

Developments in real time personal diesel particulate monitoring in mines

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ABSTRACT: 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/non metal mine regulation limits of 0.2 mg/m³ submicron particulate matter, 0.16 mg/m³ total carbon particulate and 0.1 mg/m³ elemental carbon particulate. The real time DPM monitor is being developed on the base of the successful Personal Dust Monitor (PDM) unit. The objectives of recently completed Australian Coal Association Research Program (ACARP) study has been to finalize the design of a DPM unit, to undertake comprehensive and internationally recognized 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. Under the project 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. A phase of Australian mine robustness and engineering testing has been undertaken to ensure the instrument can effectively assist mine management to handle this health issue. Tests have been undertaken at points of expected high atmospheric DPM such as during Longwall face moves, Development RAM car, Eimco and PJB usages. The paper discusses how the monitors have performed within the underground mine environment in evaluating DPM during the various phases of the 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. The outcome of the project gives the industry access to an enhanced tool for understanding the mine atmosphere in the presence of DPM. Real time DPM monitoring will allow the industry to pin-point high exposure zones such as those encountered in coal longwall face moves where various vehicles work or in areas of constrained or difficult ventilation. Identifying of high DPM concentration zones allows efficient modification of work practices to reduce underground miners’ exposure. Some outcomes of the ACARP project in this area will be discussed.

1 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 an area 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 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 inertization 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 optimize 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 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 international best practice. Australia is at the international forefront here. There is a much greater emphasis on training at all levels. Much of the industry is actually or effectively long distance commute (such as Fly in Fly Out). 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 new development discussed within this paper has been supported by ACARP with substantial input from the United States agency, the National Institute of Occupational Health and Safety (NIOSH). It has received considerable additional industry financial support; mine site testing and evaluation assistance.

2 Development of Personal Dust Monitor

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.

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 has varying respirable dust conditions due to aspects such as ventilation conditions and air velocity, shearer activity and design, shield movement, armored face conveyor movement, manning position, face time of individual personnel, outbye conditions and dust levels in intake air and measurement instrument behavior. A study has evaluated the instrument as an engineering tool that can assess the effectiveness of a single change to improve dust levels in a sufficiently short 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, 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. Figure 1 illustrates the unit.

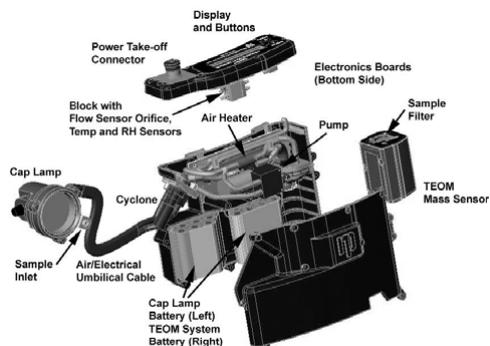


Figure 1. Major components of the PDM

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 authorize miners to adjust their activities to avoid respirable dust overexposure.

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.

3 Development of Real Time Personal Diesel Particulate Monitor

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.

- $DPM = TC + \text{inorganics} = EC + \text{organic carbon (OC)} + \text{inorganics}$
- 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 finalized will be able to be worn by a person.

Two types of sub-micrometer size-selective inlets were tested initially to effectively reduce the loading on the $0.8 \mu\text{m}$ cut point impactor collection plates to prevent overloading. The final size of mass to be measured is determined by the $0.8 \mu\text{m}$ cut point impactor with the cyclone inlets serving to collect the bulk of the mass greater than $1 \mu\text{m}$ in size, thus extending the loading capacity of the impactor plates. As a potential field instrument, the individual BGI 1- μm sharp-cut cyclone model SCC0.732 at a flow rate of 1.7 lpm in Figure 2 would be the size selective inlet of choice.

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.

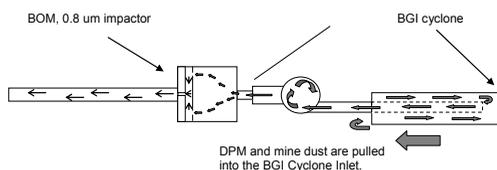


Figure 2. Schematic of prototype D-PDM Sampling Inlet.

4 Monitoring of Diesel Particulate Matter

A phase of Australian mine robustness and engineering

testing has been successfully undertaken in five 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.

4.1 Mine 1 Tests

The Mine 1 tests were undertaken in working sections with early tests qualitatively indicating that a 10 minute rolling averaging periods appears to allow a balance between ability to recognize individual diesel source vehicle movements and measurement accuracy. Some readings were taken with instruments mounted on a vehicle with no interference from vibrations.

4.2 Mine 2 Tests

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

The longwall ventilation arrangement for one set of tests is shown in Figure 3. 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 shield carriers traveled in the main gate (MG) and out the tail gate (TG). About $50 \text{ m}^3/\text{s}$ ventilation was measured in the MG and about $35 \text{ m}^3/\text{s}$ in the TG. There was a raise borehole upcasting some air.

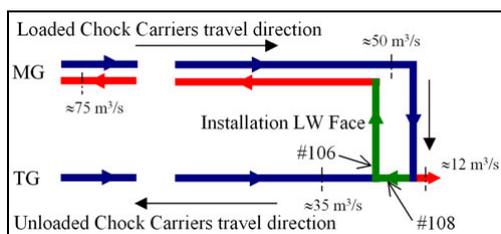


Figure 3. Longwall ventilation-shield carriers travel in on MG and out on TG.

Four shield carriers were available and a total of 10 shields were moved. Results from monitor #108 as shown in Figure 4 clearly demonstrated the ability of the D-PDM units to detect variations of DPM levels in the atmosphere as the Shield 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 shields 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 shield carriers were slower and having difficulty traveling through.

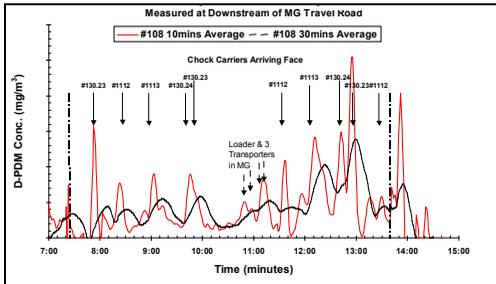


Figure 4. Observations on results at monitor 108 fixed location.

Figure 5 examined one three hour period with particular interest in the record of D-PDM readings as compared to heading air velocity shield carrier speed.

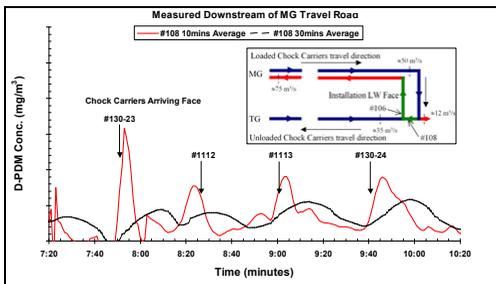


Figure 5. Observations on results over a three hour period at monitor 108 fixed location.

Close examination of results from #108 monitoring the DPM downstream of the MG and back road showed that when the shield 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 traveling 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 the peak concentration depend on the air velocity and shield carriers' travel speeds. In theory if the shield 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.

4.3 Mine 3 Tests

Mine 3 exercises monitored various ventilation arrangements of longwall face move during shield transport to the installation roadway. Figure 6 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 shield carriers traveled in and out through the TG. About 28 m³/s ventilation was measured in the MG and about 39 m³/s in the TG. There was a raise borehole downcasting about 11 m³/s. Three shield carriers were available and a total of four shields were moved.

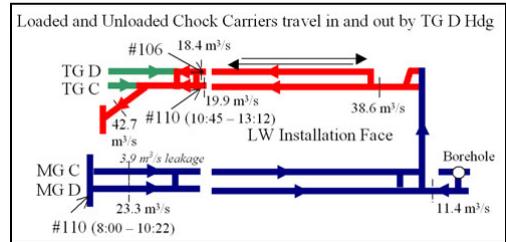


Figure 6. Longwall ventilation-shield carriers travel in and out on TG.

Figure 7 shows readings from fixed location monitoring of shield movements in the face area and nearby (D-PDM monitor #110) and from monitoring all air that had passed through the longwall panel (D-PDM monitor #106). The trace of monitor #110 illustrates clearly the arrival and departure of individual shield carriers at the Face TG end and subsequent movement shield repositioning by a diesel "shunting mule", Eimco 936 1123. The trace of monitor #106 illustrates the additional DPM in the return air picked up from the travel of shield 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.

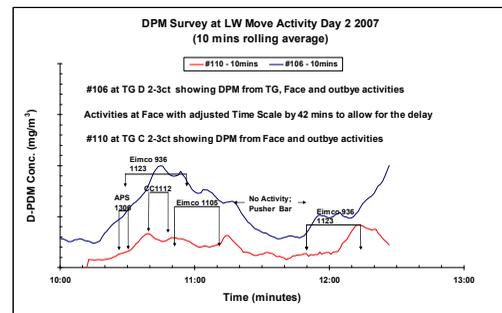


Figure 7. DPM make from LW face activity, #110 compared with DPM make from face and TG transport activities, #106.

Mine 3 results were analyzed 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 (m³/s) and the DPM

concentration ($\mu\text{g}/\text{m}^3$) 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 shield 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 shields by “shunting mules” or LHDs. The largest source was from shield carriers that carried individual shields along the length of the TG to reach the face.

Table 1. Sources of DPM identified in the installation LW panel.

Location	Sources $\mu\text{g}/\text{s}$	%	Comments
MG C & D Hdgs	3.03	18.6	Mains air at MG entrance
Borehole	0.00	0.0	back of LW panel, fresh air
LW Face	4.77	29.2	Shunting Mule or LHDs
TG D Hdg	6.96	42.6	Shield 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	

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 traveling against the ventilation the driver should always try to ensure the engine is trailing. Under these conditions driver exposure to DPM will be low if there are no other vehicle inbye. However, traveling 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 minimize exposure when traveling 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 traveling 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 shield delivery.

Points that can be established from this data are:

- In these specific tests shield 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 traveling with or against the carrier direction, the air velocity as a function of the air quantity and shield carriers’ travel

speeds.

- In theory if the shield 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 shield 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, e.g. 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.

4.4 Mine 4 Tests

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 Australian mining industry and are currently used in only a small number of mines. Tag boards are used 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 generally 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.

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 target limit. This approach optimizes the

access of diesel vehicles and replaces the existing manual tag board system. 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; vehicles have to wait and waste time until another vehicle leaves the section ventilation split.

A real time 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 target limit has been reached before allowing access of additional vehicles through the 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 m³/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 analyzed? Is it the driver and personnel on moving vehicles traveling 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 traveling 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 traveling 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. Normally 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 traveling airway can be determined as follows.

- A vehicles DPM pollution in the mine airway is measured in mg/m³ in a particular airway
- Ventilation quantity at that point is measured in m³/s
- DPM “make” is the product of the two i.e. mg/m³ x m³/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 (m³/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/m³) that is considered acceptable.

Tests were undertaken at Mine 4 to assist in Tag Board design. The exercise produced DPM make values from underground measurements supported by mine workshop/ industry published data as shown in Table 3.

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.

Table 3. DPM Make of test mine vehicles incorporating workshop and underground monitored values.

Vehicle	Engine kW	Make Av/Max* mg/s	U/G Test Series 1 mg/s	U/G Test Series 2 mg/s
Toyota	55	3.05/9.21	0.08, idle	0.78, idle 2.24 rev
SMV Drifty	63	2.97/5.94	1.34-2.14, idle 2.59 operating	-
Eimco, CAT 3306	Av 105	3.14/9.81	1.5, idle 2.07-3.27, operating 9.02, rev	1.8 - 6.6, operating

*Average and maximum make from SIMTARS workshop test industry database

Some conclusions indicated that the D-PDM real time monitors in mine static and moving positions gave good and consistent monitored results. Underground readings in general agree well with workshop tests. It was also found that convoy tests for two and three vehicles gave outputs that cumulatively agreed with Figures for single vehicles.

4.5 Mine 5 Tests

Mine 5 testing exercises monitored various activities of a longwall face move during shield transport in the longwall recovery face. Figure 8 examined one 2.5 hour period as a 37 tonne Dozer was brought in to pull shields in recovery from the LW face. The first shield for removal had D-PDM monitoring positions:

- #108 Outbye of the Dozer in LW Recovery face
- #106 Onboard Dozer
- #110 Inbye of Dozer in TG of LW Recovery face

There were about 51 m³/s of air was measured on LW recovery face. Between 14:45 and 15:32, the Dozer attempted to pull out the first shield but was unsuccessful. It worked hard much of the time at maximum revs. Between 15:32 and 16:00, a Shield Carrier Chariot was chained to the Dozer and together they successfully pulled the first Shield while working hard.

DPM exposure levels monitored by outbye monitors #106 and #108 were similar as expected. Dozer exhaust tailpipe outlet was inbye the machine. DPM levels were significant indicating the outbye face activities of removing LW pans and delivery of timbers for building of supports. DPM make by the Dozer alone unsuccessfully pulling the shield was high. This makes Figure compares well with independent measurements on Eimcos (the Dozer has the same engine as some Eimcos) revving hard over prolonged periods as shown in Table 3.

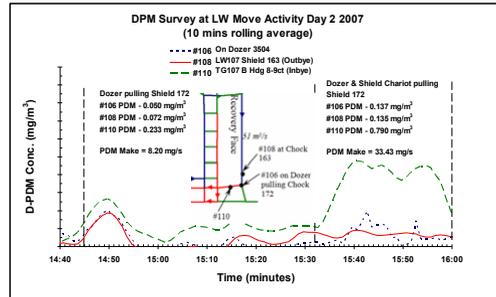


Figure 8. Submicron DPM in Longwall Recovery Face Pulling Shield.

DPM make inbye the Shield Carrier Chariot chained to the Dozer was four times that of the Dozer alone as they together successfully pulled the Shield. Both worked at maximum revs and so a high make is to be expected. This DPM make emphasizes that men should not be positioned inbye (downstream) of large machinery working very hard even for short periods.

5 Parallel SKC tests

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 analyzed 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 analyzed 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 9 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, and engine maintenance and engine behavior.

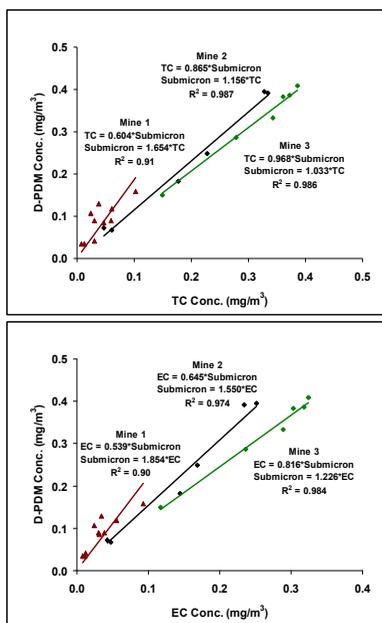


Figure 9. Mine individual relationships between TC or EC and Submicron DPM results.

Figure 10 shows combined 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. The combined mines calibration relationships are reasonably close.

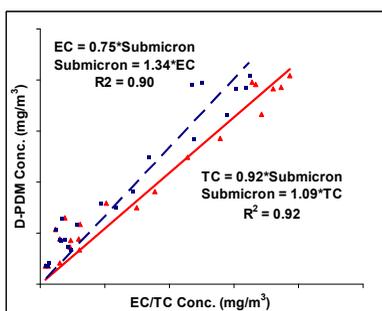


Figure 10. Combined mines relationship between EC or TC and Submicron DPM results.

6 Conclusions

A project on diesel particulate matter real time monitoring development supported by ACARP grants in recent years

has been discussed. The project received substantial NIOSH support and is an example of practical application that has received considerable additional industry financial support, mine site testing and evaluation assistance. The paper has discussed how the monitor has performed within the underground mine environment in evaluations during the various phases of a production cycle. It has closely examined the influence of aspects of the mine ventilation system. Results have been compared to alternative industry pollutant measuring approaches. The monitor is demonstrating the potential to improve understanding of the mine environment and to empower and educate operators in the control of their environment. The new monitor has application to coal and metalliferous surface mines in addition to the underground evaluations discussed.

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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*, Sept 2005.
- Gillies, A.D.S and Wu, H.W. 2006. Evaluation of a new real time personal dust monitor for engineering studies. *Proceedings of the 11th U.S./North American Mine Ventilation Symposium 2006*, pp 29-34 (Taylor and Francis Group plc.)
- 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 Rupperecht, E. 2004a. Implementing a new personal dust monitor as an engineering tool, *Proc 10th US Mine Vent Symp*, 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*, NIOSH, Pittsburgh.