Selected hazards and their control in underground mines

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Spis treści

2.4. Some Questions of Interest in Real-Time DPM Ambient Monitoring in Underground Mines*

Abstract

Mine equipment Diesel Particulate Matter (DPM) pollution is currently a matter of concern in many underground mines worldwide. A number of real-time DPM monitors has been developed in recent years that enable us to understand better the sources and levels of DPM pollution in underground activities through engineering evaluations to determine how conditions can be improved or mining personnel relocated to lower concentration levels. Studies are discussed that examine DPM concentration from vehicles under varying ventilation conditions. 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 initiative in some mines has been taken 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 a number of vehicles entering a section or panel and so as to limit the 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 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 zones allows efficient modification of mine ventilation, operator positioning and other work practices to reduce underground miners' exposure.

Niektóre aspekty monitoringu cząstek stałych z silników diesla (DPM) w kopalniach podziemnych

Streszczenie

Zanieczyszczenie powietrza cząstkami sadzy z silników dieslowskich jest obecnie kwestią zmartwień w kopalniach podziemnych na całym świecie. Ilość dostępnych urządzeń do monitoringu cząstek sadzy (DPM) wrosła w ostatnich czasach co pozwala lepiej zrozumieć źródła i poziom zanieczyszczenia powietrza w wyrobiskach podziemnych a wykorzystując inżynierskie metody obliczeń pozwala określić w jaki sposób warunki pracy mogą być poprawione lub czy zachodzi konieczność przemieszczenia załogi do miejsc z niższym poziomem stężeń. Poddano rozważaniom badania stężeń

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cząstek sadzy z pojazdów przy zmiennych warunkach wentylacji. Nowoczesne, duże kopalnie mogą posiadać jednocześnie w ruchu dziesiątki lub setki maszyn samojezdnych. Ciągły monitoring z łatwością umożliwia z inżynierskim przybliżeniem przeprowadzać symulacje, które mogą użytecznie odzwierciedlać szybkie zmiany w środowisku kopalnianym przy przemieszczaniu się pojedynczych pojazdów.

W pewnych kopalniach wprowadzono koncepcję zastosowania Tablicy Znaczków (Tag Board) lub Kontrolera Ruchu (Traffic Controller), które umożliwiały wyznaczanie granicznej liczby pojazdów wjeżdżających do partii lub rejonu eksploatacyjnego z uwagi na stężenie cząstek sadzy lub gazów spalinowych. Dieslowskie znaczki lub żetony zostały wykorzystane do kontroli liczby pojazdów wjeżdżających do partii lub rejonu eksploatacyjnego i pozwalały ograniczyć zanieczyszczenie. Sumowanie poziomu stężeń cząstek sadzy z punktów pomiarowych monitoringu wjazdu poprzez panel kontrolny demonstrują wzrost poziomu stężeń z wpływu dodatkowych źródeł poruszających się szeregowo w kierunku przepływu powietrza. Alternatywnym podejściem jest inwestowanie w podziemny ciągły monitoring gazów spalinowych, cząstek sadzy i jakości powietrza oraz zintegrowanie tych informacji w celu ustalenia czy dodatkowe pojazdy mogą wjeżdżać bez ograniczeń. Takie podejście optymalizuje wykorzystanie pojazdów dieslowskich i zastępuje ręczny system tablicy znaczków. Ciągły monitoring cząstek sadzy pozwala dokładnie wyznaczyć strefę wysokiej ekspozycji narażenia jak na przykład tam, gdzie pojazdy pracują w obszarach wymuszonej czy trudnej wentylacji. Identyfikacja stref wysokiego stężenia cząstek sadzy pozwala sprawnie modyfikować wentylację, organizację i inne roboty górnicze w celu zredukowania narażenia pracowników podziemnych.

Introduction

Mine equipment Diesel Particulate Matter (DPM) pollution is a matter of current concern in underground many mines worldwide. A number of real-time (DPM) monitors has been developed in recent years. Two of these have been developed by the National Institute of Occupational Health and Safety (NIOSH) in the US. One of them, the D-PDM (Gillies and Wu, 2008 and Volkwein, 2006) is based on an adaption of the successful NIOSH's Personal Dust Monitor (PDM) (Volkwein and others, 2004a Volkwein and others, 2004b) and unit which is being used very successfully for respirable dust monitoring. The D-PDM measures all particulate matter within a sub-micron range as classified nominally at minus 0.8 micrometers by a purpose developed cyclone, the BGI P/N 3615. The other, the FLIR Airtech, measures the Elemental Carbon (EC) component of DPM by a laser scattering approach. Both these new instruments have been evaluated underground in robustness and reliability testing in coal mines within Australia. Mine engineering testing has been undertaken to ensure the instrument can effectively assist mine management to handle this health issue. Real-time DPM monitors allow greater understanding of the sources and levels of DPM pollution in 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.

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 the real-time DPM monitors can contribute to the design of a Tag board or in fact replace the 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. 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 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 1 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 250 m wide and length is about 2.1 km with pillar lengths of about 100 m.

Figure 2 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 3 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 Hdg to concentration of 0.06 mg/m^3 and then diluted more by air from Mains B Hdg (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 Hdg (at concentration of 0.06 mg/m^3).

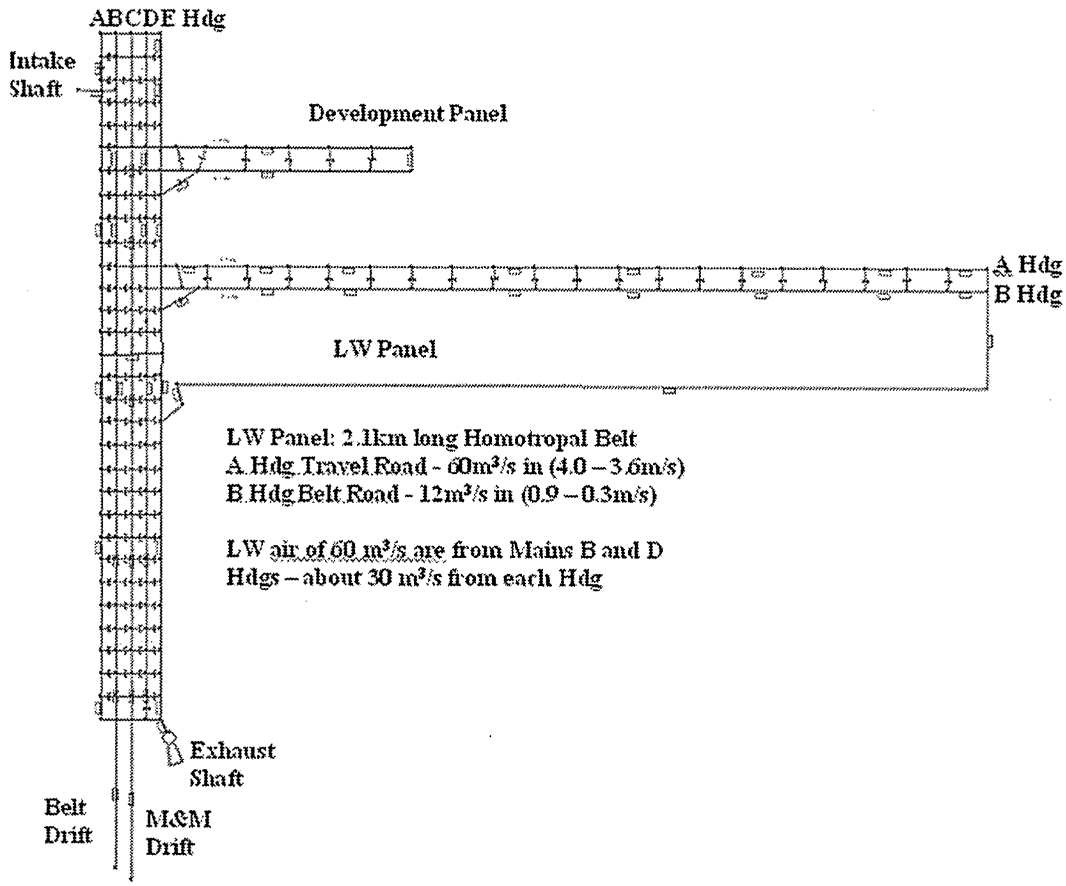

Fig. 1. Mine Ventilation Model with one Production and two Development Panels

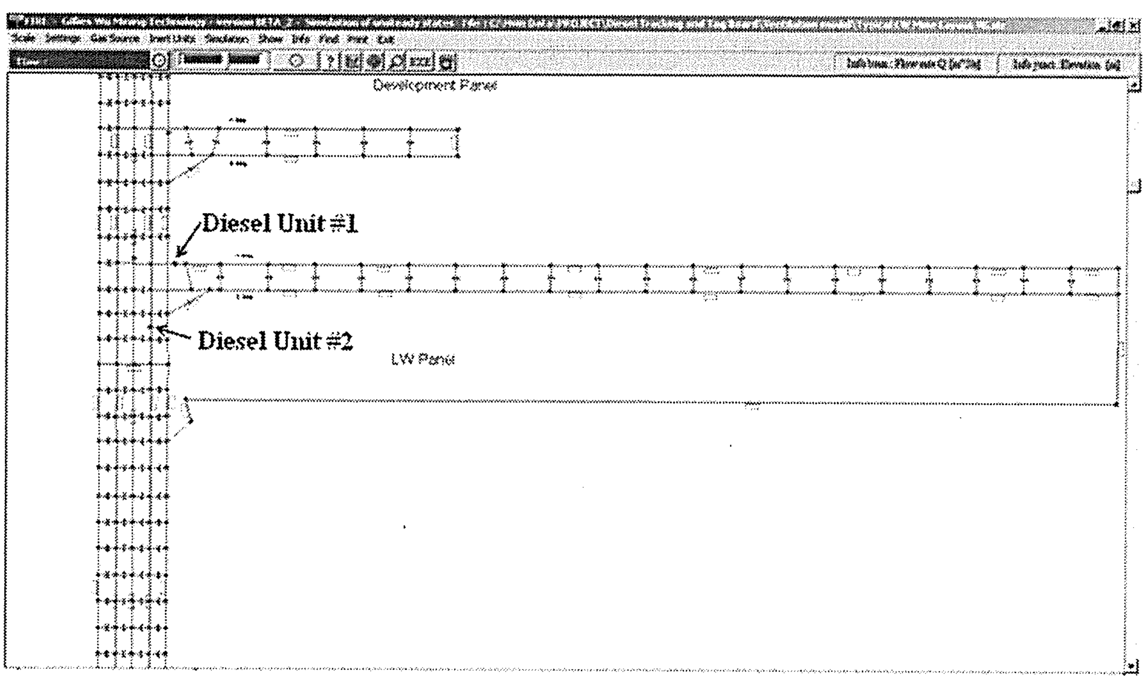

Fig. 2. Ventilation of LW Panel with two Diesels machines operating

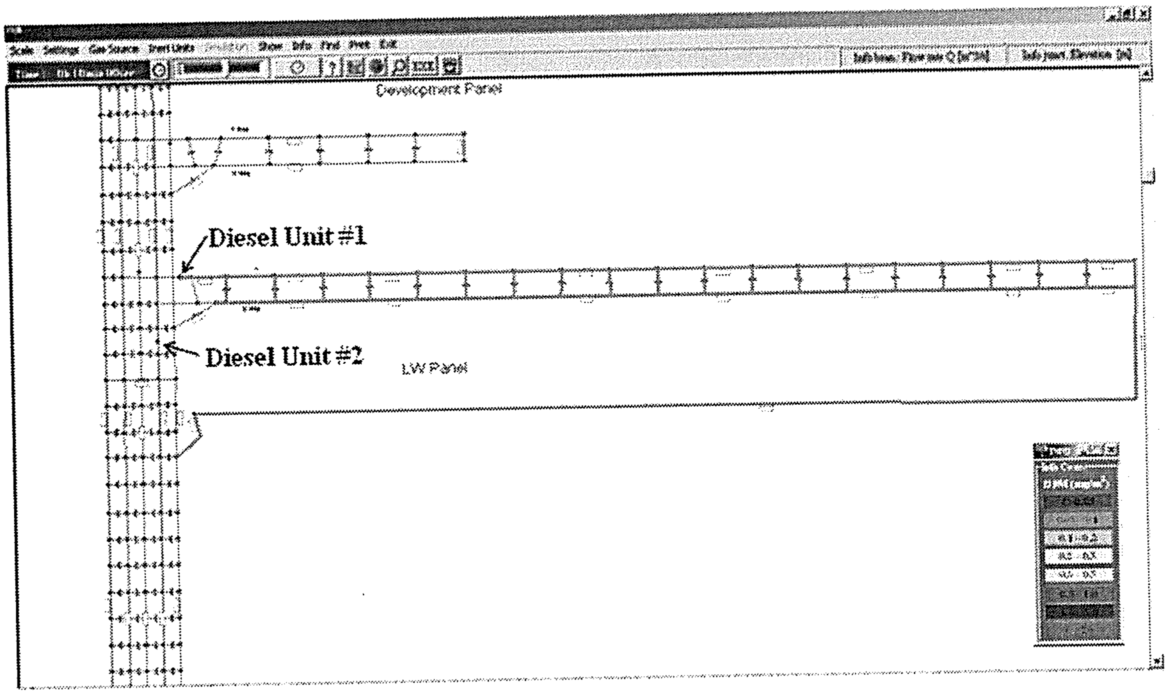

Fig. 3. Ventilation Simulation after 10 minutes

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

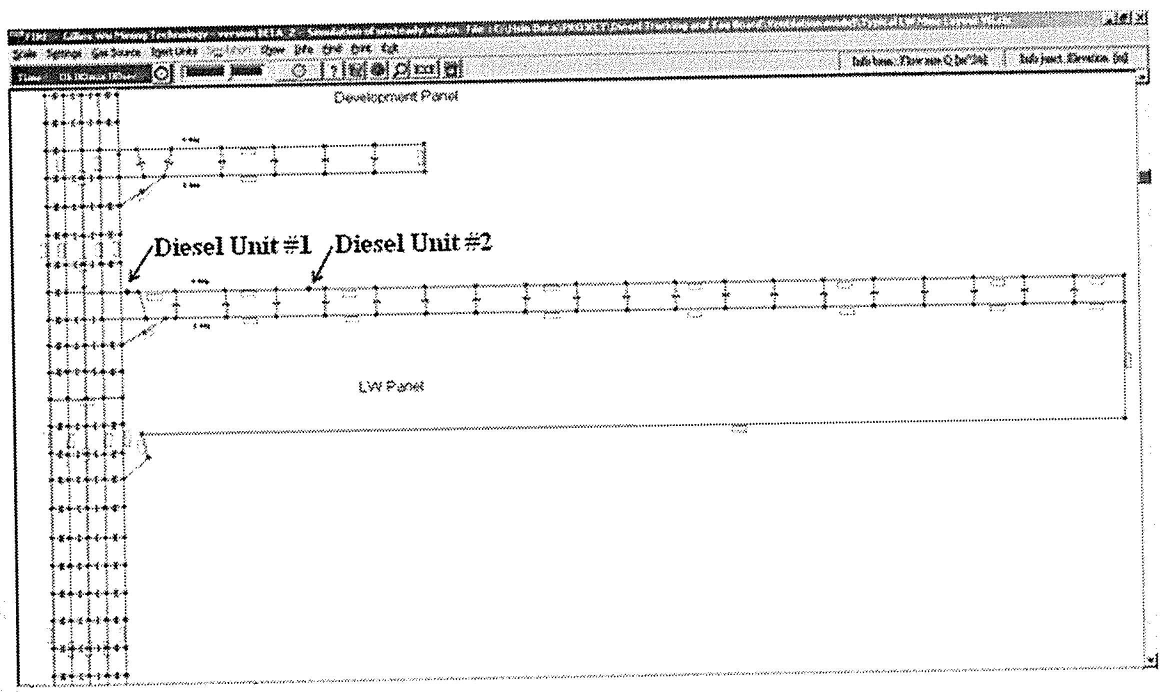

Fig. 4. Diesels units at new locations after 20 minutes

Figure 5 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 0.1 mg/m^3 (shown in light blue colour).

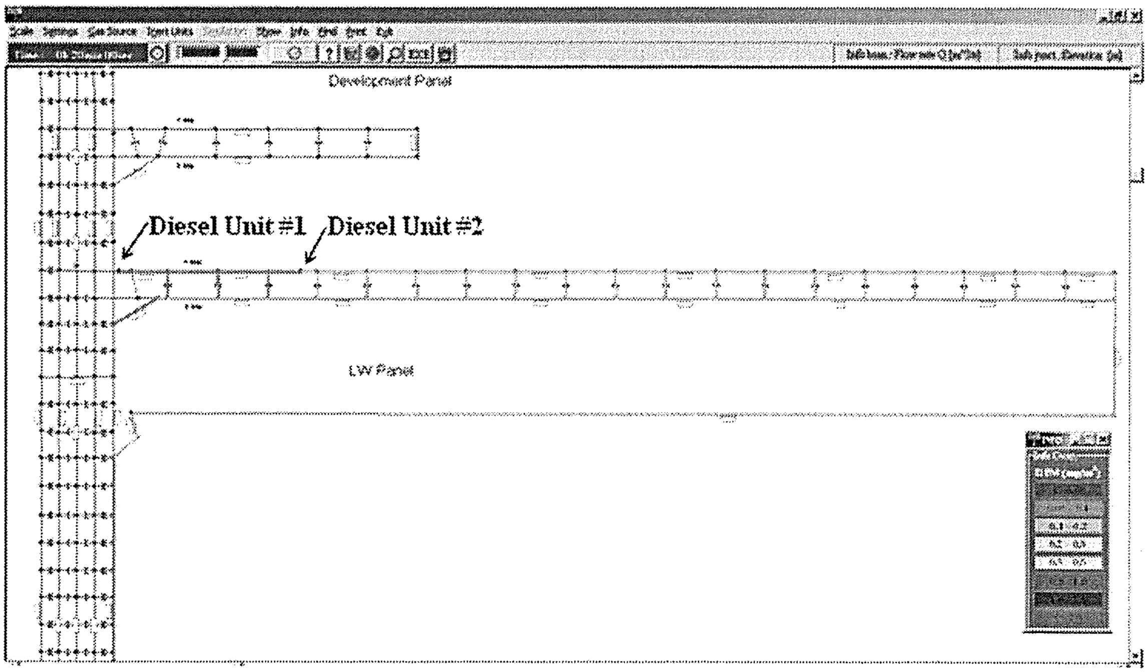

Fig. 5. DPM Readings after 20 minutes

Figure 6 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 Hdg 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 Hdg the DPM level is still higher than 0.1 mg/m^3 (at 0.12 mg/m^3) as shown in light blue colour.

Figure 7 shows DPM levels in the panel gateroad at 30 minutes after Unit #2 has been shut down for 10 minutes.

Figure 8 shows DPM levels in the panel gateroad at 40 minutes after Unit #2 has been shut down for 20 minutes.

At 40 minutes Diesel Unit #1 at panel gateroad entry was also shut down.

Figure 9 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 Hdg to be clear of DPM

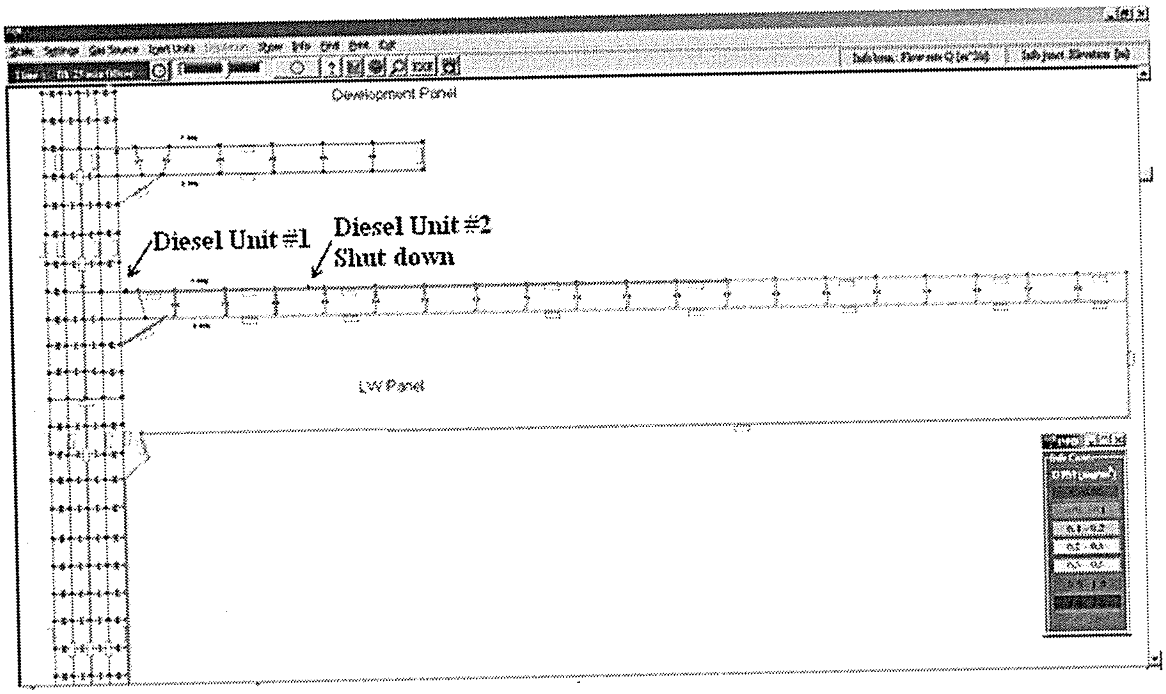

Fig. 6. DPM Readings after 25 minutes

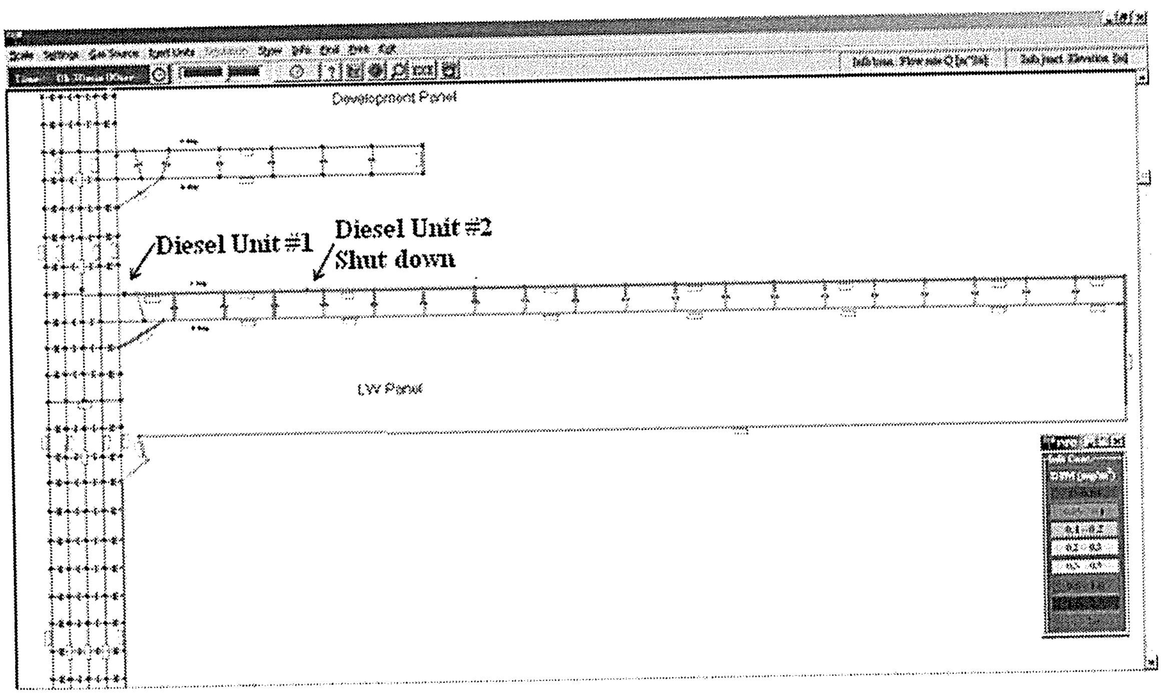

Fig. 7. DPM Readings after 30 minutes

(2050 m/ 60 s / 3.8 m/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.

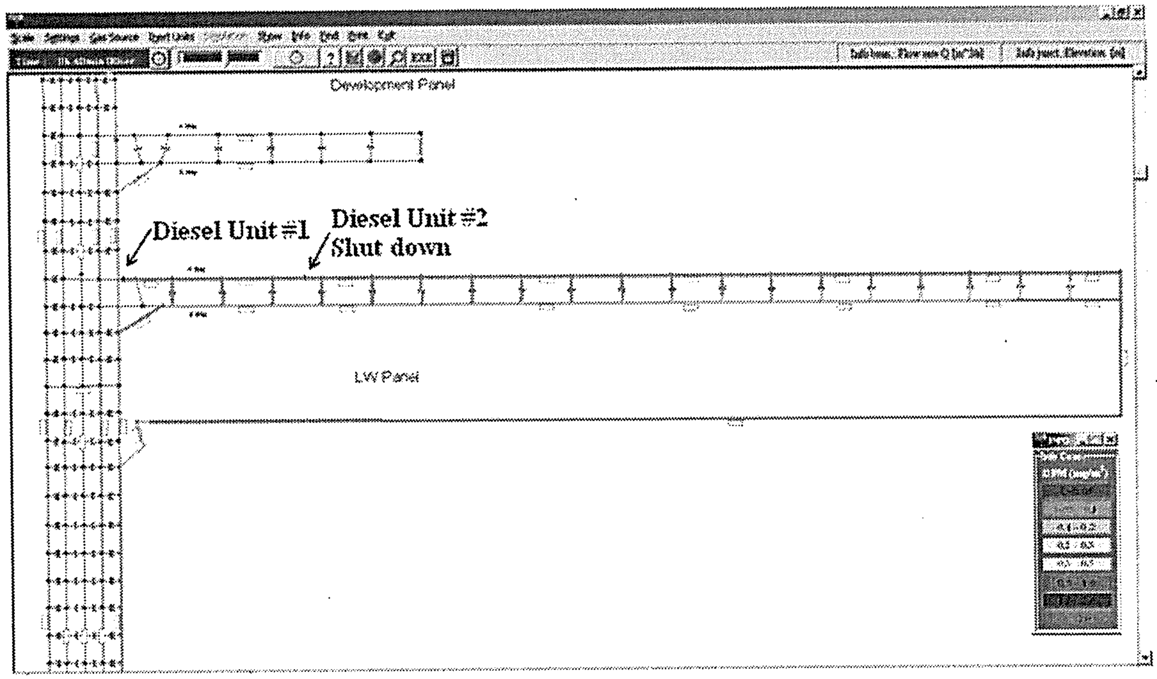

Fig. 8. DPM Readings after 40 minutes

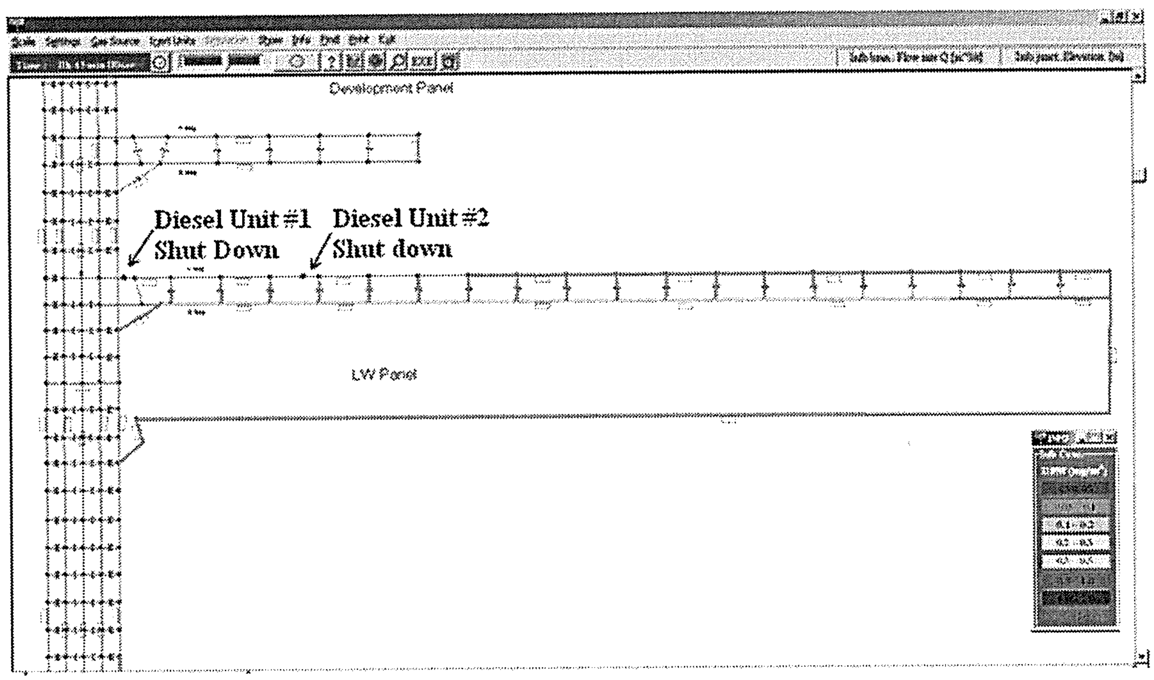

Fig. 9. DPM Readings after 45 minutes

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

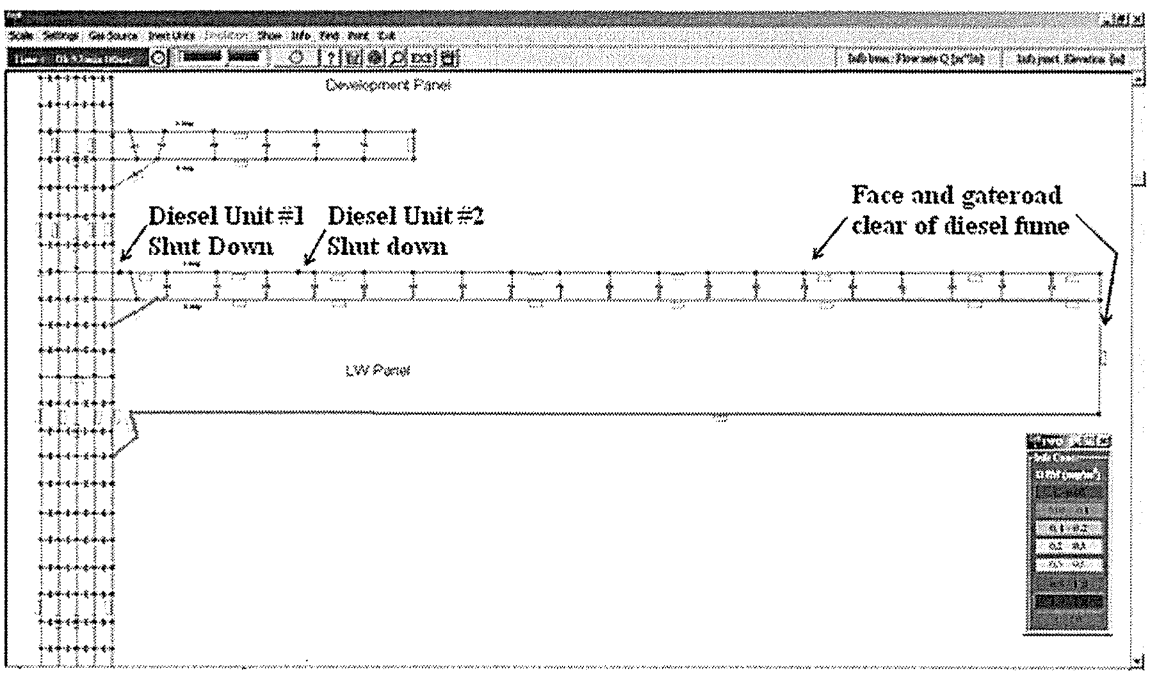

Fig. 10. DPM Readings after 53 minutes

Conclusions

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.

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