An integrated approach for managing diesel emissions controls for underground metal mines

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ABSTRACT: The National Institute for Occupational Safety and Health (NIOSH) has been working with diesel emissions control technology and the underground mining industry for a number of years. Underground isolated zone studies provided the emissions reduction performance of all of the alternative technologies currently available. A NIOSH/MSHA guide is available which provides mines with information and a process for selecting diesel particulate filters (DPF). Recent NIOSH experience suggests that more attention may be needed in managing the issues associated with diesel emissions and their control. The author argues that a holistic approach is needed which involves several key mine operations departments or disciplines by positing that workplace air can be considered as the product of a complex manufacturing process and examining how that process could be managed.

1 INRODUCTION

For the past seven years, the National Institute for Occupational Safety and Health (NIOSH) has been working closely with the underground mining industry, labor organizations, and the US mine enforcement agency – the Mine Safety and Health Administration (MSHA) – to assist in their understanding, development, and implementation of the alternative technologies to control and measure workplace concentrations of diesel exhaust contaminants. Control and measurement of diesel particulate matter (DPM) became the preeminent concern upon MSHA's issuing proposed rules, and in January 2001 the promulgation of the two distinct diesel rules – one for underground coal (30 CFR 72) and one for underground metal and nonmetal mines (30 CFR 57) – that were designed to limit the exposure of underground workers to DPM. As one of its early efforts, the fledgling diesel team at NIOSH Pittsburgh in 2000 produced an overview of the currently available control technologies in which their operating characteristics, performance characteristics, and limitations were described. This document emerged as a NIOSH publication IC 9462 (Schnakenberg & Bugarski 2002b) and is available for download from the NIOSH mining web site. The technologies that were covered included clean engine technology, alternative fuels (synthetic diesel, biodiesel, and water-fuel emulsions), diesel oxidation catalysts, disposable filter elements (DFE), and variously configured diesel particle filter (DPF) systems using wallflow monoliths of cordierite or silicon carbide. Some of these DPF systems, when engine exhaust temperatures were favorably high, would passively burn off the DPM as it was collected; other systems designed for application at prevailing exhaust temperatures, required an active application of a procedure to burn off the collected DPM. The process of burning off of the collected DPM in a filter is termed regeneration.

In devising its DPM rule for metal and nonmetal mines, MSHA assumed that DPF systems would be necessary (66 Fed. Reg 2001, p 5713,). Because the implementation of this technology was not simple and because the entire concept of using filters was new to most of the mining industry, MSHA asked NIOSH in the fall of 2002 to help them develop a diesel particulate filter selection guide (DPFSG). The DPFSG was placed on the MSHA and NIOSH web sites in January 2003 with a minor revision in May 2003. This guide has received high praise from those with diesel control technology experience.

During the period shortly after promulgation of the rules, NIOSH diesel researchers at Pittsburgh conducted several well controlled underground experiments designed to determine the effects of available control technology on diesel equipment emissions with the focus on DPM. These experiments were performed by operating a single unit with and without the control technology in place as it performed a repeatable work cycle that closely emulated a typical task performed by the vehicle. The equipment was run in an isolated part of a mine where the incoming ventilation rate and air quality were well controlled and could be measured. In sum, the results of these tests confirmed the beneficial effects of proper altitude adjustment of engine fueling rate and power matching for inby coal mine engines, and the laboratory performance for DPM and elemental carbon reductions obtainable with alternative fuels, disposable filter elements (DFE) and DPF systems. These tests also confirmed that DPF systems that utilized Pt-catalyzed washcoats to enhance regeneration also produce substantially elevated nitrogen dioxide (NO_2) emissions (Schnakenberg & Bugarski 2002a, Bugarski et al. 2006a, b). Conducting these tests did not, however, throw much light on the issues concerning the implementation of these technologies into an actual production situation. Although the implementation is quite technology and mine specific, NIOSH is currently executing a study to expose many of the implementation issues in order to assess their impact and develop solutions.

The implementation issue study currently underway, as well as a reflection on the situations experienced during the in-mine control technology testing, has emphatically shown that engine maintenance to keep emissions low is not a general or well understood practice. Aberrant engine emissions owing to maladjustment, use of an inappropriate replacement part, and a general failure to comprehend the concept were evident in the underground experiments noted above. The DPFSG recognized that emissions-based maintenance is a necessary prerequisite for DPF implementation, but assumed that most mines had the resources and comprehension to readily adopt or had in place a sufficiently adequate engine maintenance program that controlled DPM emissions and as a result did not present the details of such a program other than by reference.

Additionally, the DPFSG stated that the management of worker exposures to DPM emissions was not the exclusive responsibility of equipment maintenance department but required an integration and interaction of several departments including health and safety, ventilation, and production, in addition to equipment maintenance. However, the DPFSG did not go into much detail on this subject. This paper is an attempt to provide these details.

2 AIR QUALITY MANAGEMENT

One must consider that the deployment of diesel powered equipment into an underground mine creates a complex system involving several mobile and varying emission sources emitting of a variety of contaminants which are diluted and transported by the prevailing ventilation at the point of emission (equipment tailpipe). To this system is added the worker who is mobile (often coincident with a local source of contaminant) and is the consumer of the local contaminant concentrations, which may be mitigated by an environmental cab. One can take the view that this entire system can be modeled as a "manufacturing" process in which the final product is the air inhaled by the worker, and that air is "produced" by the interactions of the systems and process components mentioned.

Considered thusly, the air quality, as measured by the level of diesel exhaust contaminants present in the inhaled air, is the responsibility of the manager of this "manufacturing process or plant" who must produce acceptable air quality at the lowest possible cost. This manager will have a team of process stream supervisors or specialists who are responsible for controlling the quality of their product as it is utilized and as they individually contribute to the quality of the final product.

Although the "factory" for the production of "contaminated" workplace air is well established by virtue of operating just a single unit of diesel powered equipment underground, it is unlikely that any management system to control and assure the quality of workplace air was established at the same time. Continuing with the analogy, underground mining operations usually have the requisite management departments for the individual production processes contributing to the final product, but they are not organized or focused on integrating their efforts towards producing the workplace air product; rather they are focused on other objectives. Equipment maintenance, for example, is focused on maximizing equipment availability and is repair oriented. The tailpipe emissions, the very "raw" ingredient so to speak of workplace air quality, are not emphasized or treated as an important and necessary output of their efforts.

3 DEPARTMENTAL ROLES

The initial task for a manager of an underground mine utilizing diesel powered equipment is to recognize that controlling worker exposures to diesel emissions contaminants will require an integrated approach and is not the sole responsibility of one department or specialist. Because of the complexity and interactive nature of the underground diesel operation system, all departments or specialists which influence exhaust contaminant concentrations must work together. In many mines, this approach will be novel and most likely require an effort to shift the culture and focus of the affected departments. Mine management must be aware of the effort required and must prepare convincing arguments to effect the required changes for they have no other alternative if diesel emissions are to be controlled efficiently and effectively.

3.1 *Engine Maintenance*

The major contributor to workplace air quality, and a negative one at that, is the tailpipe emissions from the diesel equipment. It should be obvious that fresh air is being contaminated by the diesel emissions and, as a consequence, lower emissions are better and consistent with the air quality goal. Thus maintaining the tailpipe emissions of each piece of equipment to at or below its prescribed level should be a major objective of this department. Note that each piece of equipment should be assigned a prescribed level for each of the diesel contaminants. What these levels are will or may have been set by the analysis performed by production and ventilation departments in consort with the engine emission specialist. However, it should be rather clear from the cost of ventilation that in practice the maximum level for a particular engine's emissions will not be much greater than that obtained for a properly running engine including properly installed and operating control technology. When exhaust aftertreatment systems are required, their maintenance is the responsibility of engine maintenance department as is the maintenance of any ancillary systems such as exhaust back pressure gages or monitors and filter regeneration systems required for the proper operation of aftertreatment systems.

The above additional requirements may be considered to affect the "culture" of existing maintenance operations. The focus must shift from "doing what it takes to keep an engine running" to "doing what it takes to keep an engine running and running clean." It is the responsibility of management to ensure that this latter goal is understood, implemented and rewarded. It is probably safe to state that, in general, the current maintenance departments are not adequately staffed with personnel sufficiently trained to perform the tasks required nor are adequate resources allocated to provide the required equipment and training. It is quite possible that finding and hiring suitable individuals to train is a problem in some areas of the country.

Achieving the goals of engine maintenance cannot be done in isolation. The production department must understand that they cannot use a piece of equipment that runs but is not running cleanly. Their equipment operators need to be sensitive to their equipment's emissions and report any changes such as the development of visible black smoke.

3.2 *Ventilation*

The role and objective of the ventilation department is to provide dilution and transport of the diesel exhaust contaminants released from the vehicle tailpipe so that the concentrations of these contaminants are within accepted limits. Despite the simple appearing objective, the efforts needed to achieve it are highly complex and involved, and the dealing with diesel emissions may be only one of the objectives. The details are too extensive to go into in this paper. For example, there are several diesel exhaust contaminants – the gases CO_2, CO, NO, and NO_2, and diesel particulate matter (DPM) – each with a spatially varying emission level as the equipment loads the engine differently as it moves throughout the mine with different prevailing airflows and each with its own acceptable air quality level. The tailpipe emissions may be altered by control technology which affect an entire fleet (in the case of an alternative fuel) or an individual piece of equipment as in the case of oxidation catalyst or exhaust filter. There will be a balancing act between the amount of ventilation that can be supplied to an area (and the quality of that air if it has been contaminated upstream) and the number of production vehicles that simultaneously occupy that area. The ventilation department must work closely with the production department who may want three trucks in a loading area when there is only ventilation enough to support two.

Additionally, ventilation allocation is planned on paper, but must be carried out underground. Having proper ventilation at the required locations demands that the hardware which supplies that air not only be installed properly, but functionally verified and properly maintained. Torn tubing must be replaced, fans kept running, etc. In coal or gassy non-metal mines, ensuring and maintaining adequate ventilation to support diesel operation may be straightforward or at least has been a necessary and common practice because of the requirement to ventilate for methane. In most metal and nonmetal mines, however, ensuring adequate ventilation for the control of diesel contaminants at all times and locations can be a novel and difficult challenge.

As noted above, diesels emit a limited variety of contaminants. The ventilation engineer must know what each of these are and how they are affected by control technology. He/she must know the occupational limits of the contaminants and work closely with the industrial hygienist or health and safety department. The ventilation engineer should be aware of the engine's nameplate ventilation rate provided for MSHA certified engines, know how this rate is obtained, and know how to use such information to calculate ventilation air quantities. The use of after-treatment device is not accounted for in the MSHA ventilation rate determination unless in a rare instance it is part of the engine. The almost ubiquitous use of diesel oxidation catalysts (DOC) which effectively reduce CO and hydrocarbons (when they are working) means that a low or undetectable level of workplace CO is no assurance that ventilation is adequate. On the contrary, the introduction of a new DOC or a platinum catalyzed exhaust filter may temporarily or permanently increase tailpipe NO_2 concentrations to the point of requiring more ventilation air than that specified by MSHA for the engine without the DOC control.

The ventilation engineer should also realize that one critical contaminant would remain if all other tailpipe emissions were reduced to an insignificant level. That contaminant is carbon dioxide. CO_2 is an irreducible product of the burning of fuel diesel fuel, and as such leads one towards the rule that there always must be enough ventilation air to dilute the CO_2 from the fuel being consumed. The monitoring of workplace CO_2 concentrations is a little used but exceedingly useful tool for assessing the adequacy of localized (or general) ventilation to deal effectively with the localized (or general) burden of diesel equipment exhaust. Additionally, because CO_2 is unaffected by emissions control technology yet is affected by ventilation along with the other tailpipe contaminants emitted with it, one can determine the effectiveness of a control strategy by simultaneously measuring CO_2 along with the measurement or sampling of a controlled contaminant such as elemental carbon. For example, the use of a diesel exhaust filter on one or more pieces of equipment in a loading area should result in a drastic reduction in the EC to CO_2 ratio. The ratios are independent of ventilation.

Since tailpipe emissions and ventilation are inseparably linked, the ventilation engineer must be cognizant of vehicle deployment and utilization. The relationship between fuel burned and DPM emissions must be assessed for every vehicle or vehicle class. It is becoming more commonly known that the ubiquitous utility vehicle using low horsepower but rather dirty engines can be a major contributor to DPM burden and exposures. It seems that the ventilation department should perform the engineering calculations which will prescribe engine emission limits and, if needed or possible, the appropriate control technology for these vehicles. These limits are then transmitted to engine maintenance department who perform the necessary tasks to maintain engines to the prescribed emission levels.

Since the objective of the ventilation department is to mitigate the effects of tailpipe emissions on workplace air quality, it will probably be their role to indicate when the ventilation system cannot adequately control DPM emissions to meet the compliance standard and the reduction of DPM emitted by the vehicle must be reduced using control technology. The selection of the most cost effective and appropriate control technology can be quite a complex decision which involves fleet-wide solutions (alternative fuels) and/or equipment-specific emission controls such as replacing the engine with a cleaner one or the addition of an exhaust filter. Once the need to control equipment emissions is realized, the development of a control strategy and selection of specific control technologies must be a collaborative effort of all departments.

The above only touches the surface of the complex role of the ventilation department. They must work closely with those responsible for selecting new diesel powered equipment and control technology as well as with production department who need to utilize the equipment and with the health and safety department. The position is so pivotal for DPM control that it seems as if the ventilation department should assume the lead role for developing the overall mine strategy for controlling worker exposure to DPM.

3.3 *Health and Safety Department*

The health and safety department or industrial hygienist (IH) performs the quality assurance function by measuring workplace air quality and personal exposures to ensure that the air quality meets expectations. They must also work very closely with the ventilation department to convey to them the workplace contaminant limits for exposure and the relative toxicological importance of each. The IH and safety officials should be involved on an ongoing basis with those who are responsible for selecting control technology. In the process of considering a control technology, the IH needs to ask probing questions of the technology supplier as to how and what emissions are affected and let the ventilation engineer determine the impact on ventilation. The safety officials need to determine whether there are any safety issues with the technology.

There is an obvious overlap between worker exposure measurements and workplace air quality measurements performed by the IH and ventilation department. The objectives of each department's measurements are different and both are important. The measurements should not be the exclusive purview of one department; they should be coordinated when possible. Personal exposure measurements by the IH could be considered as proof that the air quality "production system" is functioning properly; that is, tailpipe emissions, vehicle deployment and ventilation together are controlling worker exposures. If exposures are not acceptable, then workplace or worker exposures to CO_2 can be used to assess the adequacy of ventilation, and contaminant to CO_2 ratios can be used to determine if control of tailpipe emissions (a malfunctioning engine or control technology failure) is the cause for unacceptable exposures.

3.4 *Production*

The obvious objective of production department is to get the most rock to the surface as safely and quickly as possible by efficiently utilizing available equipment and operators. After all, production is the money maker for the mine. Equipment availability is a prime concern and thus production supervisors push the maintenance department to service or repair equipment quickly. They may push the limits of the ventilation by wanting more pieces of equipment in an area than the local ventilation can support. However, when production goals cause engine maintenance and ventilation to less than adequately fulfill their objectives, the underground workers are the ones most affected by the decrease in air quality.

The production department, as users of equipment, must be involved in air quality management. Their input on equipment deployment and utilization is essential for designing the ventilation system and equipment emission levels. On the other hand, the equipment operators must be instilled with an appreciation of the necessity to control air quality and DPM in particular. Altering driving habits (such as a using gentle application of the throttle) may reduce excessive DPM emissions. Having the equipment operators understand the importance of correct and continual operation of exhaust filters would increase equipment availability and filter longevity, for example. Equipment operators should be encouraged to perform a key function in detecting and reporting equipment malfunction such as excessive smoke, inoperative back pressure gages, etc.

The production department is most likely heavily involved in decisions to rebuild old equipment and to select new equipment for purchase. These decisions should strive to obtain equipment using diesel engines with the lowest DPM emissions possible. This goal should be applied to any diesel-powered equipment being purchased. The intended purchase should be discussed with MSHA engine specialists, and the mine's maintenance and ventilation departments.

The production department must be involved when circumstances necessitate the utilization of diesel particulate filters because retrofitting of filters cannot be characterized as a "fit and forget" solution. How equipment is used, and the variability of use, greatly affects the selection and ultimate performance of DPF systems. DPF systems which passively regenerate can be successfully applied to relatively few vehicles and there is a consequence to ventilation from secondary emissions of NO_2. DPF systems which must be "actively" regenerated – through either the application of a regeneration cycle to the DPF when the equipment is not in use or by a DPF exchange – have a significant effect on operational logistics, mine infrastructure, and equipment operator responsibility. The selection of filters obviously requires the input and agreement of all departments.

4 SUMMARY

This paper has presented a limited discussion supporting the need for an integrated interdisciplinary approach to control worker exposures to DPM in underground mines, and that the control of workplace air quality and worker exposure to diesel exhaust contaminants is a complex task and must be approached holistically. Using a factory or production analogy with the workplace air as the final product, the author identifies the typical mining operations departments involved in producing that product, discusses their involvement and roles, and shows that they all need to work together. It is the author's view that the need for such an approach is not widely recognized within the metal and nonmetal underground mining industry, yet such an approach is necessary in order to control worker exposure to DPM to MSHA compliance levels. Management needs to form an integrated team of principals from equipment maintenance, ventilation, health and safety, and production departments and other areas which affect or are affected by measures required to control air quality. The ventilation department appears to be the most appropriate department to lead and manage the coordinated effort.

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