the 1960's although there are reports of diesel engines working underground as early as 1939. In the past 40 years or so mechanized machinery powered by diesel engines has replaced much of the pneumatic driven machines and heavy physical labour of past generations. Today there is a mechanized unit designed for virtually every underground work occupation. With the exception of certain drilling equipment and some specialty applications most of the mechanized equipment working in underground mines around the world today are powered by diesel engines.

Concern with potential health effects related to operating diesel engines underground dates back almost as far as the first application. In the 1940's the U.S. Bureau of Mines (USBM) produced a set of regulations on testing diesel powered locomotives for permissibility and recommendations for use. The Province of Ontario, Canada first introduced regulations for the use of diesel engines underground that included set exposure limits for carbon monoxide (CO), nitrogen dioxide (NO_2), aldehydes, fuel specifications, and minimum ventilation requirements to provide sufficient air for diesel engines to operate. [Vergunst 1998]

In 1986 an association of agencies with a specific interest in the development of cleaner and more efficient diesel engines for underground use was formed. This group was the Canadian Ad-Hoc Diesel Committee. Their research and projects led to the first tests of ceramic diesel particulate filters (DPFs), development of the respirable combustible dust (RCD) method of DPM sampling, and development and use of underground environmental monitoring instrumentation and protocols among others. A significant event in the history of diesel emissions health standards was the recommendation by the Ad-Hoc committee for an exposure limit for RCD in underground mines at 1.5 mg/m^3. This recommendation was consequently adopted by several Canadian provincial regulating jurisdictions.

In May of 1995 the American Conference of Governmental Industrial Hygienists (ACGIH) made a recommendation to change [ACGIH 1995] the exposure limit for DPM to 0.15 mg/m^3. This became a catalyst for the flurry of research and technologies that have followed in the years since. The first reaction to the proposed ten-fold reduction in DPM limits was the formation of the Diesel Emissions Evaluation Program (DEEP) which was a consortium represented by industry, labour, government and regulators. From the beginning the main focus of DEEP [Majewski et al 2006] was to evaluate measurement methodologies, measurement use, and emissions controls and technologies. Research with regards to health effects of DPM was specifically left out of the DEEP program. With a three year mandate DEEP became focused on working with mature technologies and research programs rather than attempting green field research requiring long term development. Another significant result of the ACGIH recommended change catalyst was the first move by United States Department of Labour – Mine Safety and Health Administration (MSHA) of convening a committee to look at recommending limits for DPM in metal-no metal mines. Their initial proposed limit was for 0.4 mg/m^3 which created great concern within the U.S. mining industry realizing that this limit would be a formidable challenge given the knowledge and technology of the day.

Between that initial ACGIH recommended change for DPM limit in 1995 and today there has been a large amount of research conducted in both Canada and the U.S. Much has been learned and more importantly, significant reductions in DPM concentrations for underground workers and a cleaner work environment have been achieved. At the same time diesel emissions regulations around the world have continued to head for lower and tougher targets driving research and technology faster and further.

Diesel Emissions Regulations in Canada and the U.S.

There are a few distinguishing characteristics worth noting between how DPM exposures are regulated in Canada and the U.S.

- In Canada DPM regulations are mandated by each individual province/Territory whereas in the U.S. it is one federal jurisdiction overseen by MSHA.
- In Canada the sampling and analysis method used for compliance remains RCD with some provinces now beginning to move towards Method 5040 whereas in the U.S. only Method 5040 for total and elemental carbon is used. [Grenier et al 1996, MSHA 2001]

- Canada and the U.S. have separate regulations for underground coal with respect to diesel activity. In the U.S. MSHA regulates DPM for coal mining based on tailpipe undiluted emissions rather than ambient concentrations as is done with metal nonmetal mines. [30 CFR Part 72 2001]

In Canada the provinces/Territories each have their own set of regulations governing the use of diesel engines underground with exception of Prince Edward Island which has no mines. Federal crown corporations and uranium mines are exempt from provincial jurisdiction and are regulated federally. A summary of current regulations [Gangal 2006] for diesel engines in non-gassy underground mines is shown in Table 1.

Province	DPM mg/m^3	CO	CO_2	NO	NO2	SO2	Engine Certification
British Columbia	1.5	25	5,000	25	3	2	CSA
Alberta	- -	25	5,000	25	3	2	CSA
Saskatchewan	- -	25	5,000	25	2	2	- -
Manitoba	ACGIH	20	5,000	25	3	2	CSA / MSHA
Ontario	1.5	25	5,000	25	3	2	- -
Quebec	0.6	35	5,000	25	3	2	CSA / MSHA
New Brunswick	1.5	25	5,000	25	3	2	CSA / MSHA
Nova Scotia	1.5	25	5,000	25	3	2	CSA / MSHA
Newfoundland	ACGIH	25	5,000	25	3	2	- -
NWT Nunavut	1.5	25	5,000	25	3	2	- -
Yukon	1.5	50	5,000	25	5	5	CSA

Table 1 - Canadian emissions regulations by province

For DPM most provinces remain at 1.5 mg/m^3 with Manitoba and Newfoundland both using the ACGIH limits. In 2002 ACGIH withdrew the notice of intended change for DPM concentration limit and thus currently has no TLV value for DPM [ACGIH 2002]. The Province of Ontario is presently in the process of changing the diesel emissions regulations through the Mining Legislative Review Committee (MLRC). The time weighted average (TWA) exposure limits for gases are quite consistent from province to province with a few slight differences. The gas TWA exposure limits in all provinces are very close to those published by ACGIH. There is some variation between provinces with respect to the requirement for engine certification. Some provinces mandate the use of the CSA certification [Gangal 2006] only which is performed by Natural Resources Canada – CANMET laboratories. Other provinces require one of either CSA or MSHA certifications while others have no requirements for engine certification. Some provinces also include provisions in the regulations with requirements for exhaust treatment systems such as diesel oxidation catalysts but are in some cases vague and generic with references to exhaust scrubbers. An exhaust scrubber in effect is an inline water reservoir on the exhaust used primarily for cooling and is not necessarily what the intent of the regulation or the end use application provides.

In the U.S. there has been a steady evolution toward lower DPM limits since the ACGIH notice of recommended change in 1995. Prior to this there had not been any recommended or enforced DPM exposure limits in U.S. mines. While there were many recommended limits proposed after 1996 the first legislated limit was not put into effect until January 2001 [30CFR 57.5060 2001] and was not used as an enforced limit until July 2003 at 0.4 mg/m^3 TC for metal nonmetal mines. The evolution of DPM regulation by MSHA is shown in Table 2. The mandated use of Method 5040 for determination of DPM concentration has combined the use of either total carbon (TC) or elemental carbon (EC) for different interim limits. In July of 2001 there was a provision added to the regulation for metal – nonmetal mines requiring all new engines being introduced be approved either by MSHA Subpart E - Part 7 or Part 36 for non-permissible use or meet certain EPA certification requirements meaning that although there are some engines that have been "grandfathered", most engines in U.S. metal nonmetal mines are either MSHA or EPA certified.

Underground coal mines in the U.S. were required to use approval under Part 7 for all engines by November, 1999.

Gas concentration threshold limit values (TLV) enforced by MSHA are:

- CO – 50 ppm
- CO_2 – 5000 ppm
- NO – 25 ppm
- NO_2 – 5 ppm metal nonmetal / 2 ppm coal

The TLV's for both CO and NO_2 are considerably higher than those recommended by ACGIH and regulated by Canadian provinces and territories.

Date	Limit mg/m3	Constituent	Interim / Final
January, 2001	0.4	TC	Interim (not enforced)
July, 2003	0.4	TC	Interim (enforced)
May, 2006	0.308	EC	Interim
January, 2007	0.350	TC	Interim
May 2008	0.160	TC	Final

Table 2 - MSHA regulations for DPM in the U.S.

Worker Exposure Concentrations for DPM

Work has been done in both Canada by Natural Resources Canada – CANMET and the U.S. by MSHA to study the trends in DPM concentrations. The studies performed by CANMET in Canada have been done for informational use only whereas the MSHA studies in the U.S. have been done both for informational use in rulemaking as well as compliance testing following rulemaking.

RCD samples collected and analyzed by CANMET from participating mines across Canada between 1995 and 2006 are shown in figure 1 [Rubeli 2006]. For most years the average concentrations have been slightly above or below 0.2 mg/m^3 for RCD. There are two or three years where the concentrations have moved closer to 0.3 mg/m^3. With the majority of Canadian provinces retaining limits of 1.5 mg/m^3 and Quebec at 0.6 mg/m^3 the results show that based on average values, worker exposures are well within regulated limits. Further analysis of the 2005 data showed that of the total samples analyzed that year, none were higher than 1.5 mg/m^3, 2% were higher than 0.6 mg/m^3 which is the limit in Quebec, and 40% were higher than 0.16 mg/m^3 which is the limit that comes into effect in the U.S. in May 2008.

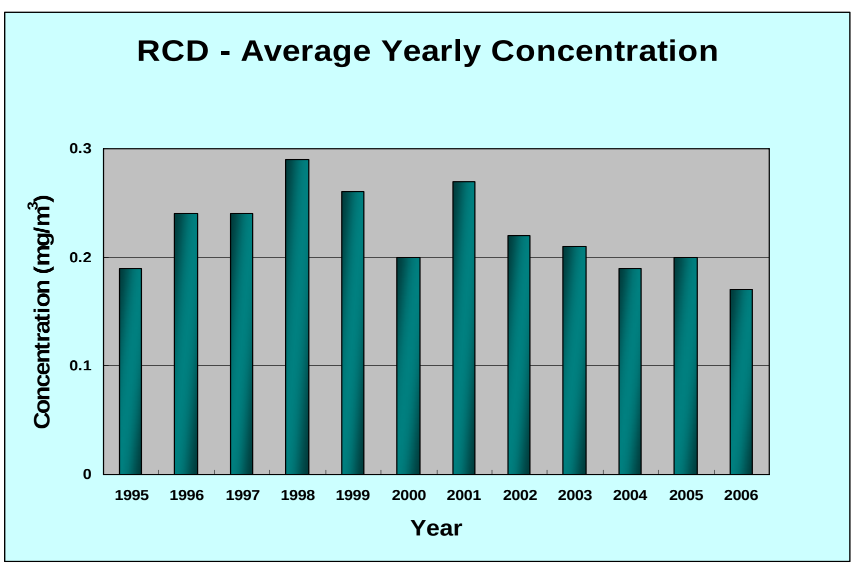

Figure 1 - Average RCD concentrations in Canada 1995 - 2006

In the U.S. as part of the ongoing rulemaking process with MSHA studies for DPM concentrations were collected after promulgation of the 2001 rule. A 31 mine study was conducted between 2001 and 2002 in advance of enforced limits and another study was done between October 2002 and August 2003. The latter study was based on data collected by MSHA mine inspectors across 183 mines to establish a baseline for DPM in future sample comparisons. The results of these two studies are shown in tables 3 and 4.

	Metal	**Stone**	**Trona**	**Other**
No. of samples	116	105	54	83
Minimum	0.46	0.16	0.20	0.27
Maximum	2.581	1.845	0.331	1.210
Median	0.491	0.331	0.82	0.341
Mean	0.610	0.465	0.94	0.359

Table 3 – MSHA 31 mine study DPM concentrations (mg/m^3)

	Metal	**Stone**	**Other N/M**	**Trona**	**Total**
No. of samples	**284**	**689**	**196**	**25**	**1,194**
Maximum	2.532	3.724	1.20	0.509	3.724
Median	0.339	0.186	0.185	0.102	0.218
Mean	0.444	0.295	0.243	0.132	0.318

Table 4 - MSHA baseline study DPM concentrations (mg/m^3)

Combined, these two studies indicate that present and future DPM regulations in the U.S. will make compliance on the part of mine operators quite challenging. The most recent data from the studies dates to 2003 with the baseline study and a maximum concentration of 3.7 mg/m^3 and mean concentrations across the study at 0.318 mg/m^3. In order to meet the present limit of 0.308 mg/m^3 which goes down to 0.16 mg/m^3 operators will need to look and work further toward technology and best practices as has been demonstrated in some instances.

Technology Implementation - Engines

Diesel engine technology has gained significant advances in the past fifteen to twenty years. The drivers of this are two-fold. The primary driver dating back to the late 1980's was fuel economy. The largest consumer market sector for diesel engines is on-road trucking and urban transit. The on-road trucking sector has grown extensively during this period and has become ever more competitive. At the same time fuel costs have risen steadily cutting into profit margins for the trucking industry. As a result engine manufacturers first started working toward improved engine technology to make engines more efficient with respect to fuel economy while at the same time increasing power and efficiency. The other driver for engine technology has been steadily more stringent emissions regulations. These regulations have been pushed towards both on-road and off-road sectors around the world under many jurisdictions. In North America the main regulatory push has come from the U.S. Environmental Protection Agency (EPA) The mining industry has benefited from the drive behind both of these factors but has not been the driver behind engine technology itself as an industry. Mining makes up a very small fraction of the markets for diesel engine manufacturers and does not have a significant enough share of the total market to drive the technology on its own. That being said, both Canada and the U.S. have regulatory agencies that certify diesel engines for underground use where emissions are measured against certified protocols and standards to calculate the mine air ventilation quantities required to operate in an underground mine environment. In Canada underground diesel engines are certified according to Canadian Standards Association (CSA) standards. The CAN/CSA M424.2-90 standard is used for non-gassy mines while CAN/CSA M424.1-88 standard is used for diesel engines destined for coal and or gassy mines. The certification procedure is conducted by Natural Resources Canada – CANMET laboratories in Bells Corners, Ontario, Canada [Gangal et al 2002]. In the U.S. underground engines are certified according to protocols established and conducted by MSHA at the laboratories in Triadelphia, West Virginia. Between 1996 and 1999 the certification protocols for MSHA were changed from the former Schedule 24 – Part 32 to the CFR 30 – Part 7 protocol that has been in use since 1999.

For mine operators in North America, having engines certified by CANMET and MSHA provides them with a tool for selecting the cleanest engine technology. Whereas engines that meet EPA Tier 2 or 3 requirements must be below certain limits for NOx and DPM emissions, CANMET and MSHA certifications provide a quantified value, ventilation rate, with which to compare engines against each other. The ventilation rates are calculated through precise measurement of all emissions parameters at steady state modes based on but not limited to the ISO 8178 8 mode protocol. In the case of the CSA CANMET certification there are also pass/fail criteria for both gaseous and particulate emissions components.

It is important to understand what information is provided with each certification and how to interpret that in order to make an informed decision. In the case of the CSA CANMET certification [Gangal et al 2002] a ventilation rate is provided in cubic feet per minute (CFM) as well as m^3/min that is calculated based on the exhaust quality index (EQI) which includes CO, NO, NO_2, SO_2, and DPM. By taking the ventilation prescription value and dividing by the engine power rating you can determine the CFM/BHP value for each engine which provides a direct comparison tool for selecting the cleanest technology.

The MSHA Part 7 certification is somewhat different in that two ventilation rates are provided for each engine certification. The ventilation quantity provided is based on the amount of air required to dilute CO, CO_2, NO and NO_2 to the ambient TLV's as mandated by MSHA. In addition there is a particulate index (PI) ventilation quantity which is calculated on the amount of air to dilute DPM to 1 mg/m^3. The PI is informational only whereas the ventilation rate based on gases is what the mine must provide for the operation of the engine underground. This provides a mine operator with double selection criteria when choosing the cleanest engine. By dividing both the ventilation quantity and the PI by the engine horsepower you can look at CFM/BHP for based on gases only or by PI. This becomes very important when looking at the difference between EPA Tier 2 and Tier 3 engines. The only criteria change mandated between Tier 2 and 3 is a reduction in NOx with DPM remaining the same for both. With the inverse relationship between NOx and DPM many engine manufacturers have sacrificed particulate levels in order to get NOx levels down to meet Tier 3 requirements. Looking at both ventilation quantities in the MSHA Part 7 certifications allows the mine operator to determine the effects of EPA Tier 2 and 3 changes and what is actually cleaner for achieving lower DPM concentrations.

Technology Implementation – Emissions Controls

Emissions controls have been used with underground mining diesel engine applications for more than 30 years with both success and failure in some cases. Diesel oxidation catalyst (DOC) technology was one of the first introduced and remains one of the most common in use today. Diesel particulate filters (DPF) were first introduced in the late 1980's and have evolved to be one of the most effective technologies at large scale reduction of DPM.

DOC's are primarily a gas reduction technology [Schnakenberg et al 2002], specifically carbon monoxide and hydrocarbons. On older diesel engines prior to EPA Tier 1 they were both applicable and effective as many of these engines were high emitters of CO and HC emissions. Though marketed as a particulate emissions control as well, DOC's are gas control devices and should only be thought of as such. With today's modern clean burning diesels there are a few common misunderstandings in the mining industry when it comes to where DOC's should and should not be used.

In general terms a DOC requires 250°C in order to oxidize CO and closer to 350°C to oxidize hydrocarbons and some of the organic component of DPM. Most of the engines in use in mines today that achieve regular operation above 250°C are larger heavy production type engines which are usually turbocharged clean burning engines above Tier 1 standards. These engines have very low engine out CO emissions and HC is also quite low with few complaints about burning eyes and irritation associated with that. Many of the engines that do merit the use of a DOC are smaller utility type applications such as Toyota Landcruisers that seldom run hot enough to reach oxidation and thus perform no emissions reduction whatsoever and can actually cause an increase in emissions due to plugging up and high backpressure if not monitored and maintained properly. In Canada there are several provinces that still require the use of this type of technology on all underground engines which often can and does create problems.

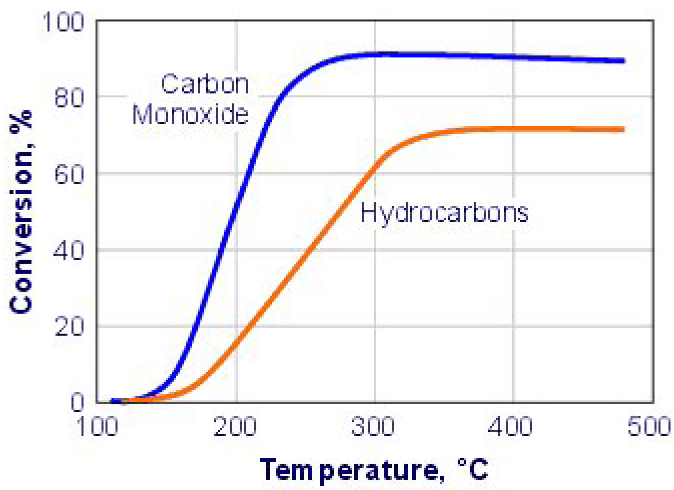

Figure 2 - DOC conversion efficiency versus temperature [DieselNet 2004]

DPF's are emerging as the single highest impact emissions control technology for DPM. The early implementation of ceramic monolith filters on mining engines was done in the late 1980's and demonstrated some short term successes but could not be sustained over the long term due to high regeneration temperatures. Regeneration is the point [Schnakenberg et al 2002] where the built up soot or DPM inside the filter will ignite and sustain combustion in order to clean itself out. The early ceramic filters were bare monoliths with no catalyst coating and required temperatures above 550°C for a minimum of 30% of the total operating time (T30) in order to regenerate. There was a renewed interest in DPF's in the 1990's with stricter emissions regulations not only in mining but all diesel use sectors around the world which brought about newer and more efficient DPF technologies. These technologies provided capability for passive filters to be much more efficient and regenerate at much lower temperatures as well as active type filters. A passive filter is one that is capable of regenerating using the heat from the exhaust gases of the engine only. An active type system is one that requires the addition of an auxiliary heat source such as electric or fuel burners to introduce additional heat for regeneration. Passive and active type DPF technologies in use today [Haney et al 2005] generally require:

- T30% > 550°C – Passive uncatalyzed bare filter
- T30% > 420°C – Passive base metal catalyzed filter
- T30% > 365°C – Passive heavily platinum catalyzed filter
- T30% > 330°C – Passive lightly platinum catalyzed filter plus fuel borne catalyst
- T30% < 330°C – Active regeneration type system

Regardless of the regeneration strategy required for successful implementation, the two main types of wall flow monolith filter medias in use today, ceramic and silicon carbide, are capable of filtering elemental carbon (EC) at higher than 90% efficiency. The two most critical aspects of successful implementation of this technology are:

- Engine duty cycle must be capable of sustaining over the long term the T30% cutoff temperatures in order to regenerate. This requires careful application engineering in every single instance and designing around worst case scenario for every day use.
- Diligent maintenance is required both for the DPF system and the diesel engine that is the DPM source. A DPF system is designed to regenerate and filter at a given soot loading factor which requires the engine to operate at near perfect efficiency. A drop in engine performance that may go unnoticed can easily cause a DPF to fail do to overloading. It is critical to be closely monitoring exhaust backpressure which indicates the level of regeneration and potential plugging inside the DPF as well. If excessive backpressure goes unnoticed both the engine and DPF can reach critical failure levels.

In recent years there have been many new DPF system technologies emerge onto the market such as dry disposable type filters and flow through filters. Although partially effective they have lower filtration efficiencies and can be cost ineffective as well. Wall flow type DPF systems, both active and passive, remain the most effective and efficient type of DPM filtration device.

Technology Implementation – Maintenance

The maintenance of diesel engines and emissions control systems is the single most important factor in any mine's emissions control strategy. Regardless of what technologies are being brought into the strategy, within a very short period of time they will require verification and maintenance in order to continue performing within expected limits. The underground mining environment presents some of the most severe operating conditions found anywhere and maintaining mobile equipment in a mine requires highly skilled people, facilities, tools, and support.

One of the first projects conducted within DEEP was the demonstration of improved engine maintenance practices [McGinn 2000] on reducing emissions. Over a period of six months the demonstration was conducted where a team produced an emissions baseline, audit with recommendations for improvement, training and an action plan. The first step was to implement an accurate and precise emissions measurement system that was still easy to use and maintain for the mechanics. With the measurement system in place the project moved to training and implementation which included emissions controls, specific engine technologies and diagnostic tools. There were also changes made to some infrastructure such as fuel handling systems and administrative procedures such as revamping the monthly engine preventive maintenance routine. The end result of this exercise demonstrated as high as 60% reductions in tailpipe emissions.

This project has served as a catalyst for many companies in the mining industry to follow in developing emissions programs centered on engine maintenance best practices. Over the past five years McGinn Integration Inc. has followed through based on the success of the DEEP project providing consulting services around the world and primarily in Canada and the U.S. on emissions control programs and maintenance strategies. What has been found over the years to be most the most critical and effective steps are:

- Have complete and explicit support from management in both production and maintenance from the very beginning and be very accurate and honest with costs, level of effort required and expectations with quantified results.
- Have an internal audit team established from the beginning that looks for strengths and weaknesses and recommendations with regular follow up on an annual basis.
- Implement diagnostic tools and equipment to support emissions testing and engine performance verification with training on an ongoing basis.

- Implement an engine specific preventive maintenance routine that covers the entire engine (intake, exhaust, fuel injection, cooling, lubrication) with an extensive list of quantitative and qualitative checks and measures.
- Manage the output of this engine PM routine so that emissions and engine performance data are tracked and stored in a database and continuous improvement is seen. Establish pass / fail and performance criteria for emissions and engine performance and ensure that they are acted upon.
- Include engine manufacturers, emissions control manufacturers, and suppliers to provide a level of training and support that will be required to make the program successful.

Summary

Mining companies in Canada and the U.S. are taking advantage of the knowledge gained from programs such as DEEP and emerging technologies to establish effective emissions reduction programs. In most cases success is based more on the ability to adapt to change and a new culture that comes with it rather than technology alone.

Stillwater Mining Company provides a good example [Collins 2007] of how an emissions program evolves over time. Stillwater operates two underground platinum – palladium mines in southern Montana, U.S.A. At the Nye mine which is the larger of the two they have been working on emissions reduction since 2002. The mining method at Nye as with most mines today is highly mechanized and their diesel powered fleet includes close to 100 LHD's and haulage trucks alone. The utility fleet is approximately 180 units. Early studies conducted in collaboration with National Institute of Occupational Safety and Health (NIOSH) showed that in testing several existing and emerging technologies there would be no "one size or type fits all" solution. In the past five years Stillwater has undertaken a large commitment to engine maintenance and now performs an engine specific maintenance PM and emissions testing every 28 days on all production equipment. This program supports the technology implementation that has included a continuous engine upgrade program to the most recent certified technology as well as implementation of both passive and active DPF systems that covers approximately 75% of all LHD's and haulage trucks. The results of this program [Collins 2007] have shown a significant reduction in DPM sampling concentration values. Average total carbon (TC) values have dropped from 0.604 mg/m^3 in 2003 to 0.333 mg/m^3 in 2007. Similarly the average elemental carbon (EC) results dropped from 0.464 mg/m^3 in 2003 to 0.229 mg/m^3 in 2007.

Many other mines have undergone and continue to undergo the process of integrating an emissions reduction program into their every day business activities. In the U.S. especially it has become no longer an option but a necessity in order to remain in compliance with current and upcoming more stringent DPM regulations under MSHA. It has become a cost of doing business as non-compliance can potentially bring mining operations to a halt. In Canada there is a similar level of pro-activity although it tends to be driven more by ethical issues between labour and industry rather than the regulatory side.

The ultimate benefit from this evolution of diesel emissions reduction in Canadian and U.S. underground mines goes down to those who work below the surface. The health and safety of underground workers is the reason why regulators, labour, management and manufacturers have pushed so hard and so far over a relatively short period of time and will continue to do so for the future.

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