Mine Real-Time Personal Respirable Dust and Diesel Particulate Matter Monitoring

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ABSTRACT

An overview is given of two new developments in mine atmospheric monitoring. A new personal dust monitor (PDM) that gives real-time respirable dust readings is discussed. The unit is mounted within the miner's cap lamp battery and internally measures the true particle mass of dust collected on its filter. Samples are available for later mineralogical analysis and results do not exhibit the same sensitivity to water spray as optically-based measurement approaches. The technique achieves microgram-level mass resolution even in the hostile mine environment and reports dust loading data on a continuous basis. The monitor has been evaluated under an Australian Coal Association Research Program (ACARP) grant and is being adopted for statutory mine respirable dust determinations in the United States (US). The monitor has particular application for determining location of high dust sources. It can evaluate the efficiency of engineering means of suppression and other approaches to reducing dust levels.

It has been recognised that the PDM's unique measurement approach has application to allow real-time atmospheric diesel particulate matter (DPM) monitoring. The industry has no real-time atmospheric DPM monitor at present. Recent surveys in New South Wales and Queensland show significant numbers of miners continue to face full shift DPM exposures in excess of internationally accepted levels. Real-time DPM monitoring will allow the industry to pinpoint high exposure zones where a number of trucks and other vehicles work in areas of poor ventilation. Knowledge of high DPM concentration zones allows efficient modification of work practices to reduce underground miners' exposure. Approaches to uses of the DPM form of the monitor and the design of tag boards are discussed. Some outcomes from mine tests with both these new instruments are given.

INTRODUCTION

Mine ventilation is a critical aspect of all underground mines. Mining technological developments and mining environment challenges are necessitating new approaches. This paper in particular examines two areas of new development.

Australian metalliferous mines currently work in a vigorous and expanding sector. High prices and export demand are in the headlines. We are seeing increased production rates and emphasis on block caving, sublevel caving and increasing numbers of open stopes in operations. There is still a ventilation need even with more remote loaders, tramming and possibly trucking. There appears to be a move away from large multi-purpose shafts with more and deeper declines. Belt transport is being used instead of shaft skips or decline trucking. The complexities of supplying high quantity and quality ventilation without major shaft infrastructure are a challenge.

There are an increasing number of small operations. These generally have a small plan area and progress to depth fast. Respirable dust make can be an issue. Many mines face high heat load situations. They also face high diesel exhaust emissions at the same time and this combination is one of the big ventilation planning challenges.

The network in many modern mines changes daily as stopes or development breaks through. Maintaining an understanding of the ventilation network is a challenge. Improved use of real-time monitoring and control may, in time, allow mines to optimise this situation. Instrumentation developments are allowing improved real-time monitoring of ventilation parameters and particularly gases, respirable dust and airflow. Understanding fires, simulation of fires and training the workforce is an area requiring priority attention.

Ventilation expenditure receives priority when it directly affects production. It is up to the ventilation practitioner to point out the real cost of the ventilation system to the overall mine capital and operating costs. Ventilation costs are not just fan electricity costs and ventilation control device budgets as some may see it. The layout of a mine is largely dictated by ventilation requirements. The provision of a pleasant and comfortable work environment returns increased miner productivity.

Many of the new developments will be contributed to by research activities. The Australian Coal Association Research Program (ACARP) has been outstandingly successful in supporting focused research efforts to benefit coal industry productivity. The five cents per export tonne levy has been leveraged by additional co-sponsoring by operating companies, universities and others. Grants from this source carry prestige and it is hoped the real value of the program will continue. The Australian Minerals Industry Research Association (AMIRA) has in the past funded some significant research in metalliferous ventilation projects. This association no longer appears to be active in the ventilation research areas.

Various mining industry accidents or disasters have led to, or reinforced, a revolution in thinking in many areas of management of the industry. Regulations are less prescriptive and now demand risk assessment incorporating international best practice. Australia is at the international forefront here. There is a much grater emphasis on training at all levels. Much of the industry is actually or effectively long distance commute (such as fly-in, fly-out). It is beyond the scope here to cover the issues that joint management, longer work shift hours and so on present to the management of ventilation. The use of increased numbers of consultants delivers both benefits and challenges.

Vehicles for publication of ventilation innovation for dissemination to the wider industry community are becoming fewer. It is the specialist conferences that have become the main archival repository of our thinking and innovations for reference in the future.

The two areas of new development discussed within this paper have been supported by industry research grants from, in particular, the ACARP with substantial input from the United States agency, the National Institute of Occupational Safety and Health (NIOSH). They are stories in practical application and have received considerable additional industry financial support, mine site testing and evaluation assistance.

MONITORING OF RESPIRABLE DUST

A new personal dust monitor (PDM) for respirable dust developed by the company Rupprecht and Patashnick (now

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Thermo Fisher Scientific) in the US, under a project funded by the NIOSH, has generated promising results in underground coal mine testing performed in the US recently (Volkwein *et al*, 2004a, 2004b). Results from an ACARP funded study undertaken to evaluate this new real-time dust monitor for personal respirable dust evaluation, particularly in engineering studies, have been described by Gillies (2005) and Gillies and Wu (2006).

This paper describes some results from mine studies that have been undertaken using the real-time PDM. The technology that forms the heart of the PDM, the tapered element oscillating microbalance (TEOM®) system, is unique in its ability to collect suspended particles on a filter while simultaneously determining the accumulated mass. The monitor internally measures the true particle mass collected on its filter and results do not exhibit the same sensitivity to water spray as optically based measurement approaches. The technique reports dust loading data on a continuous basis and miners and mine operators have the ability to view short-term dust levels. It is believed to be the first personal dust monitor instrument that reliably delivers a near-real-time reading.

The instrument has potential to be used as an engineering tool to evaluate the effectiveness of dust control strategies. Being a personal dust monitor, the instrument measures the airborne dust from the breathing zone region and so has many advantages over instruments that measure from a fixed-point location. It can quickly highlight high dust situations and allow correction. The underground workplace in both continuous miner and longwall face environments has varying respirable dust conditions due to aspects such as ventilation conditions and air velocity, shearer activity and design, chock movement, armoured face conveyor movement, manning position, face time of individual personnel, outbye conditions and dust levels in intake air and measurement instrument behaviour. A study has evaluated the instrument as an engineering tool that can assess the effectiveness of a single change to improve dust levels fast enough to ensure that other aspects have not changed.

The PDM is a respirable dust sampler and a gravimetric equivalent analysis instrument that is part of a belt-worn mine cap lamp battery. The main components of the device include a cap lamp and sample inlet located on the end of an umbilical cable, a belt-mounted enclosure containing the respirable dust cyclone, sampling and mass measurement system. A charging and communication module is used to transmit data between the monitor and a PC, while charging its lithium ion batteries for the next shift. Figure 1 illustrates the unit.

The current US Federal congressional legislative program includes responses to strengthen mine emergency response plans and the Mine Safety and Health Administration's ability to investigate accidents, enforce health and safety regulations, strengthen rescue, recovery and accident investigation practices. It includes a focus to update the 37-year-old respirable dust standard that is not effectively preventing today's coal miners from developing black lung disease. Part of this move may require miners to be equipped with the new PDMs developed and certified by NIOSH and authorise miners to adjust their activities to avoid respirable dust overexposure.

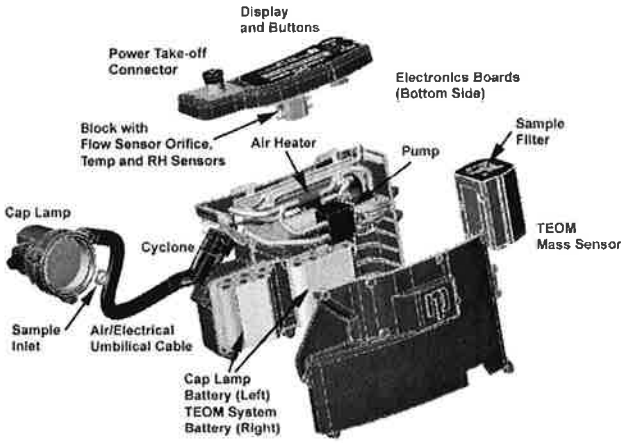

FIG 1 - Major components of the personal dust monitor (PDM).

Figure 1 shows major components of the PDM. The following sections describe underground evaluation exercises that were undertaken to monitor the dust exposure levels of various equipment operators.

Initially tests were undertaken at a development face. The PDM units can give variable time period rolling averages of dust concentration and for engineering evaluation purposes it is better to use shorter time rolling average dust concentration data as the quicker response to monitored changes shows more significant dust concentration variations. As shown in Figure 2, PDM units were put on continuous miner (CM), bolter and shuttle car (SC) operators in tests commencing at 20:15. The face crew was replaced at 21:10 by the second crew as the first crews were released for crib break. The results of the PDM tests are shown in Figure 2 as 15 minute average levels.

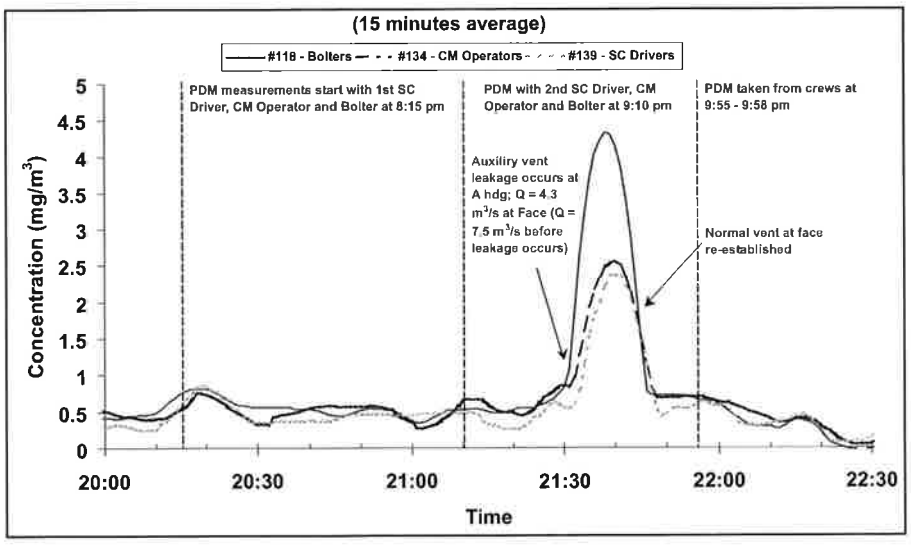

FIG 2 - Development face personal dust monitor (PDM) results.

40 minutes test period. This demonstrates that the filters used by air stream helmet can remove most of the respirable dust. Without the filters in place, average dust concentration inside the air stream helmet was consistently higher than the dust levels measured in background atmosphere. A similar phenomenon was reported by others when attempting to measure dust levels inside and outside air conditional cabs (Volkwein, 2005). It was concluded that an enclosed space acts as a dust trap when a jet stream injects dust-laden air into a constrained space, leading to higher than background dust level. In addition the jet stream in the enclosed space can keep the dust suspended for longer.

MONITORING OF DIESEL PARTICULATE MATTER

DPM issues are very high profile currently in both Australian coal and metalliferous mines. Mine atmosphere measurements of DPM in Australian mines have only been undertaken systematically since the mid 2000s. Early atmospheric readings have been taken on a shift average basis using sampling units manufactured by the SKC company. The SKC units are derived from a US NIOSH design and give readings in the surrogate total carbon (TC) or elemental carbon (EC) units after laboratory analysis procedures have been completed:

- DPM = TC + inorganics = EC + organic carbon (OC) + inorganics; and
- TC in mine testing is consistently over 80 per cent of DPM (Volkwein, 2006).

Some DPM regulatory guidelines are starting to emerge in Australia. No prescriptive mining regulations are in force internationally, although the US metalliferous mining industry is to face mine atmosphere DPM regulations from April 2008. Australian states are generally moving to acknowledge the US April 2008 final metal mine regulation limits of 0.2 mg/m^3 submicron particulate matter, 0.16 mg/m^3 TC particulate and 0.1 mg/m^3 EC particulate.

The real-time DPM monitor is being developed on the base of the successful PDM unit. A description is given of a series of underground tests undertaken to establish the robustness and reliability of the new approach. Structural changes to the PDM involving incorporation of an impactor particle size selector have been undertaken to convert it to a DPM real-time monitoring underground instrument, the D-PDM. The Pennsylvania Pittsburgh Research Laboratories of NIOSH (the group that originally contracted for the PDM development) has undertaken laboratory 'calibration or verification' testing. They have an accredited diesel exhaust laboratory and international expertise in this area. The D-PDM directly reports levels of mine atmosphere DPM in mg/m^3 from real-time readings. It can be positioned in the working place or in a mine vehicle and when the design is finalised will be able to be worn by a person. The D-PDM instrument is currently at a prototype stage and, as with all new technologies, will need industry acceptance and support to reach its full potential.

A phase of Australian mine robustness and engineering testing has been successfully undertaken in four coal mines to ensure the instrument can effectively assist mine management to handle this health issue. Tests described have been undertaken at points of expected high atmospheric DPM, such as vehicle movements, during longwall face moves and in an exercise in tag board design. The outcome of the project gives the industry access to an enhanced tool for understanding the mine atmosphere in the presence of DPM.

The Mine 1 tests were undertaken in working sections, which use diesel ram cars. The results from these limited tests qualitatively indicated that D-PDM did respond to observed diesel activity in fairly low concentration ranges. It was found that ten minute rolling averaging periods appear to allow a balance between ability to recognise individual diesel source vehicle movements and measurement accuracy. Some readings were taken with instruments mounted on a vehicle with positive results.

Mine 2 testing exercises monitored the various ventilation arrangements of a face move during chock transport to the installation roadway. It was straightforward to analyse results for arrival and departure times of diesel machines at the face. Interpretation could be made on whether the machine travelled down gate roads either with a speed faster than the air velocity (and so with high exhaust concentrations trailing) or with a speed slower that the air velocity (and so with high exhaust concentrations in advance).

The longwall ventilation arrangement for one set of tests is shown in Figure 8. The positions of the D-PDM monitors #106 and #108 are shown; #106 in the face installation road and #108 in a cut-through ventilating the face. On this test day loaded chock carriers travelled in along the main gate (MG) and out through the tail gate (TG). An airflow of about 50 m^3/s was measured in the MG and about 35 m^3/s in the TG. There was a raise borehole upcasting some air. Four chock carriers were available and a total of ten chocks were moved. Results from monitor #108, shown in Figure 9, clearly demonstrated the ability of the D-PDM units to detect variations of DPM levels in the atmosphere as the chock carriers travel in from MG and out from TG of the LW face. Significant submicron DPM readings were recorded due to the large number (ten) of chocks that were transported during the shift. Levels of DPM recorded in the second half of the shift were higher. The condition of the back road had become poor and some chock carriers were slower and had difficulty travelling through.

FIG 8 - Longwall ventilation-chock carriers travel in on main gate (MG) and out on tail gate (TG).

Figure 10 examined one three-hour period with particular interest in recording of D-PDM readings as compared to heading air velocity chock carrier vehicle speed. Close examination of results from #108 monitoring the DPM downstream of the MG and back road are of interest. In three cases when the chock carriers travel in from the MG they arrived at the TG end of the face in advance of the peak level of the DPM cloud. This indicated that the carriers were generally travelling at higher average speed than the air velocity. However, carrier #1112 arrived slightly later, indicating slower machine travel speed than air velocity. The time difference and also the peak concentration depend on the air velocity and chock carriers' travel speeds. In theory, if the chock carrier travels at the same speed as air velocity, the peak concentration will be extremely high and the carrier will arrive at the same time as the concentration peak.

Mine 3 exercises monitored various ventilation arrangements of longwall face move during chock transport to the installation roadway. Figure 11 shows longwall ventilation arrangement for tests and the positions of the D-PDM monitors #106 and #108 during the tests. On this test day loaded chock carriers travelled in and out through the TG. An airflow of 28 m^3/s was measured in the MG and about 39 m^3/s in the TG. There was a back borehole downcasting about 11 m^3/s. Three chock carriers were available and a total of four chocks were moved.

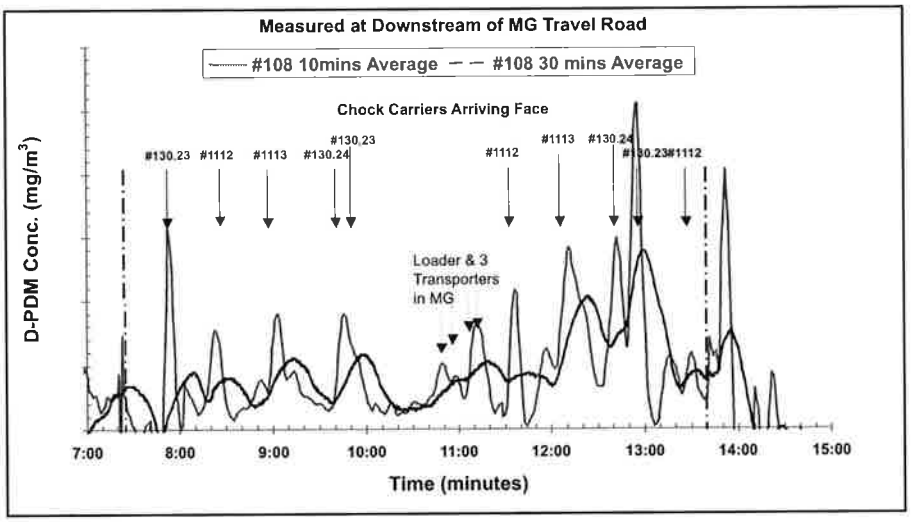

FIG 9 - Observations on results at monitor 108 fixed location.

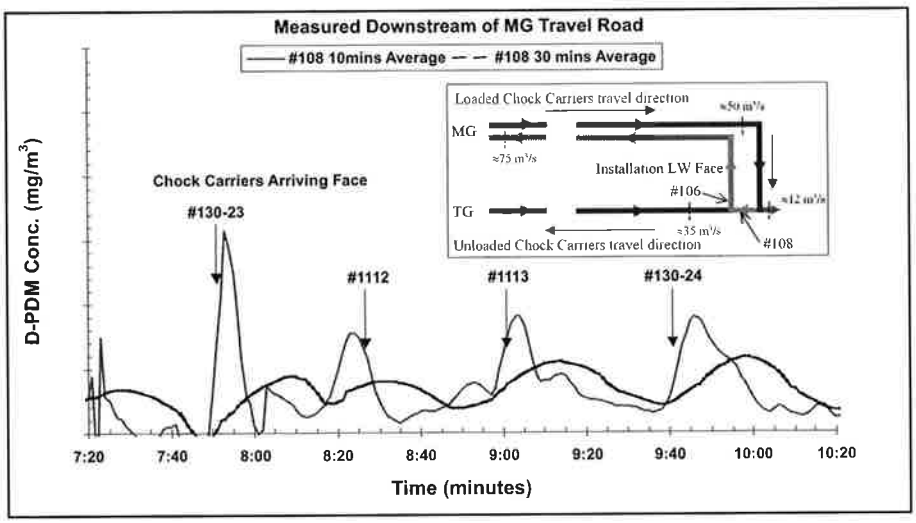

FIG 10 - Observations on results over a three-hour period at monitor 108 fixed location.

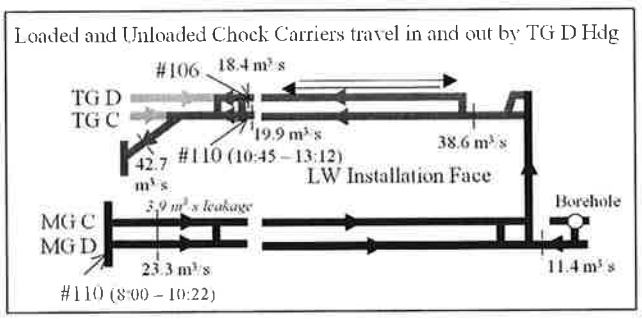

FIG 11 - Longwall ventilation-chock carriers travel in and out on tail gate (TG).

Figure 12 shows readings from fixed location monitoring of chock movements in the face area and nearby (D-PDM monitors #110) and from monitoring all the air that had passed through the longwall panel (D-PDM monitors #106). The trace of monitor #110 illustrates clearly the arrival and departure of individual chock carriers at the face TG end and subsequent movement chock repositioning by a diesel 'shunting mule' (an Eimco 936 1123). The trace of monitor #110 illustrates the additional DPM in the return air picked up from the travel of chock carriers along the length of the TG roadway. Both traces register the activity although from different air sources and it can be seen that as traffic became heavier the level of DPM increased and when the traffic eased off, the level of DPM decreased.

Mine 3 results were analysed to identify sources and levels of DPM within the panel by strategically placing the real-time DPM monitors within the longwall panel as shown in Table 1. The DPM sources (µg/s) in the table are calculated by knowing the air quantity (μ^3/s) and the DPM concentration (µg/m^3) at various locations within the panel ventilation circuit. There were significant DPM levels in MG heading D due to outbye traffic and in particular the passage of chock carriers in the mains intake air stream as they passed to the panel TG. There were also significant DPM levels added along the longwall face due to the installation of chocks by 'shunting mules' or LHDs. The largest source was from chock carriers that carried individual chocks along the length of the TG to reach the face.

As discussed by Dabill (2005) exposure of drivers of diesel vehicle to DPM can be affected by the direction of travel and the ventilation system. For vehicles travelling against the ventilation direction, it would be best to try to ensure the engine is trailing the driver. Under these conditions, driver exposure to DPM will be low if there are no other vehicles inbye. However, travelling

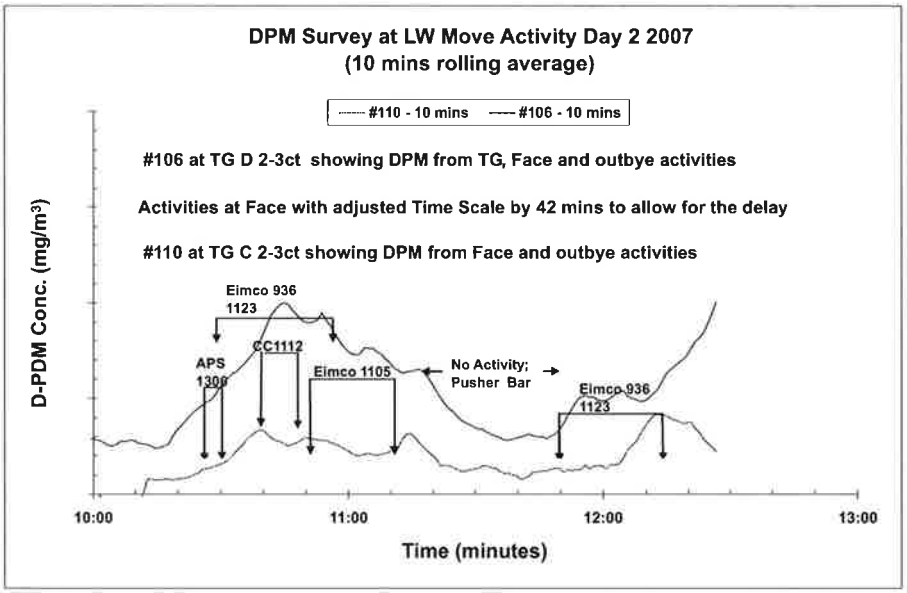

FIG 12 - Diesel particulate matter (DPM) make from LW face activity, #110 compared with DPM make from both face and tail gate (TG) transport activities, #106.

TABLE 1

Sources of diesel particulate matter (DPM) identified in the installation LW panel.

Location	Sources (µg/s)	%	Comments
MG, C and D Hdgs	3.03	18.6	Mains air at MG panel entrance
Borehole	0.00	0.0	Situated at the back of LW panel, fresh air
LW face	4.77	29.2	Shunting Mule or LHDs
TG D Hdg	6.96	42.6	Chock carriers travel way
TG C Hdg	0.00	0.0	No diesel activity
Leakages	1.57	9.6	Mains air; coffin seal and double doors
Measured total	**16.32**	**100.0**	

against the ventilation flow with the engine forward can lead to very high driver exposure and where possible this should be avoided, or at the very least reduced to as short a time as possible.

It is more difficult to minimise exposure when travelling with the airflow as no matter what speed the vehicle travels, the driver is likely to be exposed. It is important for the vehicle not to travel at the same speed as the ventilation air velocity as the vehicle driver will be operating in an ever-increasing concentration of diesel exhaust emissions and exposure could consequently be very high. If the vehicle is likely to be travelling faster than the ventilation airflow, then the engine should be trailing and if the vehicle is slower than the ventilation it should be orientated with the engine forward of the driver. By observing these rules, exposure to DPM can be kept to a minimum. Table 2 demonstrates vehicle speed and ventilation air velocity over a single travel route, Mine 3, TG Heading D, for face chock delivery.

TABLE 2

Data on chock carrier vehicle speeds and air velocities and machine against air relative velocities.

Time	Location	In/out	Distance (m)	Time (mins)	Speed (m/s)	Air velocity (m/s)	Air travel time (mins)
Chock Carrier APS 1306							
9:53	TG26 2ct	In	3400	34	1.66	1.29	43.9
10:27	Face						
	Machine against air			**Machine/air rel velocity, m/s = 2.95**			
10:31	Face	Out	3400	26	2.18	1.29	43.9
10:57	TG26 2ct						
	Machine with air			**Machine/air rel velocity, m/s = 0.89**			
Chock Carrier CC 1112							
10:12	TG26 2ct	In	3250	28	1.93	1.29	41.9
10:04	TG26 36ct						
	Machine against air			**Machine/air rel velocity, m/s = 3.22**			
10:05	TG26 36ct	Out	3250	17	3.18	1.29	41.9
11:07	TG26 2ct						
	Machine with air			**Machine/air rel velocity, m/s = 1.89**			

Points that can be established from this data are:

- in these specific tests, chock carriers travelled at higher average speed than air velocity;
- however, on poor roads machines may travel slower than the air velocity; and
- the time difference and the peak concentration will depend on the air route, whether the air is travelling with or against the carrier direction, the air velocity as a function of the air quantity and chock the carriers' travel speeds.

A possible reduction in DPM driver exposure could have been achieved by consideration of the following suggestions:

- TG travel route panel air quantity could be increased.
- Alternatively, TG air could be re-routed, eg air into the panel could flow up D Heading and return down C Heading.
- Increase in air velocity may result in air velocity and vehicle speed being very similar. This is to be avoided if vehicle travels in air direction as would have happened if vehicles came into the panel up D Heading.
- It is best if the vehicle travels against the airflow direction.
- Best conditions would be achieved if air came into panel up D Heading and returned down C Heading and traffic moved in the reverse direction. In this configuration, vehicles would always travel against the airflow direction. If the vehicle exhaust outlet trails the driver then it will pass away from the driver in both directions of travel.

DPM tests were undertaken in Mine 4 to evaluate whether the use of the D-PDM could contribute to the design of a tag board. Tag boards are relatively new to the mining industry and are currently used in only a small number of mines. Tag boards are used to limit access of diesel vehicles to a particular ventilation split or mining sections, to manage exhaust DPM and gases. Diesel tags or tokens are used to control the number of vehicles entering and so limit the level of pollution. Existing tag board systems are based on historic workshop tailpipe readings and mine plan projections of air quantity availability. A new vehicle to a section is stopped from entering until the acceptability of the current atmosphere is determined by checking whether a spare tag position is available.

An alternative approach is to invest in underground continuous real-time monitoring of exhaust gases, DPM and section air quantity and then integrate this information to determine whether an additional vehicle can enter, without exceeding the diesel token limit. This approach optimises the access of diesel vehicles and replaces the existing manual tag board system. This system would allow productivity to improve by detecting dirty engines and permit the maximum number of vehicles to be in use in a ventilation split based on real exhaust contamination. The basis of the system is to determine whether an additional vehicle can enter without exceeding the section ventilation split DPM or gas limits. Currently the predetermined 'tag' allowance may be excessively stringent for a well-maintained vehicle and so vehicles have to wait and waste time until another vehicle leaves the section ventilation split.

Real rime monitoring can help to objectively determine how many vehicles can be in the ventilation circuit of an underground section. At present, a particular vehicle may require one or two tag positions on the board before entering a section. This approach is pragmatic but does not account for many aspects of engine performance or maintenance status. The real-time system could be tied to a mine vehicle tracking system (of which a number of commercial systems are available) to identify individual units. This approach would actually measure the exhaust DPM and CO gas concentrations in the ventilation circuit with a number of vehicles present and determine whether a predetermined limit has been reached before allowing additional vehicles through the access or tracking system entry point.

From a brief review of the Australian mining industry it is concluded that there is currently no generally accepted industry approach to tag board design. Those that exist have mostly been designed from exhaust gas level considerations. Some are designed from ventilation indices for engine exhaust gas output such as 0.06 $m^3/s/kW$ output. Some are designed from the original equipment manufacturer's published ventilation requirements for exhaust gas outputs for particular engines. Recently some mines have started to take account of engine exhaust DPM from Bosch meter tests (smoke interference) in workshop tests. SIMTARS (a section of the Queensland Department of Mines and Energy) has been collecting industry information in this area from Queensland underground mines. To date none has been designed to account for underground mine atmosphere DPM concentrations.

Levels of gaseous pollutants allowed in mine workplaces are well understood and measured underground by fixed electronic monitors, tube bundle measurements or hand-held multi-gas monitors. Approaches to understanding what are acceptable levels of DPM pollutants in mine workplaces in Australia and overseas are at a formative stage.

A tag board design exercise has been undertaken to examine the implications of using directly measured mine atmosphere exhaust gas and DPM readings. The underground monitoring used in the tag board design exercise was based on evaluation of DPM from various vehicles under working conditions. Tag board design needs to consider a number of issues, including:

- Who is being analysed? Is it the driver and personnel on moving vehicles travelling in and out of the panel? Or is it the crew within the panel and particularly those at the face?
- What is the relationship between 'make' of DPM from a particular vehicle and airflow for dilution within the travelling airway?

The DPM breathed by vehicle occupants will depend on the vehicle engine's exhaust output, the airflow ventilation route, the roadway and whether it is uphill or downhill, whether the air is travelling with or against the vehicle direction, the air velocity as a function of the air quantity and the vehicle's travel speeds. Exhaust pollution effects can be significantly reduced if vehicles do not travel in convoy or close together. Effects can be reduced if vehicles either travel slower than ventilation air velocity so that the plume of exhaust travels faster than the vehicle or alternatively, travel faster than ventilation air velocity so that the plume of exhaust is left behind.

The effect of DPM on crew members at a working face is important. All DPM contaminant exhausted while a vehicle is in a section passes through the working place, except for leakage that short circuits through stoppings and other ventilation control devices. Crew members are thus affected by a vehicle's DPM 'make', which is best determined by testing it during normal working conditions. This should take into account operational conditions such as road conditions, road gradient up or down, engine revving or idling periods and so on. From this, a particular vehicle's DPM operational signature can be determined.

The relationship between 'make' of DPM from a particular vehicle and airflow for dilution within the travelling airway can be determined as follows:

- a vehicle's DPM pollution in the mine airway is measured in mg/m^3 in a particular airway;
- airway ventilation quantity at that point is measured in m^3/s; and
- DPM 'make' is the product of the two, ie $mg/m^3 \times m^3/s = mg/s$.

The effect of a vehicle's make depends on air quantity in the ventilation split. Greater air quantity increases dilution. Tag board design should use information on the following:

- average make of each vehicle that may be in the ventilation split (mg/s);
- the quantity of air available for dilution (m^3/s);
- maximum number of vehicles at a particular time (and which vehicles); and
- the DPM pollutant level that is considered (by design, guidelines or regulations) to be the maximum (mg/m^3) that is acceptable.

Tests were undertaken at Mine 4 over one day to assist in tag board design. The exercise produced DPM make values from underground measured values supported by mine workshop/ industry published data as shown in Table 3.

Monitored values indicated that:

- The one Toyota reading was very low compared with the workshop value. Further investigation is needed.
- The Driftrunner outputs 2.0 - 3.0 mg/s in normal use. There was a good agreement between underground and workshop test measures.
- The Eimco also outputs 2.0 - 3.0 mg/s in normal use; more under heavy load. There was a good agreement between underground and workshop test results.

It was also found that convoy tests for two and three vehicles gave outputs that cumulatively agreed with figures for single vehicles.

Some conclusions for tag board design for DPM requirements indicated that future evaluations should undertake extensive tests with single and vehicles convoys and undertake tests at extremes of operation, eg heavy loads, steep gradients and prolonged idling. Tests over longer routes on a representative set of road surfaces; particularly more roads in 'bad' condition should be undertaken. Some tests should be undertaken in a quieter period, such as during night shift to reduce or eliminate interference from other (non-test) vehicles and there should be some underground tests while vehicles are parked and idling. Testing for DPM requirements for tag board design have been undertaken over one day. The D-PDM real-time monitors in mine static and moving positions gave good and consistent monitored results representative of the underground environment. Underground readings in general agree well with workshop tests. Recommendations were formulated on some additional tests to increase confidence in the results.

The real-time DPM monitor is being developed on the base of the successful PDM unit. The only other unit available in Australia for directly measuring mine atmosphere DPM is the NIOSH developed SKC impactor system. The SKC system delivers shift average results which are not real-time results. The SKC system results are analysed by the NIOSH 5040 method and the only Australian site for this analysis is the Singleton, New South Wales Coal Services Laboratory. During this research, parallel underground SKC samples were taken for comparison with the mine real-time DPM monitor results. Under the SKC system the sample is drawn first through a respirable cyclone sampler and then through an impactor before passing onto a quartz filter. It can then be analysed for carbon; both the OC associated with the absorbed organic substances and EC from the soot cores themselves. TC is the sum of the OC and EC. TC according to Volkwein (2006) makes up consistently over 80 per cent of the submicron DPM material that passes through the impactor in the SKC system. From various research and studies conducted so far, TC has been measured at over 80 per cent of submicron DPM sample mass. Dabill (2005) states that comprehensive research has shown that over 95 per cent of diesel particulate has an aerodynamic diameter of less than 1 µm, whereas virtually all coal dust has particles larger than 1 µm. Consequently, by collecting the submicron fraction, the coal dust is effectively eliminated.

Figure 13 shows results from the first three mine test series compared with SKC impactor collection determinations of EC and TC particulate shift average results taken in the particular

TABLE 3

Diesel particulate matter (DPM) make of some test mine vehicle incorporating workshop and underground monitored values.

Vehicle	Engine (kW)	Av make Av/max† (mg/s)	U/G test 1 (mg/s)	U/G test 2 (mg/s)	U/G test 3 (mg/s)	U/G test 4 (mg/s)
Toyota	55	3.05/9.21	0.08, idle	-	-	-
Driftrunner	63	2.97/5.94	2.14, idle	1.34, idle	2.59	-
Eimco, CAT 3306	Av 105	3.14/9.81	1.5, idle	9.02, rev	3.27	2.07

† Average and maximum make from SIMTARS workshop test industry database.

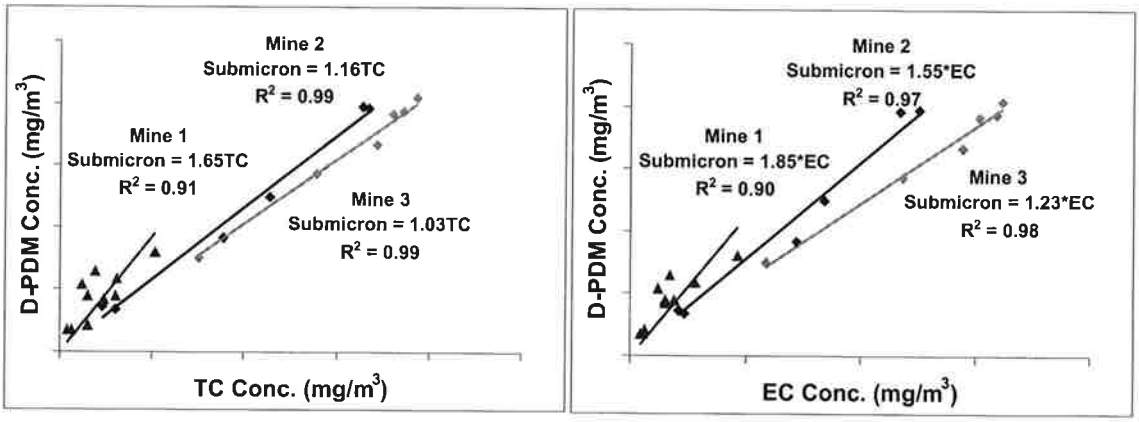

FIG 13 - Mine individual relationships between total carbon (TC) or elemental carbon (EC) and submicron diesel particulate matter (DPM) results.

mine at the same time. Close correlations were found for all cases and in particular for Mines 2 and 3. The results demonstrate that calibration relationships vary from mine to mine, due to differences in aspects such as mine atmospheric contamination, fuel type, engine maintenance and engine behaviour.

CONCLUSIONS

Two project areas of new real-time monitoring development supported by ACARP grants in recent years have been discussed. The projects received substantial NIOSH support and are a practical application that have received considerable additional industry financial support, mine site testing and evaluation assistance. The paper has discussed how the monitors performed within the underground mine environment in evaluating respirable dust and diesel particulate matter during the various phases of a production cycle. Results have been compared to alternative industry pollutant measuring approaches. These monitors give the potential to improve understanding of the mine environment and to empower and educate operators in the control of their environment. Both monitoring approaches have application to coal and metalliferous surface mining operations in addition to the underground evaluations discussed.

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