2008

Underground Atmosphere Real Time Personal Respirable Dust and Diesel Particulate Matter Direct Monitoring

S. Gillies
Gillies Wu Mining Technology, Queensland

H. W. Wu
Gillies Wu Mining Technology, Queensland

UNDERGROUND ATMOSPHERE REAL TIME PERSONAL RESPIRABLE DUST AND DIESEL PARTICULATE MATTER DIRECT MONITORING

Stewart Gillies[1] and Hsin Wei Wu[1]

ABSTRACT: An overview is given of two new developments in mine atmospheric monitoring. A new personal dust monitor (PDM) that gives realtime 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 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 where a number of trucks and other vehicles 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. Approaches to design of Tag Boards are also discussed. Some outcomes from mine tests with both these new instruments are 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 in particular 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 raised gas, dust and heat level environments.

Many of our 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.

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 realtime monitoring of ventilation parameters and particularly gases, respirable dust and airflow. 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 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. ACARP has been outstandingly successful in supporting focusing research efforts to productive coal 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.

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

[1] *Gillies Wu Mining Technology Pty Ltd, The Minserve Group, Queensland 4068*

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 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 that 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 industry research grants from in particular the ACARP with substantial input from the United States agency, the National Institute of Occupational Health and Safety (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 PDM for respirable dust developed by the company Rupprecht and Patashnick (now 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 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 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 and update the 37 year old respirable dust standard that is not effectively preventing today's 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.

Tests for underground evaluation exercises 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 (such as 55 mins) as the quicker response to monitored changes shows more significant dust concentration variations. As shown in Figure 2 a development face was monitored. Two PDMs were used with one worn by the Continuous Miner (CM) operator and one by the bolter. The CM operator was using a remote control unit and stood on the right of the heading. The bolter was using the left hand machine mounted unit. Ventilation to the face area was good and ducting was extended approximately every 25 minutes.

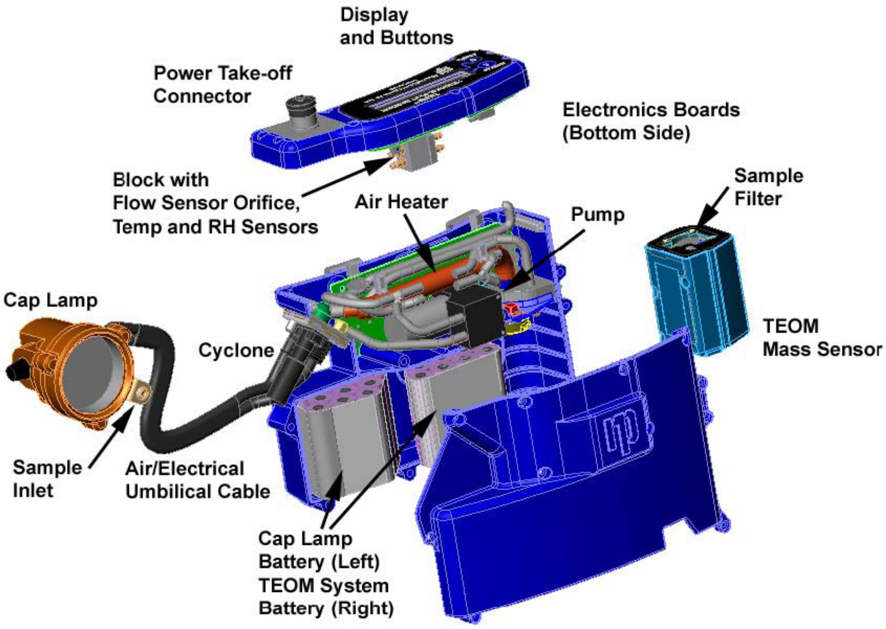

Figure 1 - Major components of the PDM

The exposure levels experienced by the CM operator who was standing very close to the open end of the exhausting ducting and so was in the best face area ventilation stream were consistently lower that those recorded by the bolter. During the period from 17:20 the CM holed through to a previously mined cut through. It is clear that the detrimental change caused in face ventilation from the hole through overwhelmed any change in relative exposure recorded by the two face crews because of the geographic positioning.

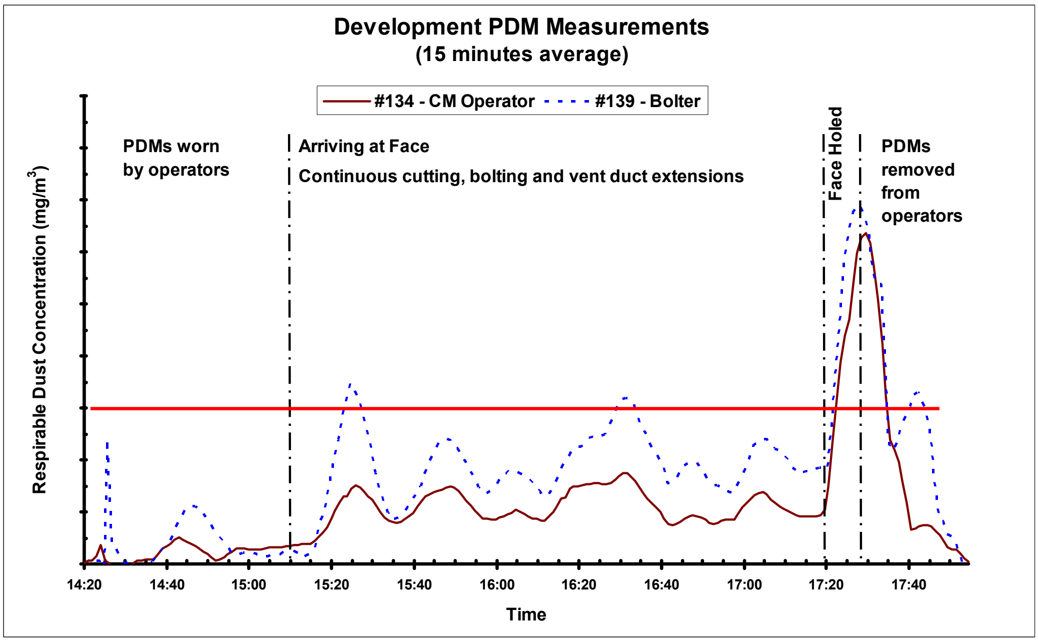

Figure 2 - Development Face PDM results

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 generally took 90 to 120 minutes. It can be seen in the figure that 4.5 complete cutting cycles occurred across the 9.5 hour study time period with good regularity. One afternoon period of almost two hours was lost to a breakdown.

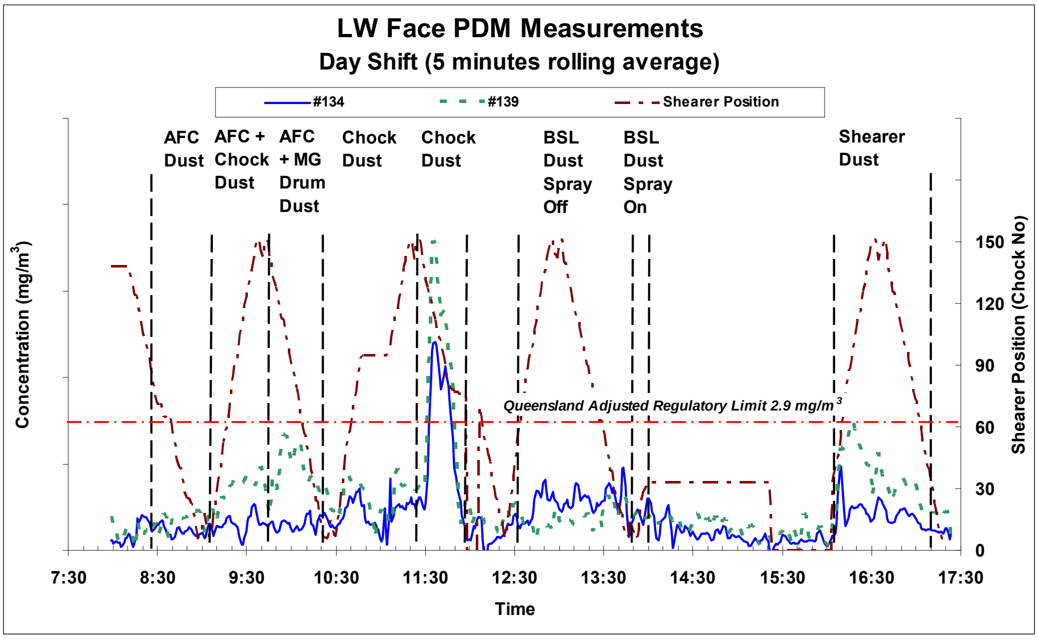

Figure 3 - **LW Face Dust Surveys Shearer Position and dust monitored points and Levels**

Figure 4 examines variation of dust make with shearer advance rates in tests in the same mine. Two MG to TG cuts were examined; one taking over 31 minutes for the cut and the other only taking 25 minutes. It is clear that although there is virtually the same dust make in the two cuts at the same operator position (inbye of the TG shearer drum) the dust exposure of average 1.22 mg/m^3 for the faster cut is greater than for the slower at 0.91 mg/m^3.

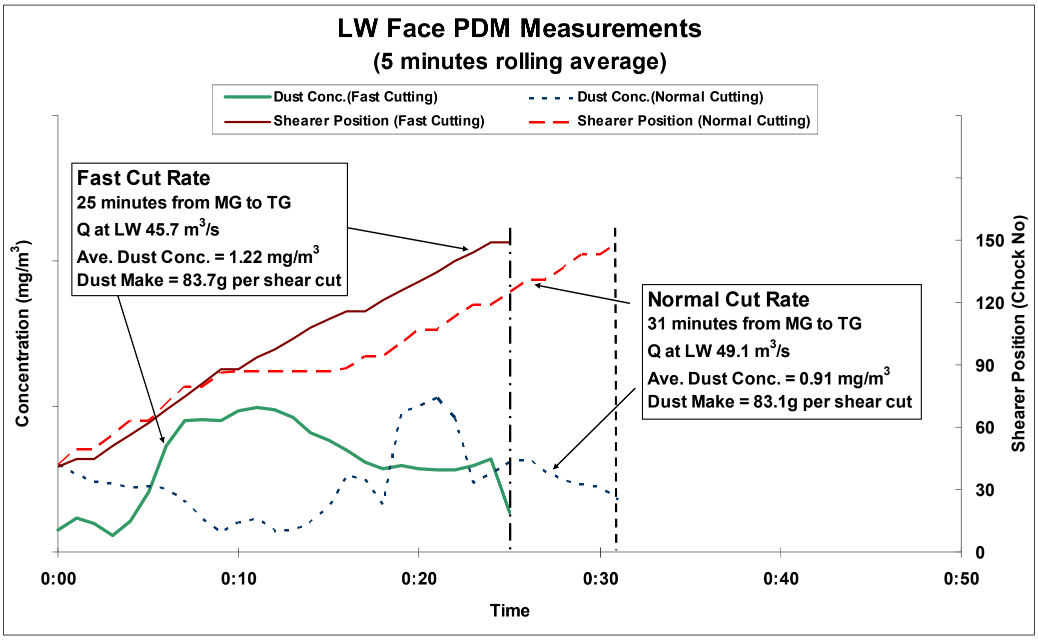

Figure 4 - **Variation of dust make with shearer advance rates**

One of the LW faces tested advances the first five MG chocks during the TG to MG cutting sequence due to roof condition. Large amount of dust during this chock advance are generated and face operators are exposed to this dust as the cloud passes along the face. Figure 5 shows for the shearer MG operator position comparisons of dust generated by MG chocks (1 to 5) advance sequences (highlighted by hatching) and LW full cutting cycle face dust measured for two consecutive shearer cutting cycles. Almost half (48.2 and 49.8%) of this particular LW face dust exposure generated during the cutting sequence is comes from MG chock advance dust at this particular LW mine. In tackling respirable dust reduction lessening, removing and/or isolating this chock dust source is warranted.

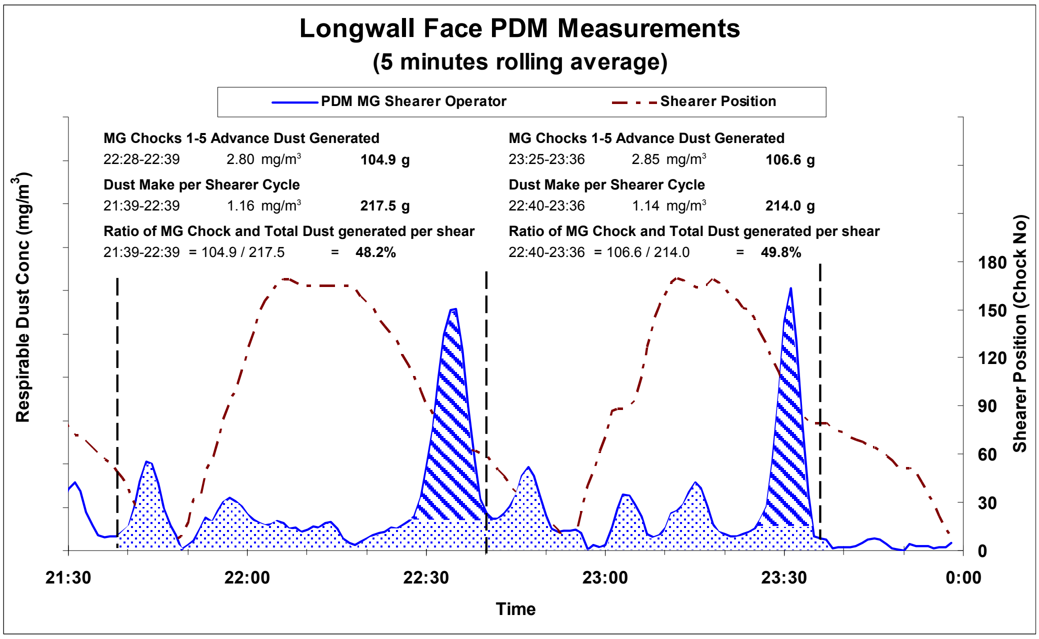

Figure 5 - MG chocks 1-5 advance dust compared with total LW face dust at shearer MG operator position

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.

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 measured systematically since mid 2000s. Early atmospheric readings have been taken on a shift average basis using SKC sampling units. The SKC is derived from a US NIOSH design and gives 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
- TC in mine testing is consistently over 80% of DPM (Volkwein 2006).

Some DPM regulatory guidelines are starting to emerge in Australia. However 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 US April 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. A description is given of an underground series of tests undertaken 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. The D-PDM directly reports levels of mine atmosphere DPM in mg/m^3 from real time readings. It can be placed in the working place or in a mine vehicle and when 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 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 vehicles 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 with use of diesel powered 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 10 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 various ventilation arrangements of a longwall face move during chock transport to the installation roadway. 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).

The longwall ventilation arrangement for one set of tests is shown in Figure 6. 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 tail gate (TG). About 50 m^3/s ventilation was measured in the MG and about 35 m^3/s in the TG. There was a raise borehole upcasting some air.

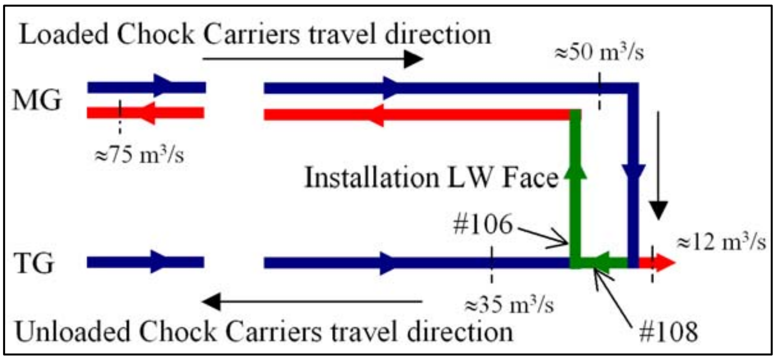

Figure 6 - Longwall ventilation-chock carriers travel in on MG and out on TG

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 become poor and some chock carriers were slower and having difficulty travelling through.

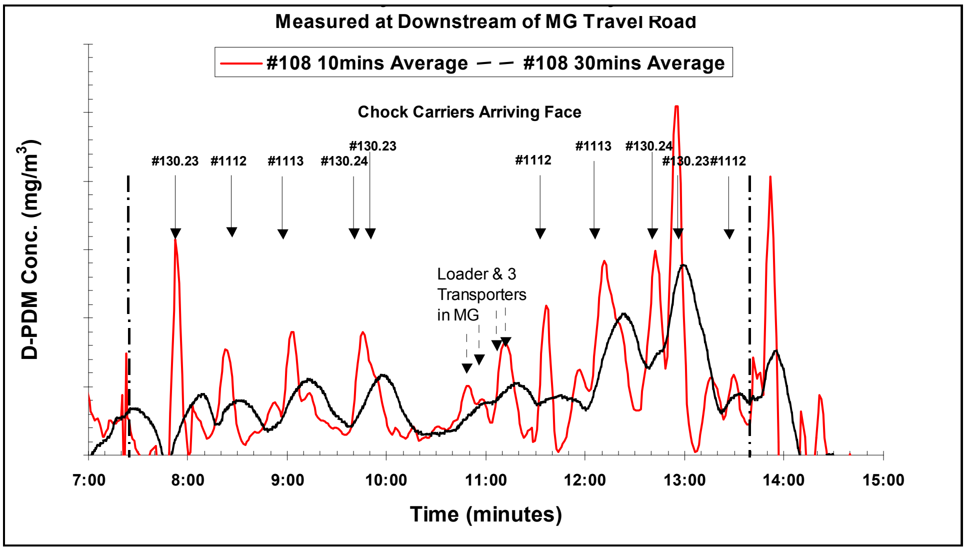

Figure 7 - Observations on results at monitor 108 fixed location

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.

Mine 3 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.

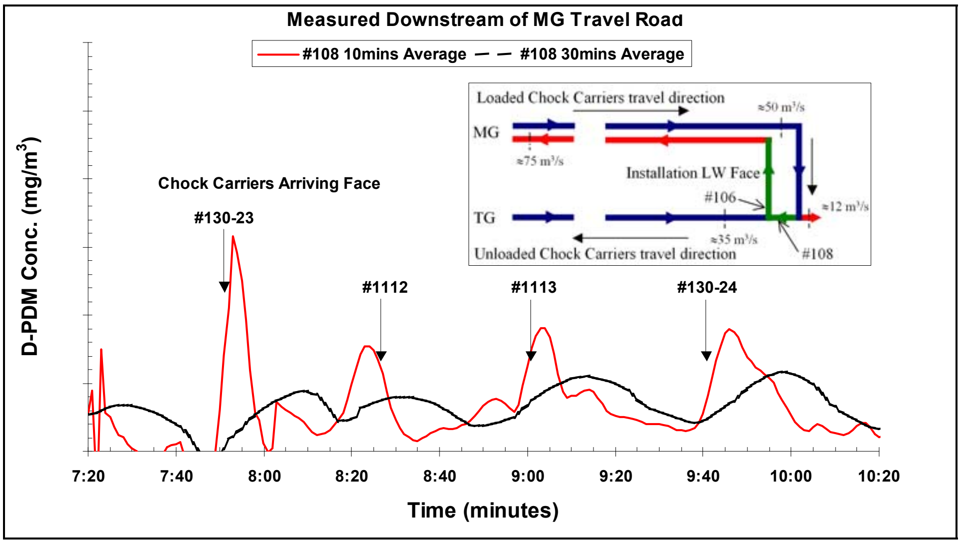

Figure 8 - Observations on results over a three hour period at monitor 108 fixed location

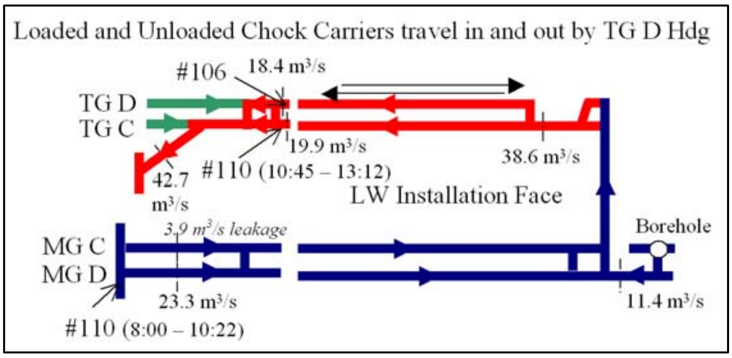

Figure 9 - Longwall ventilation-chock carriers travel in and out on TG

Figure 10 shows readings from fixed location monitoring of chock movements in the face area and nearby, D-PDM monitors #110 and from monitoring all 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", 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 reduced.

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 (m^3/s) and the DPM concentration ($\mu g/m^3$) 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 activities 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.

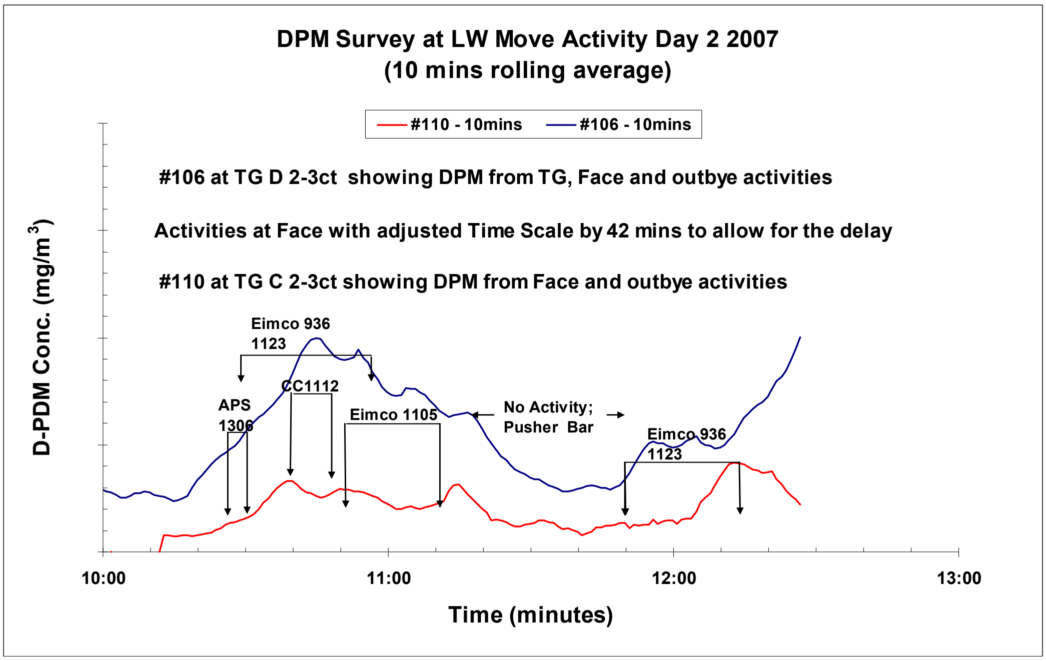

Figure 10 - DPM make from LW face activity, #110 compared with DPM make from both face and TG transport activities, #106

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 carriers 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 vehicle speed and ventilation air velocity over a single travel route, Mine 3 TG Heading D, for face chock delivery.

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 could be extremely high.

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 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**			

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

- TG travel route panel air quantity could be increased.
- Alternatively TG air 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 would 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.

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 entering 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 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 as determined by a check as to whether a spare tag position is available is made.

An alternative approach is to invest in underground continuous real time monitoring of exhaust gases, DPM and section air quantity and integrate this information to determine whether an additional vehicle can enter without exceeding diesel token limit. This approach optimises the access of diesel vehicles and replaces the existing manual tag board system based on historic workshop tailpipe readings. This system would allow productivity improvement by detecting dirty engines and permitting 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 gases limits. Currently the pre-determined "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.

A real rime monitoring approach puts on an objective basis the process for determining how many vehicles can be in the ventilation circuit of an underground section. Currently systems in place across various mines refer to historic workshop tailpipe readings or manufacturers' guidelines. A particular vehicle may be determined to require for instance 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 contaminant in the ventilation circuit with a number of vehicles present and determine whether a predetermined limit has been reached before allowing access of 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 OEMs' 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 have been designed taking into account underground measured levels of mine atmosphere DPM levels.

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 not well understood and at a formative stage.

A Tag Board design exercise has been undertaken to examine implications of this approach 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.

- 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 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 do not travel at the air velocity and 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 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 vehicles DPM pollution in the mine airway is measured in mg/m^3 in a particular airway
- Air way ventilation quantity at that point is measured in m^3/s
- DPM "make" is the product of the two i.e. mg/m^3 x 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 in considering the face crew members must have 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)
- The DPM pollutant level that is considered (by design, guidelines or regulations) to be the maximum (mg/m^3) that is considered 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.

Table 3 - 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	-	-	-
SMV Drifty	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*

Monitored values indicated

- The one Toyota reading was very low compared with workshop value. Further investigation from this one value is needed.
- Single Drifty outputs 2.0 to 3.0 mg/s in normal use. Good underground and workshop test agreement.
- Single Eimco also outputs 2.0 to 3.0 mg/s in normal use; more under heavy load. Good underground and workshop test agreement.

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 requirement indicated that future tests should undertake more extensive tests with single and vehicles convoys and undertake more tests at extremes of operation eg, heavy loads, steep gradients and prolonged idling. Tests over longer routes on a more 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 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 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 Australian 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 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 percent 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 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 first 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.

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 stories in practical application that have received considerable additional industry financial support, mine site testing and evaluation assistance. The paper has discussed how the monitors have performed within the underground mine environment in evaluating respirable dust and diesel particulate matter during the various phases of a production cycle. They have closely examined the influence of aspects of the mine ventilation system. 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.

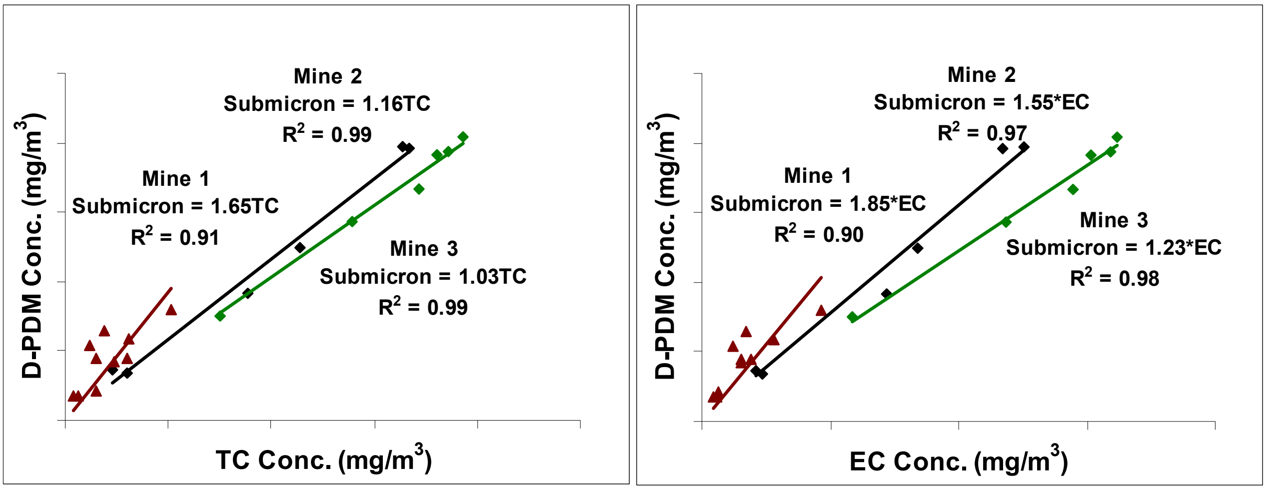

Figure 11 - Mine individual relationships between TC or EC and Submicron DPM results.

ACKNOWLEDGEMENTS

The author acknowledges the support of ACARP and NIOSH in supporting initial projects that form the basis of this paper. They extend thanks to the various mine site managers, engineers and ventilation officers who supported the projects and the evaluation efforts undertaken across a diversity of mine conditions. Their efforts ensured that the principal development and mine site testing aims of the projects were accomplished and a significant contribution made to future mine health and safety in Australia.

REFERENCES

Dabill, D. W., 2005. Controlling and monitoring exposure to diesel engine exhaust emissions in coal mines, Report HSL/2005/55, Health and Safety Laboratory, Buxton, England

Gillies, A. D. S., 2005. Evaluation of a new real time personal dust meter for engineering studies on mine faces. ACARP Grant C14010 Report, September 2005.

Gillies, A.D.S and Wu, H.W. 2006. Evaluation of a new real time personal dust monitor for engineering studies. *Proc Eleventh US Mine Ventilation Symposium, State College, Pennsylvania,* Balkema, The Netherlands.

Volkwein, J.C., 2005. *Personal communication*.

Volkwein, J.C., 2006. *Technology transfer workshop - better use of diesels underground*, Mackay 22 September and Belmont 26 September 2006.

Volkwein, J.C., Thimons, E., Yanak, C., Dunham, D., Patashnick, H. and Rupprecht, E. 2004a. Implementing a new personal dust monitor as an engineering tool, *Proc 10th US Mine Ventilation Symposium,* Balkeima.

Volkwein, J.C., Vinson, R.P., McWilliams, L.J., Tuchman, D.P. and Mischler, S.E, 2004b. Performance of a new personal respirable dust monitor for mine use, RI 9663, National Institute for Occupational Safety and Health, Pittsburgh Research Laboratory, Pittsburgh, PA.