SOME APPROACHES AND METHODS FOR REAL-TIME DPM AMBIENT MONITORING IN UNDERGROUND MINES

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Abstract

Diesel engine particulate matter pollution is a matter of concern currently in underground mines worldwide. A number of real-time Diesel Particulate Matter (DPM) monitors have been developed in recent years; two of these by the National Institute of Occupational Health and Safety (NIOSH) in the US. One, the D-PDM, is based on an adaption of the successful NIOSH's Personal Dust Monitor (PDM) unit which is being taken up very successfully for mine respirable dust monitoring. The D-PDM measures all particulate matter within a sub-micron range as classified nominally at 0.8 micrometers by a purpose developed cyclone. The other, the FLIR Airtec, measures the Elemental Carbon (EC) component of DPM by a laser scattering approach. Both instruments have been evaluated underground in robustness and reliability testing in coal mines by the authors.

Real time DPM monitors allow greater understanding of the sources and levels of DPM pollution in underground activities. They allow engineering evaluations to determine how conditions can be improved or mining personnel relocated to lower concentration levels. Studies are discussed that examine DPM concentrations from vehicles under varying ventilation conditions. Some of these concern tests undertaken during high activity longwall face moves. They focus on evaluating DPM during the various phases of the face Chock Shield moves.

An initiative in some mines has been to limit the number of vehicles in the mining section or panel by the use of a Tag Board or Traffic Controller at the panel travel road entrance to manage exhaust DPM and gases. Diesel tags or tokens are used to control the number of vehicles entering a section or panel and so limit level of pollution. Summation of DPM levels from points monitored throughout a panel demonstrates increasing DPM levels from influence of additional equipment in series within the ventilation circuit. 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 optimizes the access of diesel vehicles and replaces the existing manual tag board system. Real-time DPM monitoring allows the industry to pin-point high exposure zones such as those encountered where various vehicles work in areas of constrained or difficult ventilation. Identification of high DPM zones allows efficient modification of mine ventilation, operator positioning and other work practices to reduce underground miners' exposures.

Keywords: Longwall, Real-time DPM, Total Carbon, Elemental Carbon, Coal mine ventilation.

Introduction

Mine atmosphere measurement of DPM in many mines around the world is of increasing importance. One real-time DPM monitor has been developed on the base of the successful PDM unit. The heart of the PDM is a miniaturized direct mass measuring sensor that measures mine dust. The PDM was originally commerialized by Rupprecht and Patashnick Co., Inc. (now Thermo Fischer Scientific) under contract from the Center for Disease Control and Prevention, National Institute for Occupational Safety and Health (NIOSH) and is now in use in many underground mines across the US.

In collaboration with an Australian Coal Association Research Program (ACARP) funded project (Gillies and Wu, 2008), Thermo Fisher Scientific and NIOSH undertook changes to the PDM to convert it to a DPM particulate submicrometer real-time monitoring underground instrument which was named the D-PDM. NIOSH undertook calibration or verification laboratory evaluations of the new unit's performance. Their Laboratory also designed a cyclone that cuts at 0.8 micron particulate size appropriate for a DPM monitor. The real-time DPM unit continually reports levels of mine atmosphere submicrometer aerosol. The D-PDM results have been correlated with parallel SKC system DPM evaluations (Birch and Cary, 1996). A phase of robustness and engineering testing has been undertaken to ensure the instrument can effectively assist mine management. Figure 1 illustrates the major components of the PDM and D-PDM.

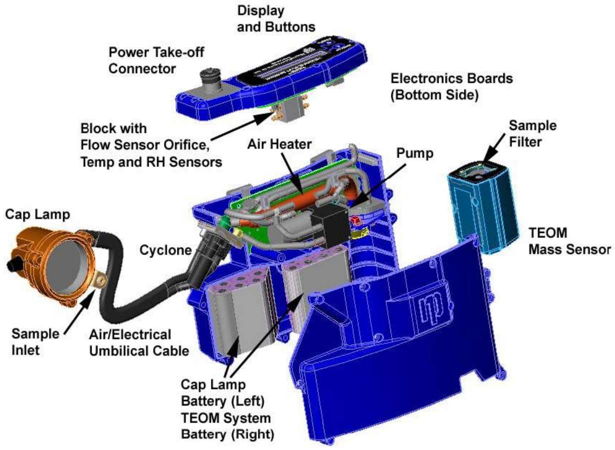


Figure 1. Major components of the PDM and D-PDM.

The real-time D-PDM monitor has in the five years period since the ACARP project been used in many mines and empowered and educated operators in the control of their environment. The monitoring approach has application to all forms of diesel powered mining. With its real-time atmospheric monitoring ability, the D-PDM monitor has demonstrated that it can be use as an engineering tool to pin-point high DPM exposure zones such as those encountered in LW face moves or on development faces using diesel haulage cars. Isolation of high DPM concentration zones allows efficient modification of work practices to keep underground miners exposure within shift length exposure regulations.

The other instrument, the FLIR Airtec, only became commercially available in 2011 (Janisko and Noll, 2008; Noll and Janisko, 2007) . It measures the Elemental Carbon (EC) component of DPM by a laser scattering approach. Results from the Airtec can be compared directly with SKC system DPM evaluations. Both new instruments have been evaluated underground in robustness and reliability testing in coal and metal/non-metal mines.

Ventilation Considerations in Handling DPM

LW moves rely on use of high powered equipment of Shield-Chock movers (chariots) and other powerful machines that produces high levels of exhaust pollutants of gases and DPM. Many mines find it a challenge to meet DPM “Target Limits” during all phases of operational moves. Approaches adopted in the mines of Australia and other similar countries as a first step rely on both ensuring there is enough air and optimization of the ventilation system design. Issues that should be considered in optimizing the design include:

- Maximize air quantity where LW face equipment recovery, movement or installation occurs.
- Have all moving equipment (at least loaded machinery) travel in opposite direction to air flow.
- Ensure that air velocity is higher than machine speed to ensure a plume of exhaust does not hang over travelling equipment in situations where machinery cannot be moved against airflow.
- Have parallel transport roads so that movement occurs in a circuit of loaded machines travelling inbye on one road and outbye on a parallel one.
- Ensure that miners are working upstream of machinery and particularly machinery that is working on faces loading or unloading and positioning.
- Divide available air so that the majority is passing along the headings used by loaded machinery.
- Monitor DPM with real-time instruments so that points where “Target” limits are not being met are identified and improvements are made during the current LW move or planned for the next move.

Development of Real-Time Personal Diesel Particulate Monitor

Mine atmosphere measurements of DPM in Australian mines have been measured systematically since the early 2000s. Most initial 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 generally 80% of DPM (Volkwein 2006).

Some DPM regulatory guidelines are starting to emerge in Australia and the individual states are generally moving to acknowledge DPM metalliferous mine limits in use in the US of 0.2 mg/m^3 full submicrometer particulate matter, 0.16 mg/m^3 TC particulate and 0.123 mg/m^3 EC particulate.

Section A. Monitoring of Diesel Particulate Matter

Mine 1

Results from real-time DPM monitoring are illustrated with examples from three coal mines.

Mine 1 examined one 2.5 hour period as a 37 tonne Dozer was brought in to pull the first Chock Shield on recovering a LW face as shown in Figure 2. About 50 m^3/s of air was measured on the LW recovery face. Between 14:45 and 15:32, the Dozer attempted to pull out the first Chock Shield but was unsuccessful. It worked hard much of the time at maximum engine power. Between 15:32 and 16:00 a Chock Shield Carrier Chariot was chained to the Dozer and together they successfully pulled the first Chock Shield while working hard. A general observation on LW moves was that some high aerosol 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 LW move routes it is best if vehicle travels against airflow direction.

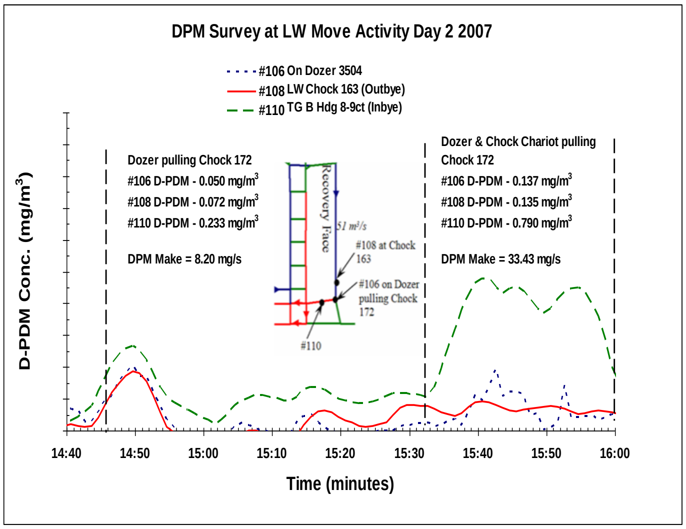
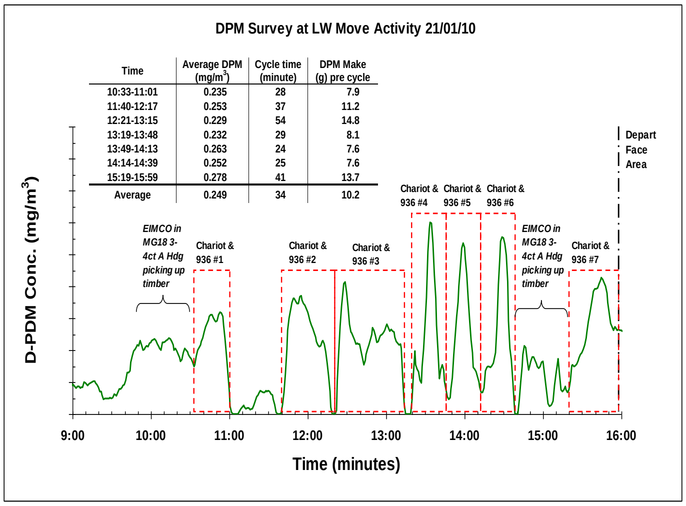


Figure 2. Submicrometer DPM in LW Recovery Face Pulling Shield.

Mine 2

Mine 2 monitored a highwall mine with no underground Mains headings. Ventilation quantity was high and air entered the panel in a clean state.



Time	Average DPM (mg/m3)	Cycle time (minute)	DPM Make (g) pre cycle
10:33-11:01	0.235	28	7.9
11:40-12:17	0.253	37	11.2
12:21-13:15	0.229	54	14.8
13:19-13:48	0.232	29	8.1
13:49-14:13	0.263	24	7.6
14:14-14:39	0.252	25	7.6
15:19-15:59	0.278	41	13.7
Average	0.249	34	10.2

Figure 3. Submicrometer DPM of a Chariot transporting Shield to Installation face.

The main diesel activities was at the LW installation face. A total of seven Chock Shields were installed during the survey period as shown in Figure 3. For the seven peaks or higher levels of DPM, cycle time and DPM make were identified. The DPM makes varied from 7.6 to 14.8 g/cycle with individual cycles time ranging from 25 to 54 minutes. This compared well with other mines' data. For example LW moves in one neighbouring mine showed DPM makes ranging from 3.0 to 22.4 g/cycle and cycle times from 16 to 29 minutes for operations of Chock Shield Chariots (arrived, unloaded shields and departed) and EMICO 936 (into face, repositioned Shields and out of face). The short cycle times in the other mine were due to the Chariots only needing to travel half the length of the LW panel.

Mine C

During LW Move real-time DPM surveys at Mine C, one of the D-PDM units was placed on board a Chock Shield chariot to identify the DPM exposure levels of operators. Significant DPM levels were recorded especially when the chariot was travelling in the new LW panel Tailgate (TG) B Heading with chock loaded. The high DPM level exposure of the chariot operator in B Heading is contributed by the following causes:

- Chariot was working under load thus more exhaust generated.
- Chariot was travelling in the same direction as the ventilation air flow thus reducing the effective air velocity over the engine exhaust.
- Chariot was blocking much of the cross-sectional area of the B Heading thus increasing airway resistance and forcing more air flow through A Heading and as a consequence leaving less air available to dilute the exhaust from the Chariot.

A simplified digitized computer ventilation simulation (Ventsim) model was created to demonstrate the last point with chariot travelling in Tailgate B Heading. Figure 4 shows the effect of the Chariot in B Heading on the ventilation air split between A and B Headings.

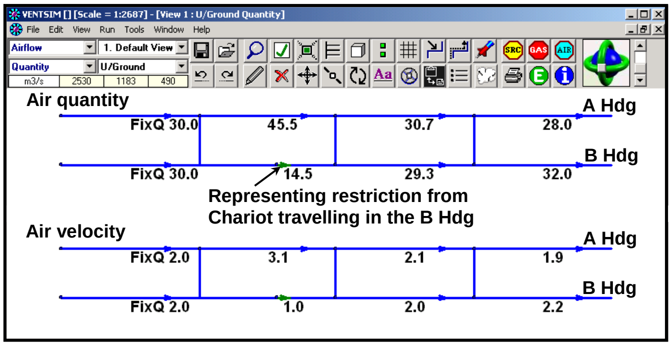


Figure 4. Simplified Ventsim model showing the effects of Chariot travel on air split.

A total of 60 m^3/s was available in the TG between A and B Headings and it was assumed that air split evenly between A and B Headings initially near Mains. A restriction of 67percent of the cross-sectional area in the B Heading by the Chariot loaded with a Shield was assumed. This restriction has reduced the airflow in B Heading from 30 m^3/s down to 14.5 m^3/s and air velocity decreased from 2.0 m/s to 1.0 m/s. It should be noted that actual air split between A and B Heading near the installation face was measured at 28 and 32 m^3/s for A and B Headings during the surveys.

A chariot took one hour to travel from B Heading near the Recovery Face to the Installation Face (over about 3.0km (and thus at an average speed of 0.83 m/s). Therefore, a relative velocity of 0.17 m/s (about 2.5 m^3/s with 14.5m^2 area) across the Chariot's engine exhaust can be calculated. The small amount of available air had caused the build up of DPM around the Chariot while travelling inbye in B Heading carrying a Chock Shield which was evidenced by the high exposure level measured by the D-PDM unit on board.

Section B. Control of Vehicles in Mine Sections

DPM monitoring approaches that have been available for some time based on shift average monitoring do not readily allow successful engineering evaluation exercises to determine acceptability of pollution levels. Modern large mines may have tens or even hundreds of diesel powered vehicles in use at any time. Real-time monitoring readily allows engineering evaluation exercises to be undertaken which can usefully reflect the fast changing mine environment and the movement of individual diesel vehicles. An audit was completed on sources of DPM within a typical LW installation panel during wall moves by strategic placement of DPM monitors. It has been found that 25 percent of pollutant was contributed from outbye diesel activities in Mains, 25 percent from diesel activities in Panel Travel Roads, and 50 percent from diesel activities within face areas.

An initiative in some mines has been to limit the number of vehicles in the panel by the use of a Tag Board or Traffic Controller at the section or panel travel road entrance. Tag boards are used to manage exhaust DPM and gases. Diesel tags or tokens are used to control the number of vehicles entering a section or panel and so limit level of pollution. The diesel Tag Board design also should consider the diesel loading from outbye Mains diesel activities. Summary of DPM levels from each shift at points monitored throughout the panel shows increasing levels from influence of additional equipment in series within the ventilation circuit. 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. Real-time DPM monitoring allows the industry to pin-point high exposure zones such as those encountered 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. A study is discussed into how simulations of DPM exposure levels can be better understood using real-time monitoring and advanced mine communication and tracking systems.

Concept of Real-Time Diesel Tag Board

DPM tests have been undertaken in various mines to evaluate whether the use of real-time DPM monitors can contribute to the design of a Tag board or in fact replace the 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. Physical tags or tokens are used to control the number of diesel vehicles entering a section or panel 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 is checked as determined by examination as to whether a spare tag position is available. The basis of the system is to determine whether an additional vehicle can enter without exceeding the section ventilation split DPM or gases limits or "target levels". 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. This system allows 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.

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 although there is general acceptance that DPM is the most critical pollutant. Some are designed from ventilation indices for engine exhaust gas output such as 0.06 m^3/s/kW output and others from Original Equipment Manufacturers' 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 undertaken in maintenance workshops. To date none have been designed taking into account measured levels of mine atmospheric DPM. 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

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

- 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?
- What are the effects of vehicle travel direction, roadway surface, gradient, exhaust output and ventilation conditions?

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 close together or in convoy. Effects can be reduced if vehicles do not travel with speeds at the air velocity in the same direction and either travel slower than ventilation air velocity so that the plume of exhaust travels faster than the vehicle and ahead 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. Very often DPM contaminant from a vehicle within a panel passes along the working face. Crew members are thus affected by individual vehicle's DPM "make" which is best determined by testing 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 vehicle's DPM operational signature can be determined. The relationship between DPM "make" from a vehicle and airflow for dilution in the traveling airway can be determined as follows:

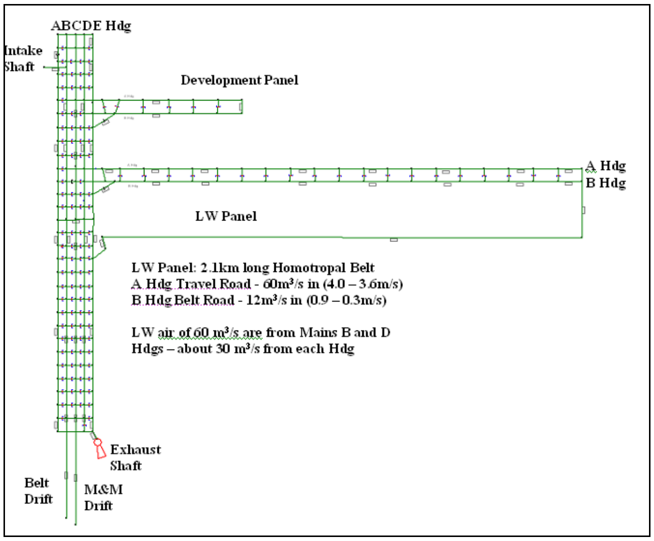
- A vehicles DPM pollution in the mine airway is measured in mg/m^3 in a particular airway.
- Ventilation quantity at that point is measured in m^3/s.
- DPM "make" is the product of the two i.e. mg/m^3 x m^3/s = mg/s.
- The effect of a vehicle's make depends on air quantity in the ventilation split. 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.

In relation to the future development of a "predictive" model to allow the effects of spot diesel DPM readings to be calculated for inbye parts of the mine over time, a simple LW 'U' ventilation system was simulated and analyzed with one diesel vehicle and then when a second vehicle entered the ventilation circuit. The ventilation simulation model at this stage was developed to demonstrate how DPM concentration levels will vary over time with the ventilation flow around a "U" ventilation system (into a section or panel along a Maingate or Headgate, along the face and back down a return roadway/ Tailgate). The model simulates the situation with a number of diesel vehicles entering a panel and how their exhaust fumes are diluted and flow around the U-circuit of the panel, based on typical data previously gathered for DPM and other diesel fume pollutants of NO_x and CO. The mine model represents a typical LW mine with one LW production panel and two development faces (one within the Mains and one in a Development panel). Figure 5 shows the initial model set up. Some key parameters of the model are as follows.

- Total Quantity of air passing through the mine is 173 m^3/s with one exhaust shaft.
- Longwall (LW) panel has 60 m^3/s measured at 1 ct and 45 m^3/s at the face with homotropal ventilation arrangement.
- LW panel is 250m wide and length is about 2.1km with pillar lengths of about 100m.



LW Panel: 2.1km long Homotropal Belt
A Hdg Travel Road - 60m³/s in (4.0 – 3.6m/s)
B Hdg Belt Road - 12m³/s in (0.9 – 0.3m/s)

LW air of 60 m³/s are from Mains B and D Hdgs – about 30 m³/s from each Hdg

Figure 5. Mine Ventilation Model with one Production and two Development Panels

Figure 6 shows the situation at start of the simulation when two diesel units are in operation and affecting the ventilation system; one (Unit #1) in the Mains and the other (Unit #2) in the panel gateroad entry first pillar length.

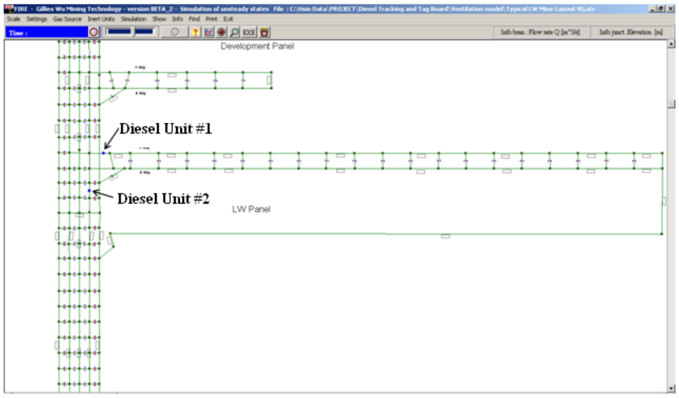


Figure 6. Ventilation of LW Panel with two Diesels machines operating.

Figure 7 shows the DPM Levels after ten minutes has elapsed

- The ventilation zone affected by these two units
- The contamination levels of exhaust DPM fumes after a 10 minute interval are shown.
- Fumes from Unit #1 were diluted initially by air in Mains D Heading to concentration of 0.06 mg/m^3 and then diluted more by air from Mains B Heading (down to 0.03 mg/m^3) as the different air streams join at the LW Panel entry.
- Fumes from Unit #2 were diluted by air entering into the LW Panel via A Heading (at concentration of 0.06 mg/m^3).

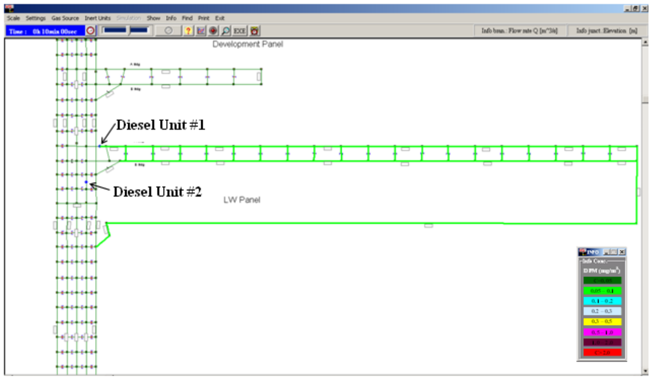


Figure 7. Ventilation Simulation after 10 minutes.

Figure 8 shows the results after another 10 minutes has elapsed, so that at 20 minutes, Diesel Unit #1 has travelled from Mains D Heading into LW panel entry while Diesel Unit #2 has travelled inbye along the gateroad to about 4ct.

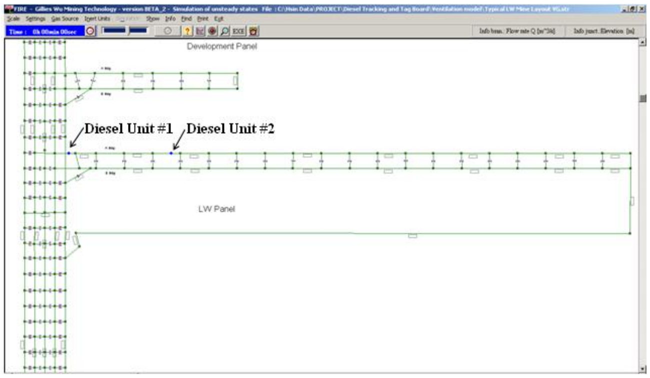


Figure 8. Diesels units at new locations after 20 minutes.

Figure 9 shows the areas and levels of exhaust fumes at the 20 minute point mark affected by these two units are as follows.

- Diesel Unit #1 is still putting out the same amount of fumes and the DPM level just inbye the Unit #1 is about 0.06 mg/m^3 as shown in light green colour.
- Diesel Unit #2 still producing the same amount of fumes as before.
- Fumes and DPM from both units are now combined just inbye of the Unit#2 with DPM combined level over 0.1mg/m^3 (shown in light blue colour).

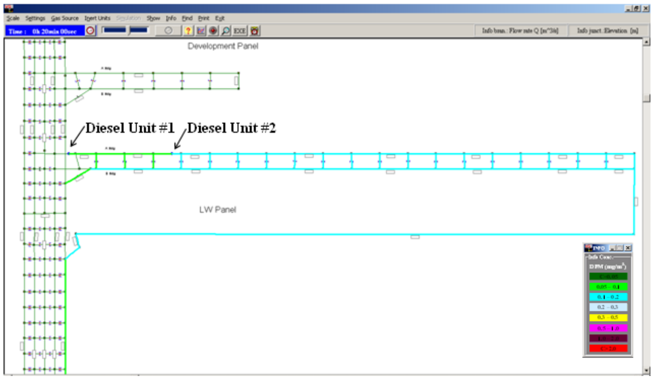


Figure 9. DPM Readings after 20 minutes.

Figure 10 shows the simulated Diesel Unit #2 shut down at 20 minutes. The areas and levels of exhaust fumes affected by these two units at 25, 30 and 40 minutes are shown. The 25 minutes screen shows the DPM level inbye of the Unit #2 in gateroad A Heading up to 12ct is reducing from light blue colour at 20 minute screen to a light green colour as DPM level in this section have reduced down to 0.06 mg/m^3. Inbye of the 12ct of gateroad A Heading the DPM level is still higher than 0.1 mg/m^3 (at 0.12 mg/m^3) as shown in light blue color.

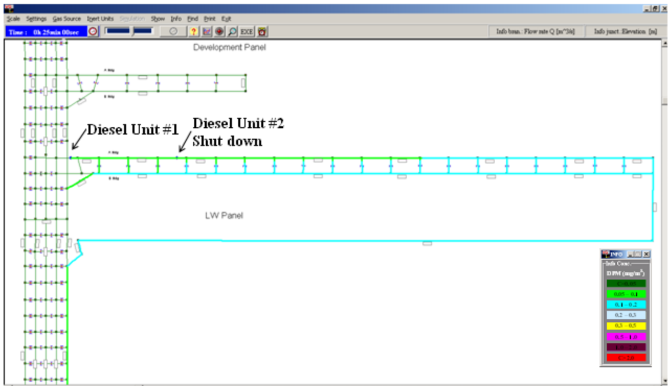


Figure 10. DPM Readings after 25 minutes

Figure 11 shows DPM levels in the panel gateroad at 30 minutesafter Unit #2 has been shut down for 10 minutes.

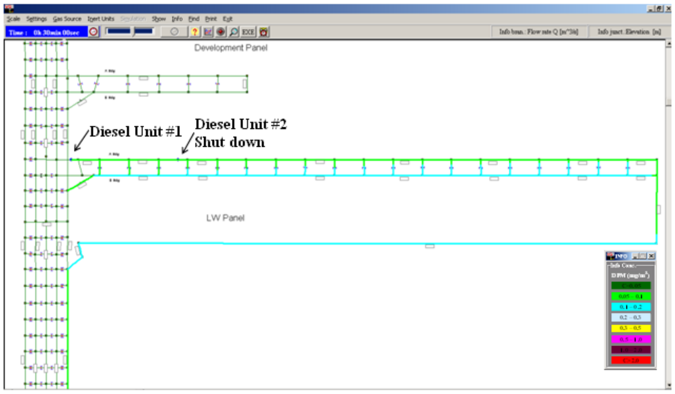


Figure 11. DPM Readings after 30 minutes.

Figure 12 shows DPM levels in the panel gateroad at 40 minutes after Unit #2 has been shut down for 20 minutes.

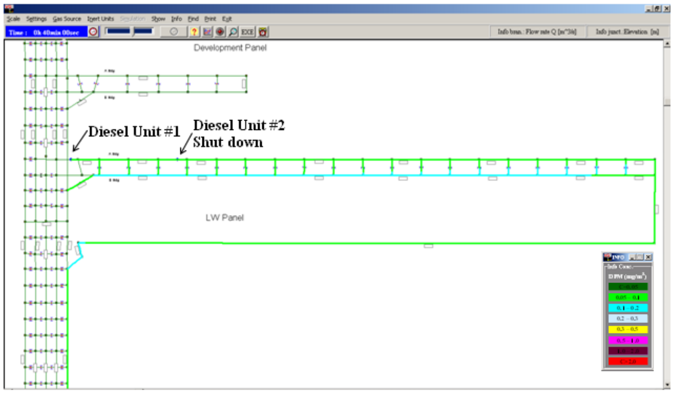


Figure 12. DPM Readings after 40 minutes.

At 40 minutes Diesel Unit #1 at panel gateroad entry was also shut down. Figure 13 shows exhaust fumes' levels from the two units at 45 and 53 minutes.

- At 53 minutes (or 12 minutes after Diesel Unit #1 shut down), the gateroad and face areas were clear of diesel fumes. It took about 9 minutes for A Heading to be clear of DPM (2050m/ 60s / 3.8m/s = 9.0 minutes) and another 3 minutes to have the LW face line clear of DPM.
- Time for fumes to be cleared in the panel depends on the ventilation air velocity and the length of panel as demonstrated in the simulation.

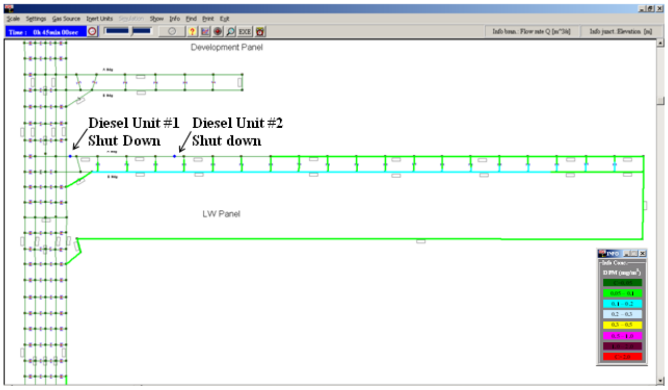


Figure 13. DPM Readings after 45 minutes.

This ventilation simulation confirmed the potential of such modelling in being able to contribute to a predictive model to better manage air quality with DPM real-time monitored data. It also underscores the complexity of such a model in a mine wide scenario, and the considerable development effort that would be required to achieve a useful software tool for such a purpose. The location and number of DPM monitors would depend on the reliability of any predictive model. In the simple LW layout analysed a minimum number of DPM monitors would be three or four with these spaced:

- One at the start of the panel.
- Another at the Maingate on the LW face.
- Another at the Tailgate at the end of the face.
- And possibly a fourth on the Maingate half way into the panel.

Figure 14 shows DPM levels in the panel at 53 minutes with the Maingate introducing fresh intake air and the Face is clear of fumes.

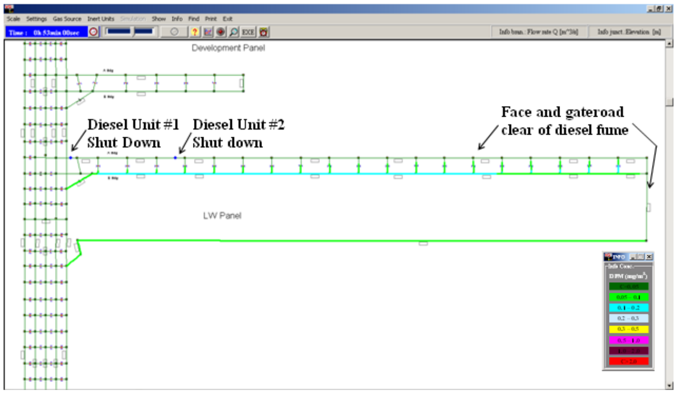


Figure 14. DPM Readings after 53 minutes.

Tag boards are used to manage exhaust DPM and gases. Physical tags or tokens are used to control the number of diesel vehicles entering a section or panel and so limit level of pollution. A Tag Board design exercise has been undertaken to examine implications of using directly measured mine atmosphere exhaust gas and DPM readings. In relation to the future development of a “predictive” model to allow the effects of spot diesel DPM readings to be calculated for inbye parts of the mine over time, a simple LW ‘U’ ventilation system was simulated and analyzed with one diesel vehicle and then when a second vehicle entered the ventilation circuit. The ventilation simulation confirmed the potential of such an approach to contribute to a predictive model to better manage air quality with DPM real-time monitored data. It also underscores the complexity of such a model in a mine wide scenario, and the considerable development effort that would be required to achieve a useful software tool for such a purpose.

The density of DPM monitoring points would need to increase if the predictive model was suffering limitations in capacity or accuracy. This would increase the complexity of the physical installation of the DPM devices and that of the power supplies and data transmission links. The balance between the cost and complexity of the predictive model and the required number of DPM monitors to support the model capabilities would form an important decision criteria in the further development of this DPM monitoring and access control system. Further development effort can only be justified when a reliable, fixed position DPM Monitoring device is available to provide constant, real-time DPM readings from a number of strategic locations in the mine.

Acknowledgement

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References

Birch, M.E. and Cary, R.A., 1996. Elemental Carbon-based Method for Monitoring Occupational Exposures to DPM Exhaust. Aerosol Science and Technology 25: 221-241.

Birch, M.E. and Noll, J.D., 2004. Submicrometer Elemental Carbon as a Selective Measure of Diesel Particulate Matter in Coal Mines. J Environ Monit, 6: 799-806.

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

Gillies, A.D.S and Wu, H.W., 2008. Evaluation of a first mine real-time diesel particulate matter (DPM) monitor, Australian Coal Association Research Program Grant C15028, Final Report, April.

Janisko S., Noll J.D., 2008. Near real time monitoring of diesel particulate matter in underground mines. In:Wallace K, ed. Proceedings of the 12th U.S./North American Mine Ventilation Symposium. Reno, Nevada: 509 513.

Noll, J.D., Janisko, S., 2007. Using Laser Absorption Techniques to Monitor Diesel Particulate Matter Exposure in Underground Stone Mines. In: Cullum B, Porterfield, D, ed. Proceedings for SPIE: Smart Biomedical and Physiological Sensor Technology V. Vol. 6759 Boston, Massachusetts: SPIE, pp. 67590P-1 67590P-11.

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 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.

Volkwein, J.C., 2006. Technology Transfer Workshop - Better Use of Diesels Underground, ACARP – Mackay 22 September and Belmont 26 September 2006.