WHAT CAN WE EXPECT TO FIND IN UNDERGROUND DPM AMBIENT MONITORING

Keynote Address

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ABSTRACT Diesel Particulate Matter issues are very high profile currently in underground mines world wide. Real time DPM monitors are becoming available which allow understanding of the sources of unhealthy levels of DPM pollution in underground activities. They allow engineering evaluations to determine how conditions can be improved or mining personnel removed from areas of high concentration. Studies are discussed that examine DPM concentrations from vehicles under varying ventilation conditions. The use of Tag boards to restrict or control vehicles from entry to particular areas is examined. The relationship between respirable dust and DPM loadings in mine intake airways is investigated.

The DPM monitoring approaches that have been available for some time based on shift average monitoring did not readily allow successful engineering evaluation exercises to determine acceptability of pollution levels. Real time monitoring readily allows engineering evaluation exercises to be undertaken. The outcomes of various studies have demonstrated that the mining industry has access to an enhanced tool for understanding the mine atmosphere in the presence of DPM. Real time DPM monitoring allows the industry to pin-point high exposure zones such as those encountered in coal longwall face moves where various vehicles work in areas of constrained or difficult ventilation. Identification of high DPM concentration zones allows efficient modification of mine ventilation, operator positioning and other work practices to reduce underground miners' exposures. Overview of this broad group of topics contributes to an understanding of the question "what can we expect to find in underground DPM ambient monitoring".

OVERVIEW

A project is described that has proved the concept of a new real time DPM monitoring instrument. It provides an alternative to the SKC shift average monitoring system, currently the only atmospheric DPM determinant in use in Australian coal or metalliferous mines. This Diesel Particulate Matter real time atmospheric monitoring (D-PDM) unit gives real time evaluations and so is very powerful in allowing understanding of DPM emission patterns in the fast changing mine production cycle and in undertaking engineering evaluation exercises. A number of mine test studies are discussed that examine DPM concentrations from vehicles under varying ventilation conditions.

This D-PDM monitor has allowed innovative investigations to be undertaken. One described is the use of Tag boards to restrict or control vehicles from entry to particular underground areas. Another is the relationship between respirable dust and DPM loadings in mine intake airways.

An underground series of tests has been undertaken to establish the robustness and reliability of the new approach to DPM measurement. Some laboratory workshop tests were also undertaken. The real time D-PDM monitor has been developed on the base of the successful PDM recently developed by Thermo Fisher Scientific in the US under contract from the National Institute of Occupational Health and Safety (NIOSH). The D-PDM development has been built on this success and supported by the Australian Coal Association Research Program (ACARP). Results of tests at seven underground coal mines are referred to. These underground studies have examined the influence of aspects of the mine ventilation systems. Results from some laboratory workshop tests are referred to.

Stages describing the finalization of the design of a Diesel Particulate Matter real time atmospheric monitoring unit and the undertaking of comprehensive and internationally recognized NIOSH laboratory testing to evaluate the new design have been described by Gillies and Wu (2008) and Wu and Gillies (2008).

A number of related issues are examined. Results have been successfully compared to alternative industry pollutant measuring approaches. Comparisons of mine and laboratory tests with the only other unit available in Australia for measuring mine atmosphere DPM, the NIOSH developed SKC impactor system, are made and discussed. A brief discussion and comparison between respirable dust and DPM monitored results at specific measuring points is made. Overview of this broad group of topics contributes to an understanding of the question “what can we expect to find in underground DPM ambient monitoring”.

MINE TESTS

The mine tests by their very nature were restricted to equipment available for testing underground during the mine visits. Five of the mine visits (Mines A to E) focused on Longwall equipment moves from one panel to another, one (mine F) focused on monitoring diesel powered Ram or Shuttle cars and Mine G attempted to contribute to establishment of a rational approach to design of diesel Tag boards. The D-PDM monitors successfully evaluated DPM changes during the different tests and between different steps within the individual tests. Further details on these tests are described in Gillies and Wu (2008).

Mine A

Mine A testing 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 and see whether these matched the arrival of the vehicle exhaust plume. Interpretations could be made as to whether the machine traveled down gate roads either with a speed faster than the air velocity (and so with high exhaust concentration plume trailing) or with a speed slower that the air velocity (and so with high exhaust concentrations plume in advance).

Mine B

Mine B again monitored various ventilation arrangements of longwall face move during shield transport to the installation roadway. DPM levels along the shield transport route were high. An audit was completed on sources of DPM within the Longwall installation panel. Extensive tests were undertaken on vehicle speed and air velocity. It was found that it is difficult to minimize exposure when traveling with the airflow as no matter at 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 a plume envelope of increasing concentration of diesel exhaust emissions and consequently exposure could be very high. Some detailed conclusions were reached on how the mine's Longwall change transport approach could have been modified to reduce exposure. Some positive comparisons between static DPM monitoring and monitoring on moving vehicles were made.

Mine C

Mine C D-PDM monitoring tests were largely undertaken to evaluate various points of suspected high DPM during a Longwall move. A comparison of DPM exposure of mine crew members from exhaust from three categories of mine vehicles was undertaken. DPM make is very dependent on machine operating level and consequently varies over a considerable range. Exposure is very dependent on ventilation conditions. Taking these differences into account there was some reasonable agreement between Workshop and underground monitored sources of data. It was concluded that a review of Longwall move DPM exposure of mine crew 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 recovery and installation panels? Or is it the crew working within the panels 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? A general observation on Longwall moves was that some high submicron DPM readings were recorded due to the large numbers of diesel activities in working sections of the mine. This was contributed to by frequent vehicle movements or traffic jams. Miners should not be placed working inbye heavy vehicles working very hard such as the dozer when pulling shields. For the Longwall Move routes it is best if vehicle travels against airflow direction.

Mine D

Mine D D-PDM monitoring tests were largely undertaken to evaluate suspected high DPM during a Longwall Move within a "Punch mine" or highwall mine with no underground Mains headings. With no entries outbye the panel air entered in a clean state and ventilation air quantity were high. It was found over a number of tests that 62 percent of DPM within the panel was generated by Carriers hauling Shields in the gateroads and 38 percent generated by vehicle movement along the Longwall face. Air passing along the segregated belt gateroad arrived at the face clean and could have been used to better effect on the face where operators were installing newly arrived Shields. General recommendations from the evaluation were that every mine when planning a Longwall move should evaluate and review all alternatives for ventilating Shield travel roads to the longwall face. Alternatives noted here were that consideration should be given to

- Use of Panel antitropal belt air on the installation face,
- The bringing intake air up the Tail Gateroad to the installation face,
- The dumping of contaminated Shield travel route air to a homotropal belt return Heading.

Mine E

Mine E D-PRM tests were undertaken over a short haulage route between two adjacent longwall panels. DPM monitoring during this Longwall Move could focus on both the recovery and installation crews' exposures. Crew on the recovery face were in a well ventilated situation with clean gateroad belt heading air significantly diluting any DPM pollution from the gateroad travel heading. An electric tracked "mule" moved Shields along the face and did not add DPM pollution. However the installation face crew were exposed to unnecessarily high DPM levels. Shields were delivered to the face in the single available intake gateroad. A diesel dozer moved Shields along the installation face and placed them in their final positions. General recommendations from the evaluation were that when planning the Longwall move it would have been advantageous to evaluate and review all alternatives for ventilating Shield travel roads to or from the longwall recovery and installation faces. Consideration in future should be given to

- Not having ventilation in series for both the Recovery face and Installation face,
- Establishment of a new ventilation circuit for the installation face before commencement of the move,
- Reventilating the installation panel with intake air in the Headgate road so that the installation crew is in fresh air,
- Keeping the recovery crew in a separate intake circuit.
- Avoidance of re-handling the shields in Travel Roads as this practice increased the DPM loading in the ventilation circuit.
- Avoidance of use of diesel dozers or mules on faces in which activity was taking place.

Mine F

Mine F results were tempered by the fact that this was the first time in the world that real time DPM readings in a mine were undertaken. Significant time was given to developing appropriate test procedures. The mine was well ventilated as were the development panel testes and so DPM concentrations were low. In spite of this detailed analysis of the responses of three D-PDM units at different sampling stations to the diesel Ram car activities was carried out. Analyses showed that the units all responded showing some peak readings when the diesel Ram car was passing the monitoring stations. Investigation of appropriate averaging periods was undertaken and it was concluded that 10 minute averaging periods appeared to allow a balance between ability to recognize individual diesel source vehicle movements and measurement accuracy.

Mine G

Mine G evaluated whether the use of the D-PDM could contribute to the design of a Tag board. There is resurgence in use of Tag boards in the Australian mining industry. Tag boards are used to limit access of diesel vehicles entering a particular ventilation split or mining sections to manage exhaust DPM and gases. Existing Tag board systems are based on historic workshop tailpipe readings and mine plan projections of air quantity availability. This exercise was designed to examine the effect of addition of monitored DPM pollutant results to the deliberation approach. Some conclusions for Tag board design for DPM requirement indicated that future tests should undertake more extensive trials with single and vehicles convoys and undertake more tests at extremes of operation such as with 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. 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 and the tests contributed to understanding of this design issue.

SKC MINE COMPARISON TESTS

Mine SKC Test Results

It is appropriate to compare field results from the real time DPM monitor with another available measuring instrument. The only other unit available in Australia for measuring 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 laboratory NIOSH 5040 method.

During investigations parallel underground SKC samples have been taken for comparison with the mine real time DPM monitor results at all mines where studies have been undertaken. Under the SKC system the sample is drawn first through a respirable cyclone sampler for organic carbon (OC) associated with the absorbed organic substances and elemental carbon (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.

For comparison purposes of a related set of results, namely those from Longwall moves highlighted in Section 2, figures 1 and 2 show results from Mines A to E 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 ($R^2 \geq 0.98$) for TC versus D-PDM. All EC versus D-PDM correlations were good ($R^2 \geq 0.90$) except for one set of mine results. The results demonstrate that calibration relationships (the slopes of the individual mine relationships) vary between mines. This differences in suspected to be due to variations from mine to mine in aspects such as mine atmospheric contamination, vehicle fleet variations, fuel type, engine maintenance, engine combustion efficiency and engine behavior.

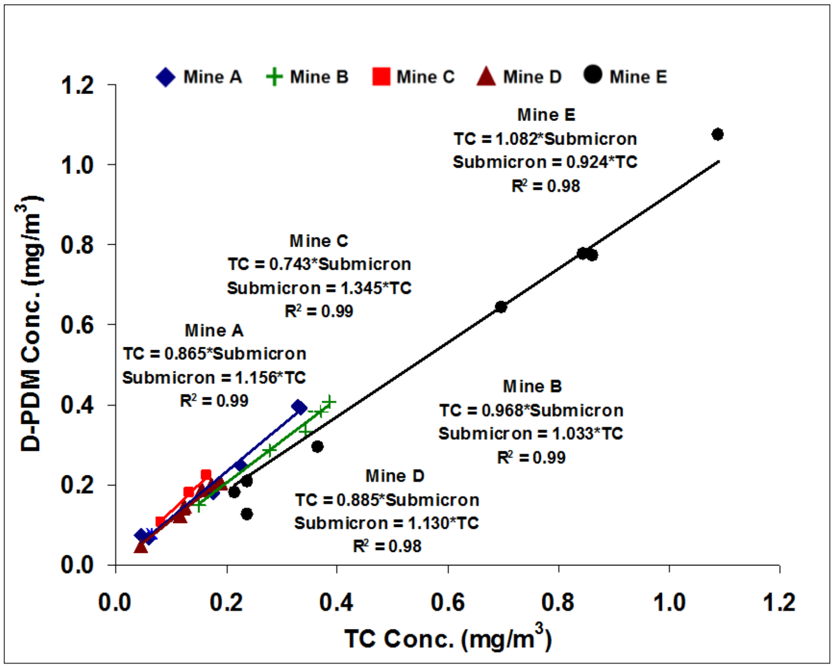

Figure 1 Mine individual relationships between TC and Submicron DPM

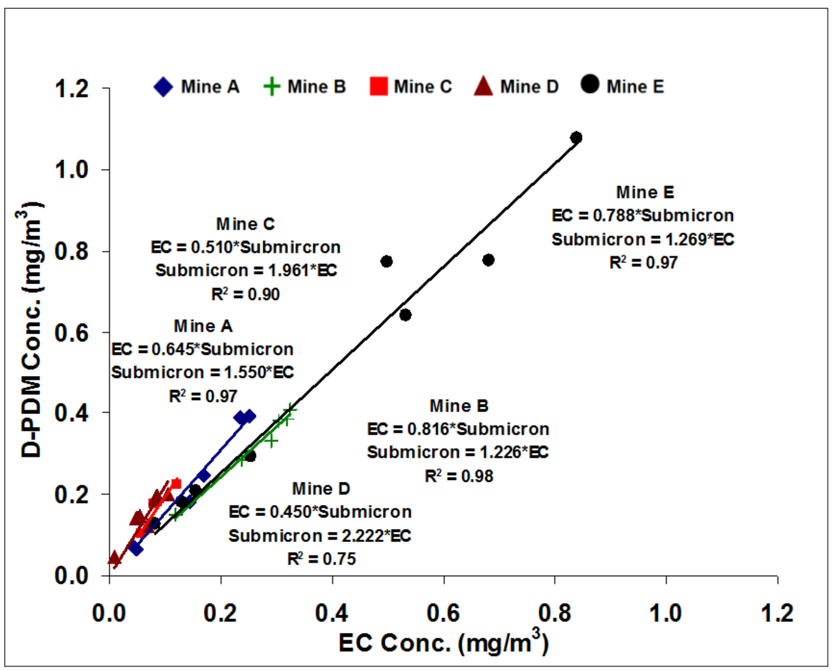

Figure 2 Mine individual relationships between EC and Submicron DPM

Figure 3 shows combined results from the all 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 close with R^2 = 0.95 for TC compared with submicron D-PDM and R^2 = 0.96 for EC compared with submicron D-PDM.

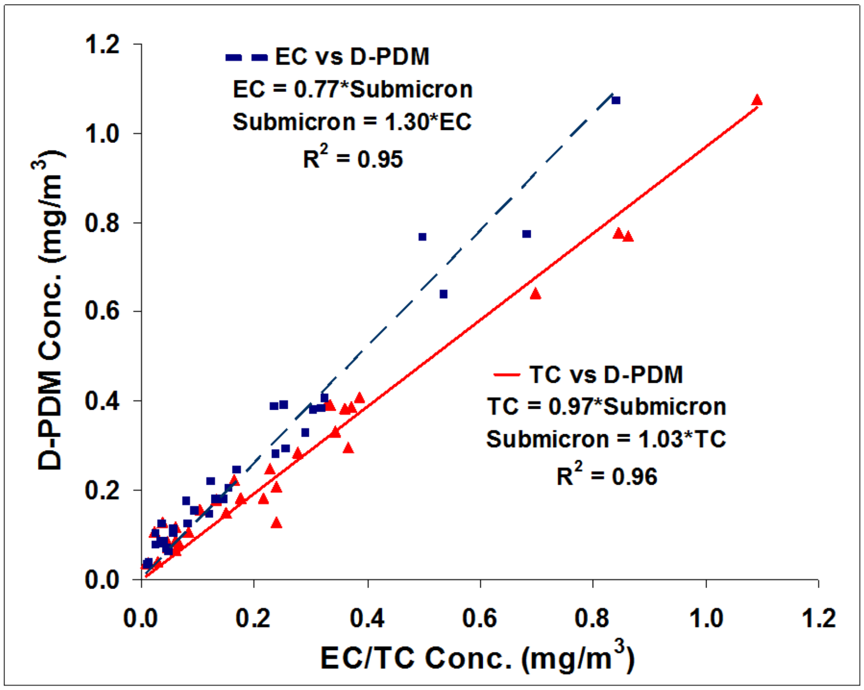

Figure 3 Combined relationships for five mines between EC or TC and Submicron DPM.

There is some international debate on the DPM monitoring issue of whether submicron DP, TC or EC should be evaluated. The D-PDM is the only real time instrument available to measures submicron DP. Various international studies show that in the normal mine atmosphere (with moderate loadings of respirable dust below statutory limits) the differences and the potential levels of error between the three approaches in monitoring DPM are relatively minor (Birch and Cary, 1996, Birch and Noll, 2004 and Dabill, 2005).

Comparison between D-PDM and SKC Monitoring

A comparison between D-PDM and SKC monitoring systems has been drawn and indicates the following. The D-PDM monitoring system has the following comparative advantages and disadvantages.

- D-PDM gives real time results that can be used to assess whether an atmosphere is safe for work immediately.
- D-PDM gives immediately available results that can be used to improve the mine system and work practices.
- Mine atmosphere results can be compared directly with Workshop engine monitored results.
- D-PDM can be used for both real time analysis of situation and shift duration comparison.
- Total Costs (capital cost and operating costs) for D-PDM analysis are likely to be less over a period than for SKC analyses as no laboratory analyses needed.
- D-PDM based on all submicron particulate (TC plus other mineral matter).
- D-PDM results at low levels may be influenced by coal dust interference but this error is less than 5 percent according to Dabill, 2005.

- D-PDM results may also be influenced by some other particulates such as smoking and welding fumes (not an issue in coal mines).

On the other hand the SKC monitoring system has the following advantages and disadvantages.

- SKC gives shift duration results that can only be used for some regulatory purposes.
- SKC gives shift duration results that can only be used retrospectively to assess whether an atmosphere some days or weeks before was safe to work in.
- SKC results cannot be used effectively for engineering evaluation and improvement exercises in the complex mine atmosphere and working place.
- SKC gives a surrogate estimation of atmosphere submicron particulates DP based only on TC and EC and does not include the presence of other mineral matter found in DPM.
- Relationship between TC/EC and DP varies mine to mine. This is at least partly due to the fact that the presence of other relatively varying masses of mineral matter found in DPM have not been accounted for.
- SKC results may be influenced by some other particulates such as smoking and welding fumes (not an issue in coal mines).

The SKC approach has been in use since the mid 1990's while the D-PDM approach is a more recent development.

LABORATORY TESTS ON ENGINES

A series of engine tests were undertaken in a Brisbane surface laboratory workshop. Ventilation ducting was designed and assembled to dilute the raw diesel exhaust for tested engines as the D-PDM units are not designed to work in raw diesel exhaust samples. A variable speed fan attached to the ducting was used with a honeycomb structure mixing arrangement to ensure the raw diesel exhaust was fully mixed. The D-PDM monitors were used in evaluations of engine systems and in parallel testing made with the SKC monitoring system. Subsequently some engine control system changes were made and evaluated.

Figure 4 gives one example of monitored results from diluted engine exhaust taken at the end of the ducting with the engine tested under varying dynamometer loads. These tests were undertaken over intervals of 20 minutes with monitor results reporting on a 10 minute rolling average basis. The load or engine speed was set at the beginning of the 20 minute period. The engine was given 10 minutes for adjustment to new conditions and the average DPM emission calculated over the subsequent 10 minutes.

The results demonstrate that under heavy loads DPM exhaust levels can be extremely high. The conclusion to the tests was that workshop data corroborate the D-PDM results obtained from underground mine testing and in particular the results obtained when machines were placed under very high working loads for even short periods.

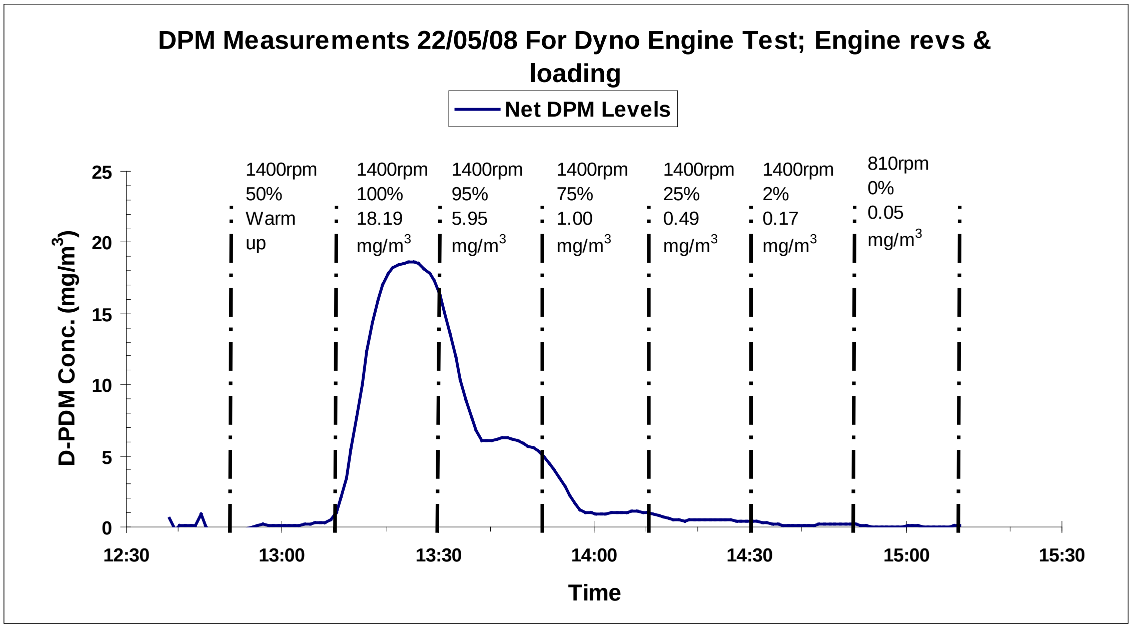

Figure 4 Monitored results from diluted exhaust with the engine tested under varying dynamometer loads (load shown as percentage of maximum).

MINE DIESEL EXHAUST TAG BOARD DESIGN

DPM tests were undertaken in Mine F to evaluate whether the use of the D-PDM could contribute to the design of a Tag board. Tag boards usage is relatively new to the Australian mining industry and they are currently used in only a small number of mines. Tag boards are used to assist in management of exhaust DPM and toxic 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. Little or no cognizance is taken of outbye pollutant levels.

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 should 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 toxic 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 or NO_x 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 m^3/s/kW engine output. Some are designed from Original Equipment Manufacturers (OEMs)' published ventilation requirements for exhaust gas outputs for particular engines. Recently some mines have started to take account of engine exhaust DPM from smoke interference meter tests in Workshops. 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 engine load variability with uphill or downhill travel, 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/m^3 in a particular airway
- Ventilation quantity at that point is measured in m^3/s
- DPM "make" is the product of the two i.e. $mg/m^3 \times m^3/s = mg/s$

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

COMPARISON OF WORKSHOP RAW EXHAUST AND UNDERGROUND ATMOSPHERIC MONITORED RESULTS

Tests were undertaken in a number of mines 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 1.

Table 1 DPM make of test mine vehicles incorporating workshop and underground monitored values.

Vehicle	Engine kW	Workshop Average Concentration, mg/m^3 Exhaust Av/Max*	Underground Monitoring Mine 4 mg/m^3	Underground Monitoring Mine 5 mg/m^3
Toyota	55	3.1/9.2	0.08, idle	0.8, idle 2.2, revving
SMV Driftrunner	63	3.0/5.9	2.1 - 3.4, idle 2.6 operating	-
Eimco, CAT 3306	Av 105	3.1/9.8	1.5, idle 2.1 - 3.3, operating 9.0, revving	1.8 - 6.6, operating

**Av/Max Make from SIMTARS workshop exhaust database using 1.0 minute standard test*

Monitored values indicated

- One Toyota underground reading was very low compared with the other and workshop values. Further investigation of this situation is needed.
- Single Drifty outputs 2.0 to 4.0 mg/s in normal use. Good underground and workshop test agreement.
- Single Eimco also outputs 2.0 to 4.0 mg/s in normal use; more under heavy load. Good underground and workshop test agreement.

Conclusions from underground tests indicated that the D-PDM real time monitors in mine static and moving positions give 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.

PARALLEL REAL TIME RESPIRABLE DUST AND DPM SURVEYS ON VARIOUS MINE SECTIONS AND ACTIVITIES

A number of studies have been undertaken in which PDM units and D-PDM monitors have been used to record mine atmosphere particulate matter over an extended period of a shift. Figure 5 shows monitored results with one PDM (#134) and one D-PDM (#106) side by side at a point in underground intake air in which diesel engine vehicles are operating. The trend lines move together over time and show that the diesel particulate mater level is generally 50 to 70 percent of the respirable dust level through out the shift.

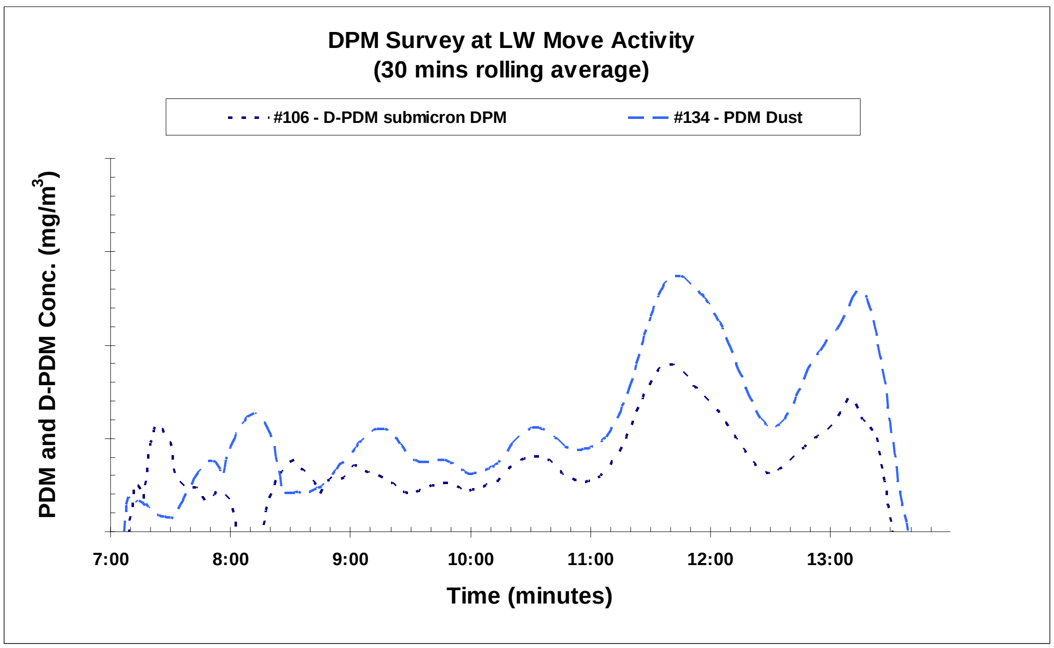

Figure 5 Monitored results with one PDM (#134) and one D-PDM (#106) side by side at a point in underground intake air in which diesel engine vehicles are operating

There was no actual coal production involved in any of the activities monitored. All PDM respirable dust readings taken (ranging from 0.18 - 0.76 mg/m^3) were well below the regulatory limits for respirable dust.

Figure 6 shows monitored results undertaken at another mine with two PDMs and two D-PDMs in use simultaneously. PDM (#139) and D-PDM (#106) were side by side (lower trend lines) and were at a surface portal while PDM (#134) and D-PDM (#108) were side by side (upper trend lines) in intake air just outbye a longwall face during installation of shields. Conclusions that can be drawn are:

- Portal air records little DPM or respirable dust. Minor variations were due to vehicles waiting in a line and dust from equipment movement.
- The trend lines for the monitoring position just outbye the face move together over time and show that the diesel particulate mater level is generally 50 to 70 percent of the respirable dust level through out the shift.
- There was no actual coal production involved in any of the activities monitored. All PDM respirable dust readings taken were well below the regulatory limits for respirable dust.
- Significant DPM and respirable dust are added to the intake air as the ventilation moves towards the panel face. At times these are above what may be considered as "target levels".

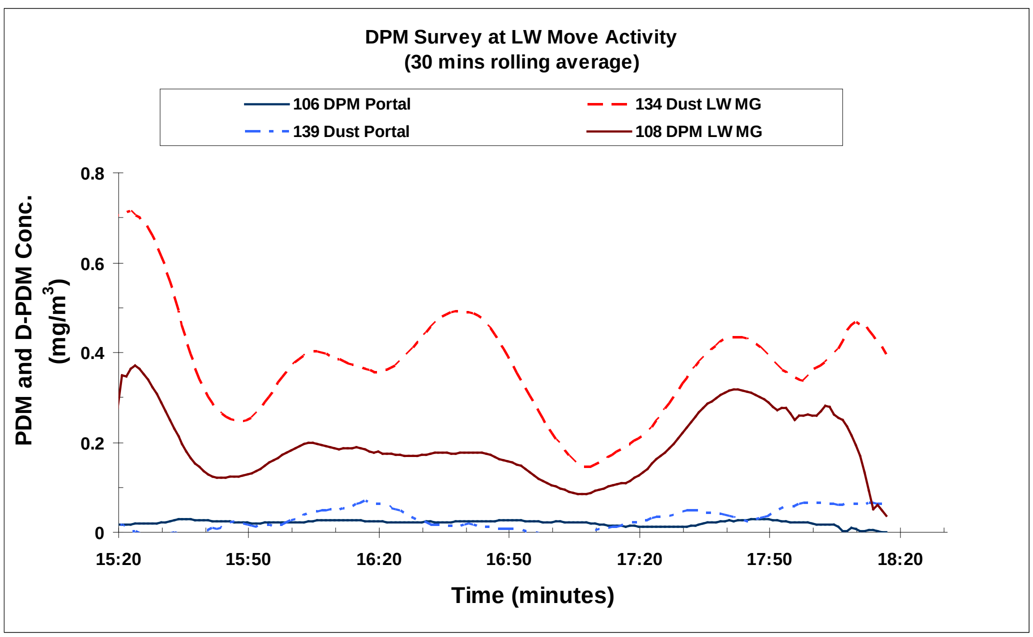

Figure 6 Monitored results with PDM (#139) and D-PDM (#106) side by side (lower trend lines) and PDM (#134) and D-PDM (#108) side by side (upper trend lines).

THE FUTURE

An aim of this project was to highlight some areas for new approaches and research to allow improvement of DPM conditions within the Australia coal industry. Industry, management, technical engineering staff and the workforce all give strong recognition to the challenge of DPM as an increasing hazard with higher production and the use of more diesel equipment underground.

Some design issues to make the unit more robust and with a permanent inlet classification system are under consideration.

A recommendation is to investigate the benefits of an automated Tracker and real time DPM and air quantity monitoring system to replace conventional Tag boards used in development and longwall panels. Currently some mines use physical Tag boards to limit access of diesel vehicles to longwall and development sections to manage exhaust DPM and gases. 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 ventilation circuit. An approach proposed in a recent ACARP grant application for a tracker project will combine use of automatic vehicle tracking system with real time monitoring of DPM and section air quantity. It will take real time data streams from DPM and air quantity and quality monitoring and integrate with tracker information. A new vehicle to a section will be stopped from entering until the acceptability of the current atmosphere is examined as to whether an additional vehicle can enter without exceeding the design DPM limit. This will optimize the access of diesel vehicles and replace the existing Tag board system based on historic workshop tailpipe readings. The proposed system will allow productivity improvement by permitting the maximum number of vehicles to be in use in a ventilation circuit based on real exhaust output. The project would best be undertaken in a number of stages. An early stage would use both off-line and on-line instrumentation to monitor and establish the viability of the system. Once the approach's viability has been proved a later stage would be undertaken to put all monitoring on an on-line basis. The DPM Tracking system could be built on top of general tracker systems recently introduced in a number of Australian collieries.

With its real time atmospheric DPM monitoring ability, the D-PDM monitor has demonstrated that it can be use as an engineering tool to pin-point high DPM exposure zones within mines such as those encountered in longwall face moves, heavy movement operations or development faces using diesel Ram cars. Isolation of high DPM concentration zones will allow efficient modification of work practices to keep underground miners exposure within shift length exposure regulations.

It also possible to use the D-PDM monitor as a tool to evaluate the effectiveness of various currently available or under-development diesel exhaust management and control systems within the underground mine environment during their normal operations and usages. These systems could profitably include

- Diesel engines and fuel injection systems such as Tier II and Tier III,
- Improved diesel engine management systems,
- Use of disposable diesel exhaust filters,
- Improved diesel exhaust scrubbers,
- Use of various diesel fuels including bio-diesel fuels

It is also possible to utilize the D-PDM monitor in a comprehensive series of mine tests to optimize the design of diesel exhaust management and control systems.

It is recommended that further simultaneous tests to establish relationships between airborne coal dust and DPM across particulate mass loadings typically found in mine airways are undertaken.

Considerable technology transfers from the outcomes of the project have occurred during its tenure and in following publications. The project has allowed sections the industry (as part of the mine testing program or through exercises in technology transfer) to evaluate the new realtime D-PDM instrument over a comprehensive series of underground tests. The behavior of DPM in the mine atmosphere is complex. Mine employees with a need to understand DPM issues include mechanical engineers, maintenance employees, mining engineers, ventilation officers and other managerial and technical employees. It is recommended that the mining industry makes increased efforts with DPM related education and support new innovations, approaches and work practices. The D-PDM monitoring approach has application to coal and metalliferous surface mining operations in addition to the underground evaluations discussed.

CONCLUSIONS

The underground mine evaluation in seven operating mines and a laboratory workshop have proved that the monitor is capable in normal mine atmospheres of accurately measuring DPM levels in real time. The D-PDM results have been supported closely by parallel DPM SKC system evaluations. The monitor has successfully reported data when used in situations of a static or stationary instrument, when placed within the cab of a moving vehicle and when worn on a person's belt.

The monitor has the potential to improve understanding of the mine environment and to empower and educate operators in the control of their environment. The monitoring approach has application to coal and metalliferous surface mining operations in addition to the underground evaluations discussed.

It provides an alternative to the SKC shift average monitoring system, currently the only atmospheric DPM determinant in use in Australian coal or metalliferous mines. The D-PDM unit gives real time evaluations and so is very powerful in allowing understanding of DPM emission patterns in the fast changing mine production cycle and in undertaking engineering evaluation exercises.

There is some international debate on the DPM monitoring issue of whether submicron DP, TC or EC should be evaluated. The D-PDM is the only real time instrument available to measures submicron DP. Various international studies show that in the normal mine atmosphere (with moderate loadings of respirable dust below statutory limits) the differences and the potential levels of error between the three approaches in monitoring DPM are relatively minor (Birch and Cary, 1996, Birch and Noll, 2004 and Dabill, 2005). It is for these reasons that the future use of the D-PDM in the mining industry should be given serious consideration.

The outcome of the project is that the objective testing over a number of different approaches and the comparisons with the SKC monitoring approach lead to the conclusion that the D-PDM is accurate when compared to existing measurements from the SKC method.

The principal industrial application of the D-PDM will be to give a greater understanding of DPM levels in mine environments in regulatory, statutory and engineering evaluation exercises. The underground tests have given examples of many applications of the D-PDM for future industry use.

Some design issues to make the unit more robust and with a permanent inlet classification system are under examination. New industry applications of the D-PDM that may be successfully implemented in the future warrant attention.

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