MINE REAL TIME PERSONAL RESPIRABLE DUSTAND DIESEL PARTICULATE MATTER MONITORING

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ABSTRACT

An overview is given of some new developments in mine atmospheric monitoring approaches. In particular two areas of new endeavour are highlighted.

A new personal respirable dust monitor (PDM) that gives realtime 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 US. It has particular application for determining high source locations and efficiency of engineering means of suppression and other approaches to handling the problem.

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 continue to 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 pin-point high exposure zones such as those encountered in coal longwall face moves, where a number of trucks, loaders, coal ram cars work or in areas of poor ventilation. Pinpointing of high DPM concentration zones will allow efficient modification of work practices to reduce underground miners exposure. Some outcome of a currently funded ACARP project in this area will be discussed.

INTRODUCTION

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

The coal industry is vigorous and expanding and driven by high prices and export demand. The push is unrelenting for increased production rates particularly from longwall production. Faces quantities and velocities continue to increase in more aggressive gas, dust and heat level environments. Many of Australia's mines face high seam gas levels in conjunction with high propensity to spontaneous combustion. There will continue to be better and more innovative approaches to gas drainage. Atmospheric inertisation was first introduced as a tool to fight fires. It is now accepted as a component of the production cycle in some mines.

Australian metalliferous mines also 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, sub level 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-purposes 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 is an increasing number of smaller operations. These generally have a small plan section and progress to depth fast. Many face high heat load situations. They also face high diesel exhaust emissions at the same time. This combination is the big ventilation planning challenge.

The network in many modern mines changes daily as stopes break 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 realtime monitoring of ventilation parameters and particularly gases, respirable dust and airflow. Old worked out areas and goafs are becoming bigger. The issues they present are demanding thought and priority research. Understanding fires, simulation of fires and training the workforce will continue as a priority area.

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 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 has been outstandingly successful in supporting focusing research efforts to productive industry benefit. The 5 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 has in the past funded some significant research in metalliferous ventilation projects. It is disappointing that this scheme no longer appears to be active in the mine ventilation research areas.

The 1994 Moura Number Two and 1996 Gretley mine disasters 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. There is a much greater emphasis on training at all levels.

Much of the industry is actually or effectively long distance commute (Fly In Fly Out). It is beyond the scope here to cover the issues of joint management, longer work shift hours and so on that this presents to the management of ventilation. There is more use of consultants than ever before; a situation than again presents many issues.

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 Australian Coal Association Research Program grants in recent years. 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 respirable dust monitor (PDM) developed by the company Rupprecht and Patashnick (now Thermo Fisher Scientific) in the US under a project funded by the National Institute of Safety and Health (NIOSH) has generated promising results in underground coal mine testing performed in the US recently (Volkwein et al, 2004a and 2004b). Results from an ACARP funded study undertaken to evaluate this new realtime 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 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 the situation to be corrected. 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 in sufficiently short a time 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, and a charging and communication module 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 2007 US Federal 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 and update the 35 year old respirable dust standard that is not effectively preventing today's miners from developing black lung disease. Part of this move will require miners be equipped with the new PDMs developed and certified by NIOSH and authorise miners to adjust their activities to avoid respirable dust overexposure.

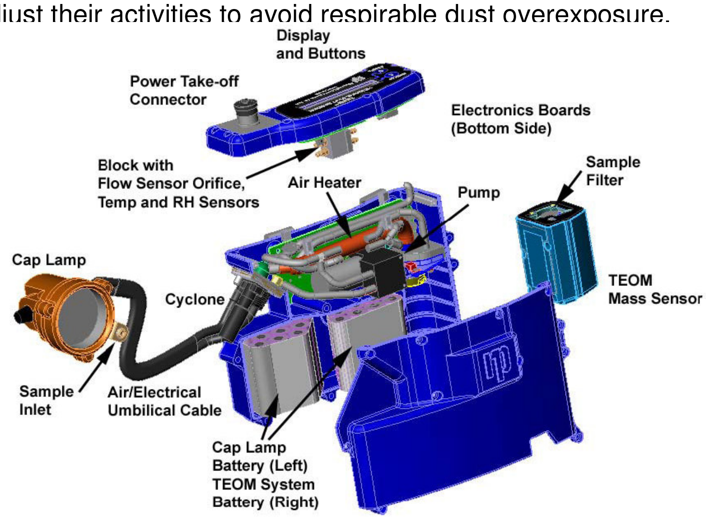

Figure 1 Major components of the PDM.

Tests were undertaken at a development face to monitor the dust exposure levels of various equipment operators. 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 pm 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 dust levels.

During the tests an unplanned event took place. The end cap of ventilation ducting in an inactive adjacent face of the development section was sucked in and caused reduction in the ventilation air quantity available to the face being monitored from 7.5m^3/s to 4.3m^3/s. This caused a significant loss of suction head in the ventilation ducting at the face resulting in the dust-laden air at the face billowing back onto operators. All PDMs worn by the three operators have registered sharp rises in dust level. In fact this unplanned event was first noticed by one of the operators who had checked the real time display on the PDM he was wearing at the time. The failure of the end cap piece in the inactive face was soon rectified and the normal ventilation flow re-established. Readings from all PDMs show the immediate reduction in duct concentration upon rectification.

The longwall panel has a number of potential dust sources. A detailed survey can assist in evaluating the contribution of each component source, show the contribution from a number of major sources and the cumulative dust level faced by a miner at different points throughout the panel. In undertaking Longwall studies it is important to maintain consistency with measurement conditions along the face activities. Figure 3 indicates studies undertaken over the majority of a shift with two PDM units. The shearer position data was downloaded from the mine monitoring system. A cutting sequence took on average slightly less than an hour. It can be seen in the figure that seven cutting cycles occurred across the seven hour study time period with good regularity. One early period of 45 minutes of cutting was lost to belt structure removal.

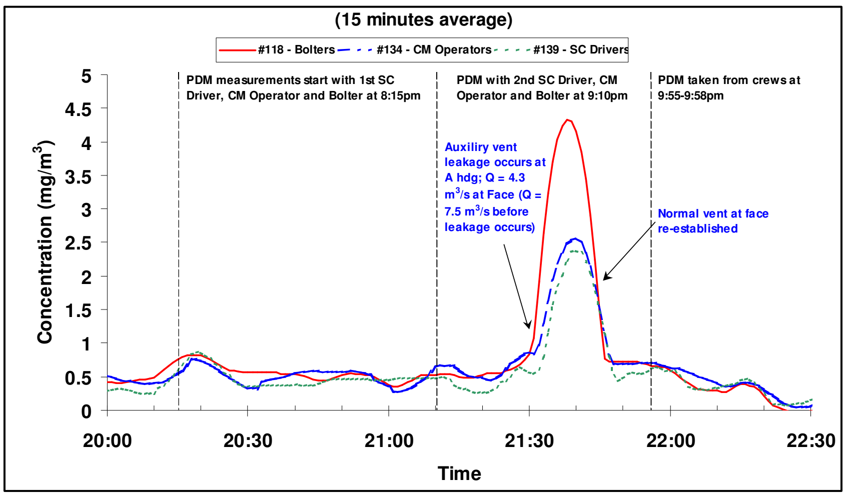

Figure 2 Development Face PDM results.

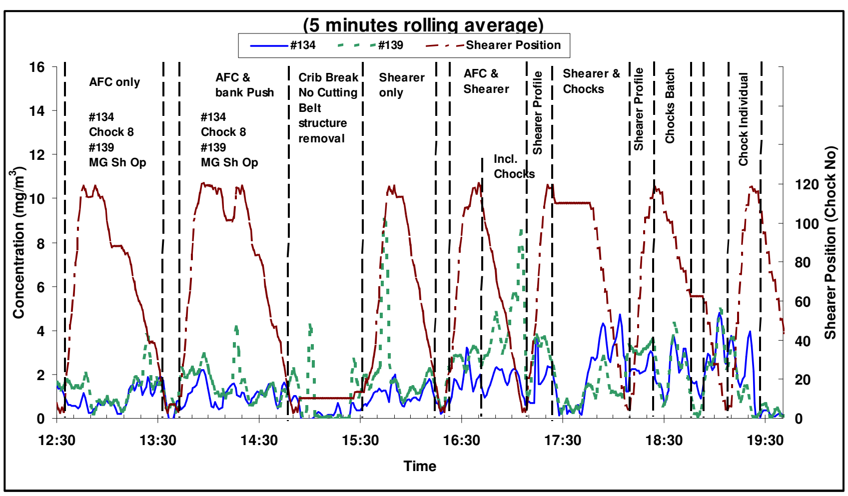

Figure 3 LW Face Dust Surveys Shearer Position and dust monitored points and Levels

Measurements were carried out at longwall face positions monitoring the dust levels experienced by shearer and chock operators in a unidirectional mining cutting sequence. Results of these tests are shown in Figure 4 and 5 for various operator position combinations.

Figure 4 illustrates dust exposure at the MG Shearer and TG Chock operator positions as the cutting sequences moves along the LW face. This shows under Unidirectional cutting that during the TG to MG cutting sequence operators are advancing chocks downstream of the shearer and so experience relatively high dust exposures. After snaking at the MG end chock operators following the shearer are upstream of the unit and so experience relatively lower dust exposures. The results indicate that the MG shearer operator was subjected to relatively high dust level exposure when cutting from MG to TG. When cutting from TG to MG the dust level experienced by the MG shearer operator was much lower.

Figure 5 examines variation of dust make with shearer advance rates. Two TG to MG cuts were examined; one taking over 42 minutes for the cut and one only taking 26 minutes. It is clear that although there is virtually the same dust make in the two cuts at the same shearer position the dust exposure of average 1.72 mg/m^3 for the faster cut is greater than for the slower at 1.03 mg/m^3.

Based on the tests conducted, it is concluded that the PDM has demonstrated its potential use as an engineering tool to locate and assess various sources of dust during normal mining operations. The principles and concepts used to identify and fix some of the higher dust levels are generally common sense. However, to make the most effective use of this information, training and experience in using this type of technology will be very important. Experience with the data from the unit will help miners gain confidence to use the information to maintain reduced or safe dust levels during mining.

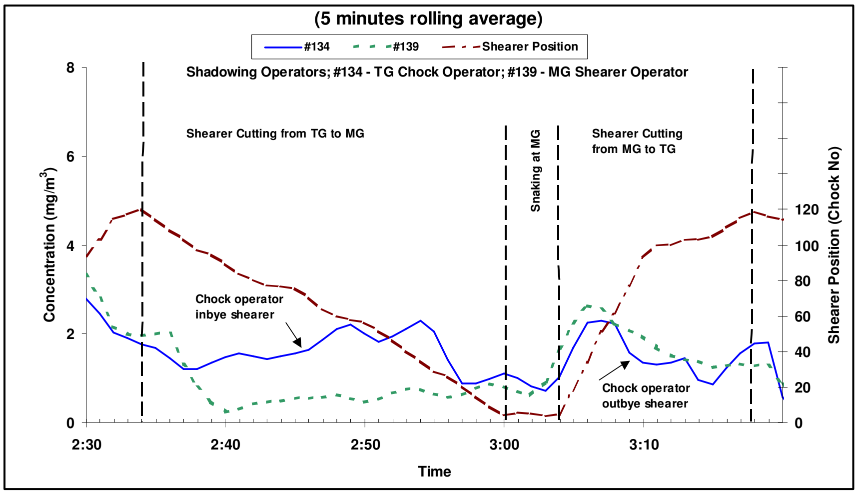

Figure 4 Relative dust make experienced by MG shearer and TG Chock operators.

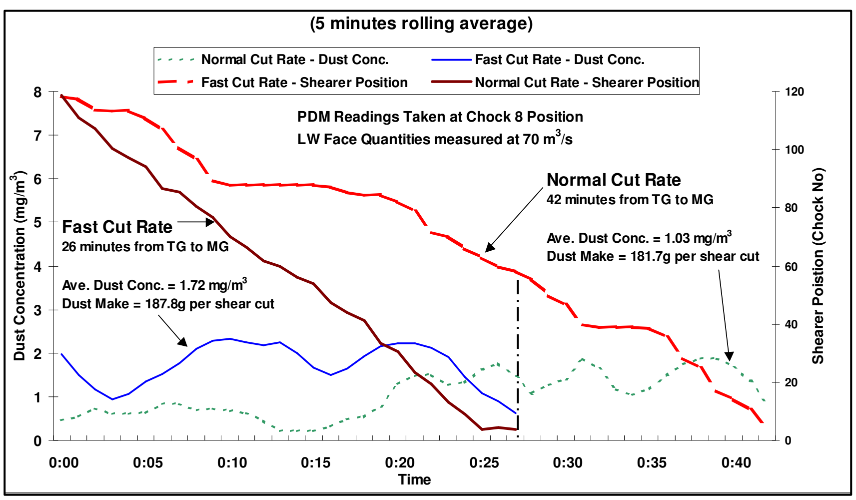

Figure 5 Variation of dust make with shearer advance rates

MONITORING OF DIESEL PARTICULATE MATTER

Diesel Particulate Matter (DPM) issues are very high profile currently in both Australian coal and metal mines and Australian states are generally moving to acknowledge and to broadly follow US 2008 final metal mine regulation limits of 0.2 mg/m^3 submicron particulate matter, 0.16 mg/m^3 total carbon particulate and 0.1

mg/m^3 elemental carbon particulate. The real time DPM monitor is being developed on the base of the successful PDM unit. The objectives of this ACARP study are to finalise the design of a DPM unit, to undertake comprehensive and internationally recognised laboratory testing to evaluate the new design and to undertake an underground series of tests to establish the robustness and reliability of the new approach.

Thermo Fisher Scientific, has undertaken structural changes to the PDM 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. A phase of Australian mine robustness and engineering testing is currently being undertaken to ensure the instrument can effectively assist mine management to handle this health issue. Tests are being undertaken at points of expected high atmospheric DPM such as during Longwall face moves, Development RAM car, Eimco and PJB usages. The outcome of the project will give the industry access to an enhanced tool for understanding the mine atmosphere in the presence of DPM.

The phase of Australian mine testing commenced in September 2006 to ensure the instrument can, in a practical way, effectively assist mine management to handle this health issue. The Mine 1 tests were undertaken in working sections with use of diesel powered Ram cars over four days. The results from these limited tests qualitatively indicated that the D-PDM did respond to observed diesel activity in fairly low concentration ranges. 10 minute averaging periods appeared 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. There had been concern that vehicle vibrations may detrimentally affect monitor accuracy.

Mine 2 testing was undertaken in December 2006. These exercises monitored various ventilation arrangements of longwall face move during chock transport to the installation roadway. Mine atmosphere DPM concentrations were in general higher than in earlier mine tests. Higher DPM concentrations allowed relatively greater accuracy in monitoring concentrations. Results were in most cases recorded as a rolling 10 minute average and so more reflected activity changes. It was straight forward 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).

Figure 6 shows Longwall ventilation arrangement for tests. 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 MG and out through TG. About 50 m^3/s ventilation was measured in the MG and about 35 m^3/s in the TG. There was a back borehole upcasting some air. Four chock carriers were available and a total of 10 chocks were moved. Results from monitor #108 as shown in Figure 7 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 (10) 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 became poor and some chock carriers were slower and having difficulty travelling through.

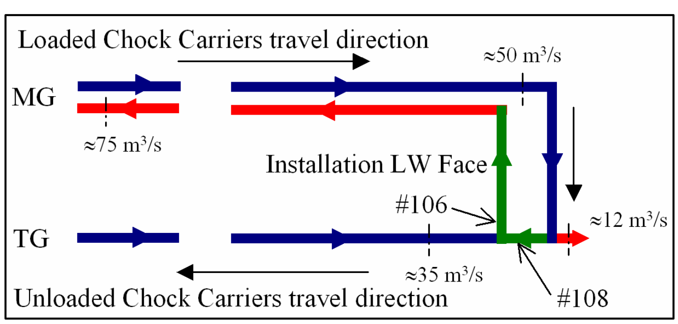

Figure 6 Longwall ventilation-chock carriers travel in on MG and out on TG.

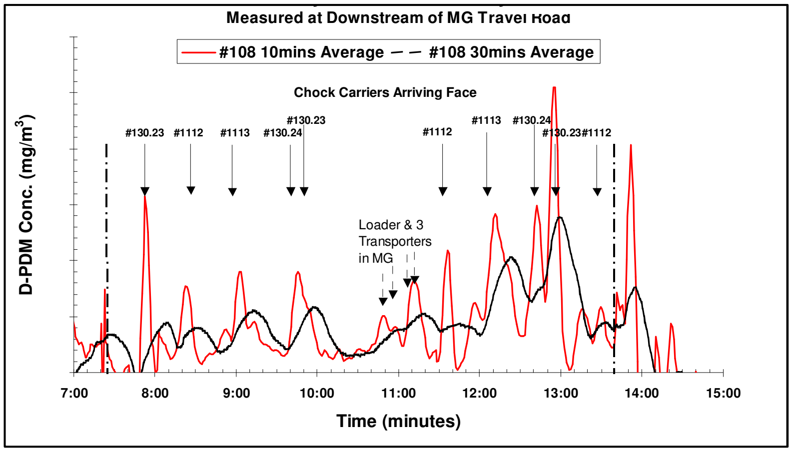

Figure 7 Observations on results at monitor 108 fixed location.

Figure 8 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 showed that when the chock carriers travel in from the MG in three cases 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 air velocity. However Carrier #1112 arrived slightly later indicating slower machine travel speed than air velocity. The time difference and also the peak concentration depends 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.

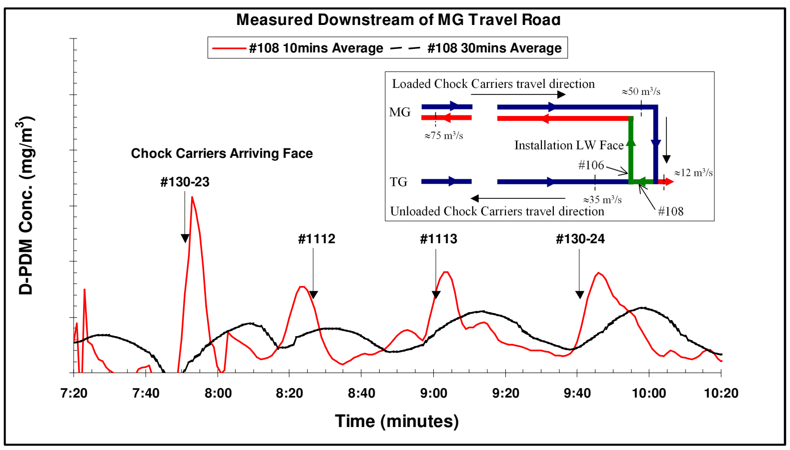

Figure 8 Observations on results over a three hour period at monitor 108 fixed location.

Mine 3 tests was undertaken in June 2007. These exercises monitored various ventilation arrangements of longwall face move during chock transport to the installation roadway. Figure 9 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. About 28 m^3/s ventilation 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.

Figure 10 shows readings from monitor 106 at the fixed location responded and illustrate clearly travel of chock carriers in the Tailgate. As traffic became heavy the level of DPM increased and when the traffic eased off the level of DPM reduced.

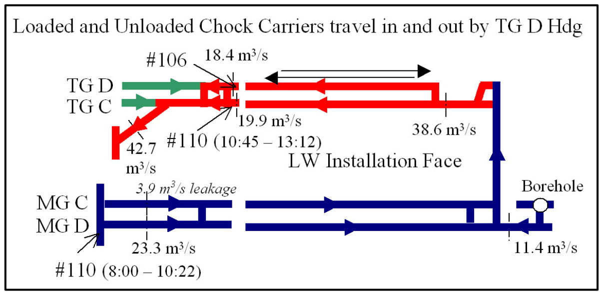

Figure 9 Longwall ventilation-chock carriers travel in and out on TG.

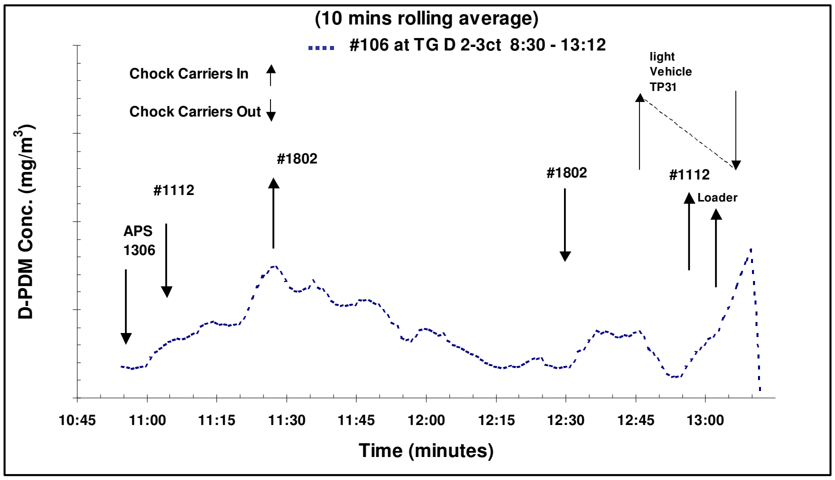

Figure 10 Observations on results over a three hour period at monitor 106 fixed location.

Mine 3 results were analysed to identify sources and levels of DPM within the panel as shown in Table 1. By strategically placing the real time DPM monitors within the longwall panel various sources of the DPM could be identified. The DPM sources (µg/s) in the table are calculated by knowing the air quantity (m^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 to the panel Tail Gate. There were also significant DPM levels added along the Longwall face due to the installation activities of chocks by “shunting mules” or LHDs. The largest source was from Chock Chariots that carried individual chocks along the length of the TG to reach the face.

Table 1 Sources of DPM identified in the installation LW panel

Location	Sources, µg/s	%	Comments
MG, C & 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 chariots travel way
TG C Hdg	0.00	0.0	No diesel activity
Leakages	1.57	9.6	Mains air; coffin seal & double doors
Measured Total	**16.32**	**100.0**	

As discussed by Dabill (2005) exposure of drivers of diesel vehicle to DPM can be limited by the direction of travel and the ventilation system. For vehicles travelling against the ventilation always try to ensure the engine is trailing the driver. Under these conditions driver exposure to DPM will be low if there are no other vehicle inbye. However, travelling 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 consequently exposure could be very high. If the vehicle is likely to be travelling faster than the ventilation airflow then have the engine trailing and if the vehicle is slower than the ventilation have it orientated with the engine forward of the driver. By observing these rules exposure to DPM will be kept to a minimum but will not be eliminated altogether. Table 2 demonstrates on vehicle speed and ventilation air velocity over a single travel route, Mine 3 Tail Gate Heading D, for face chock delivery.

Table 2 Data on chock carrier speeds and air velocities and machine against air relative velocities

Time	Location	In/Out	Distance m	Time mins	Speed, m/s	Air Vel m/s	Air Travel Time mins
Chock Carrier APS 1306							
9:53	TG26 2ct	In	3,400	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	3,400	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	3,250	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	3,250	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.

- In these specific tests chock carriers travel at higher average speed than air velocity.
- However on poor roads there could be slower machine travel speed than air velocity.
- 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 carriers' travel speeds.
- In theory if the chock carrier travels with the air at the same speed as air velocity the peak concentration around the vehicle will be extremely high.

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

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

The real time DPM monitor is being developed on the base of the success PDM unit. The only other unit available in Australia for measuring directly mine atmosphere DPM is the NIOSH developed SKC impactor system. The SKC system delivers shift average results and not real time results. The SKC system results are analysed by the NIOSH 5040 method and the only site for this analysis is the Singleton, New South Wales Coal Services Laboratory. During this research parallel underground SKC samples have been 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 organic carbon (OC) associated with the absorbed organic substances and elemental carbon (EC) from the soot cores themselves. Total Carbon is the sum of the Organic and Elemental Carbon. Total Carbon (TC) according to Volkwein (2006) makes up consistently over 80 percent of the submicron DPM material that passes through the impactor in the SKC system From various research and studies conducted so far, TC is consistently over 80 percent of submicron DPM sample mass. Dabill (2005) states that comprehensive research has shown that over 95 percent 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 11 shows results from the three mine test series compared with SKC impactor collection determinations of EC and TC particulate shift average results taken in the particular 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 mine to mine due to differences in aspects such as mine atmospheric contamination, fuel type, engine maintenance and engine behaviour.

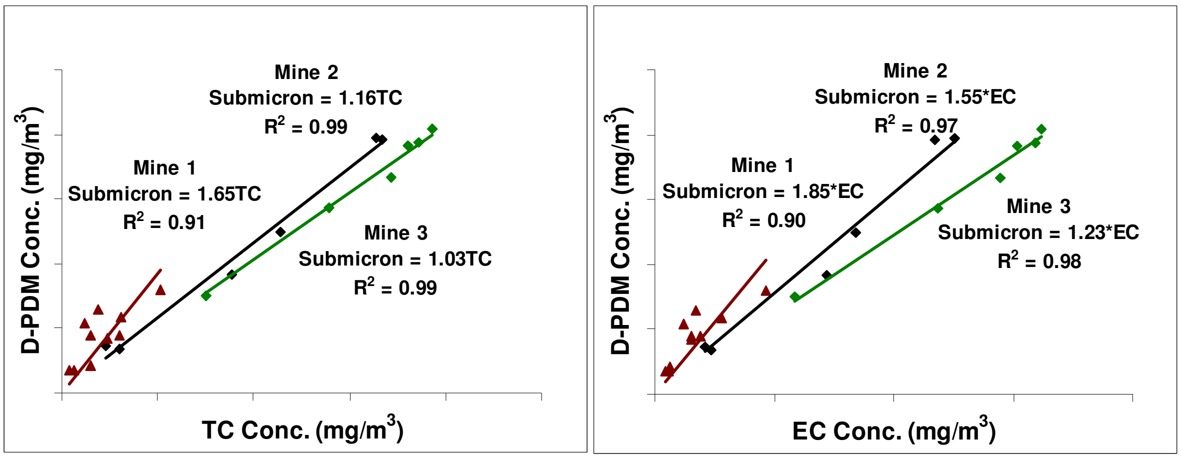

Figure 11 Mine individual relationships between TC or EC and Submicron DPM results.

CONCLUSIONS

Some observations have been made on the current state of mine ventilation within the Australian mining industry. Two areas of new real time monitoring development supported by ACARP grants in recent years have been discussed. They are stories in practical application and have received considerable additional industry financial support, mine site testing and evaluation assistance.

There have been predictions for many years that mine operations are about to move dramatically towards the provision of a pleasant and comfortable work environment or put another way a mining environment based on quality of life. In the last five years there have been dramatic improvements in many aspects of mine ventilation in a substantial number of both coal and metalliferous mines. There continues to be a high awareness of dust with new emphasis or developments in dilution and scrubbers. Awareness of DPM is receiving much emphasis at present. Newly emerging real time monitors will assist here. The paper has discussed two areas which are contributing to enhanced health and safety. Improvements in productivity that result from raising of mine atmosphere quality are the most likely to receive financial priority.

ACKNOWLEDGEMENTS

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