Review of Dust Control Strategy Optimisation using Real-time Respirable Dust Monitoring

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Abstract

Respirable dust is a continuing problem in mines where it adversely affects safety and productivity. The recent detection of three Queensland coal miners with black lung (Coal Workers' Pneumoconiosis - CWP) has led to industrial actions at some Queensland coal mines. CWP has been a concern in the U.S. over the last few years despite recorded conformance to exposure level legislation. This has led to reasons to question the validity and suitability of dust control strategies and the dust sampling methodologies currently utilised in the Australia and the U.S. The U.S. Mine Safety and Health Administration (MSHA) has recently reduced the shift averaged permissible exposure limit for respirable coal dust from 2.0 to 1.5 mg/m^3. From March 2016 MSHA requires the use of the Continuous Personal Dust Monitor (CPDM) to measure real-time respirable dust exposure under certain circumstances.

Real-time respirable dust sampling technique has particular applications in determining high source locations, estimating efficiency of engineering means of suppression and in assessing other approaches to handling the problem. This paper gives an overview of case studies where real-time respirable dust monitoring was utilised to optimise dust control strategies at various Australian and US mines. The use of real-time respirable dust monitoring is able to provide mine operators with a comprehensive dust production signature of their operations hence allow the implementation of more efficient controls at individual dust sources.

Introduction

Dust on longwall production faces has always been an issue of concern for production, safety and the health of workers in the underground coal mining industry in Australia and globally. Longwall personnel can be exposed to harmful dust from multiple dust sources including, but not necessary limited to; intake roadways, outbye conveyor belts, crusher/beam stage loaders (BSL), shearers, longwall face support shields (or chocks) advances and dust resulting from falling goaf or over pressurisation of the goaf.

Production from longwall mining in Australia has increased remarkably over the last two decades. The following table shows some of monthly and annual production records that have been published in various publication sources (Erisk, 2000; Coal Age, 2005 and 2009; International Coal News (ICN), 2009 and 2015; World Coal, 2015).

With the increase in coal production due to the advancement in longwall equipment technology and methodology, dust loads have also increased and this has resulted in an increase in personnel dust exposure levels. This increased productivity has meant that more dust is being produced and controlling both respirable and inhalable dust continues to present the greatest ongoing challenge for the coal mining industry.

In Australia this increased dust exposure level for underground coal workers can be directly attributed to the increase in coal production and the continued development of medium and thick seam mines, which allow the installation of bigger and more productive longwall equipment. Dust control mitigation processes vary from mine to mine, with each individual mine having a dust mitigation setup that is effective for that particular mine operation.

Table 1 Australian longwall production records published over the years

Monthly Production Records			**Annual Production Records**		
Year	Mine	tonnes	Year	Mine	tonnes
2000	Oaky Creek	772,029	2005	Beltana	7,627,644
2005	Beltana	955,049	2009	Newlands North	8,318,421
2009	Newlands North	961,891	2015	Grasstree	10,000,000
2009	Oaky North	1,146,721	2015	Narrabri *(Projected)**	10,000,000
2015	Grasstree	1,200,537	**projected in 30 July 2015 by ICN article*		

The recent detection of several Queensland coal miners with black lung or CWP has led to industrial actions at some Queensland coal mines. CWP has been a major concern in the U.S. over the last few years despite recorded conformance to exposure level legislation. This has led to question on the validity and suitability of dust control strategies and the dust sampling methodologies currently utilised in Australia and the U.S. The U.S. MSHA has recently reduced the shift averaged permissible exposure limit for respirable coal dust from 2.0 to 1.5 mg/m^3. From March 2016 MSHA requires the use of Continuous Personal Dust Monitors (CPDM) to measure real-time respirable dust exposure under certain circumstances.

Real-time respirable dust sampling techniques have particular application for determining high source locations, efficiency of engineering means of suppression and other approaches to handling the problem. This paper gives an overview of case studies where real-time respirable dust monitoring was utilised to optimise dust control strategies at various Australian and US mines. The use of real-time respirable dust monitoring is able to provide mine operators with a comprehensive dust production signature of their operations hence allow the implementation of more efficient controls at individual dust sources.

Statutory dust measurements in underground Australian coal mines were conducted mainly by Safety in Mines Testing and Research Station (SIMTARS) and Coal Services that rely on Australian Standards AS 2985 for respirable size dust particles, and AS 3640 for inhalable size dust particles. The majority of dust sampling to date has been with cyclone separation and collection of the sized particles for weighing, generally over the period of a full shift.

Although the above statutory method provides an accurate measurement for the total dust exposure for the period sampled, it does not always accurately reflect the source, quantity and timing of respirable dust entering the longwall from different sources. This presents difficulties in determining the relative effectiveness of the different control technologies in use.

Review of Dust Controls and Monitoring

National Institute for Occupational Safety and Health (NIOSH) research (Colinet, *et al*, 2010) indicates that there are at least six individual dust sources on an average longwall production face. Studies by NIOSH in the past indicated that longwall shearers and chocks are the main dust sources on longwall faces; representing up to 80 per cent of the total dust make. As the longwall shearer travels along the face, a significant portion of dust occurs in the crushing zone around the pick tips of the cutting drum. Generally the leading drum cuts the full drum height and generates the majority of the dust, while the trailing drum produces less dust due to the lower amount of coal being cut; concurrently as longwall shields (or chocks) lowered and advanced. Crushed coal and/or rock can fall from the top of the chock canopy directly into the face ventilation airflow. Most of this dust becomes airborne, and quickly disperses into the walkways.

Dust generated due to face spalling ahead of the shearer is a major problem particularly for thick seam longwall faces. Dust can also be lifted up from the Armoured Face Conveyor (AFC) by ventilation air when the direction of coal transport is against the direction of the airflow. Dust can be generated at all the conveyor transfer points along the intake airways. The movement of any outbye equipment can also cause significant quantities of dust to be raised into the atmosphere. A portion of dust can also be produced following roof caving behind the chocks and sudden goaf falls. A significant part of this goaf dust can be pushed onto the face as the leaked airflow returns to the face along the face support line.

Longwall Dust Controls

The mining industry’s pursuit to achieve statutory dust levels worldwide has produced a number of methods for longwall dust control over the decades. These dust control methods include ventilation controls, water sprays mounted on shearer drums, deep coal cutting, modified cutting sequences, shearer clearer, dust extraction drum, water infusion, use of scrubbers at stage loader/belt transfer points and other methods. The majority of the dust control techniques have been developed in the USA, UK and some other western countries and their application is more suited to low to medium coal seam heights up to 3.0 m. Longwall mine managements have been partially successful in controlling their operators dust exposure levels by adopting a combination of the above dust control techniques.

The two main dust control approaches of administration and engineering are generally adopted for dust management by the industry. Administrative controls or work practices are designed to minimise the exposure of individual workers by positioning them in the work area in such a way as to limit the time they are exposed to a particular dust source (MSHA, 1999). Work practices can be effective in protecting some individuals only if they are followed properly and consistently, and if the environmental exposure remains constant and predictable. Unfortunately, this is not the characteristic of longwall mining in general. Furthermore, the potential for frequent change of location can make it very difficult to identify sources of dust exposure. Engineering controls aim to lower the levels of respirable dust in the mine atmosphere by either reducing dust generation or by suppression, dilution, or capturing and containing the dust. These control measures are usually designed for application to particular conditions. Some are restricted to one operation while others are more general in nature.

A typical dust control setup on a longwall includes the basic use of sprays as the first point of control. The sprays used vary considerably from mine to mine. However, a typical spray setup would include solid or hollow cone sprays for the BSL discharge and crusher with various water pressures and flow rates. The number and positioning of sprays will vary from mine to mine. The shearer will have a series of drum sprays dependent on the drum type, usually supplied by the manufacturer. Some mining operations utilise a shearer clearer which consists of a series of up to 10 sprays dependent on desired configuration. These sprays are usually in a solid cone configuration. For shield generated dust, solid cone sprays are positioned in the support canopy. In most cases the aim of dust mitigation has not been the total suppression of the coal dust, but to reduce the respirable dust from the vicinity of the mine workers.

Face ventilation has always been the primary means to dilute and remove airborne dust from the face by increasing face air quantities. Some mines modify the behaviour of the ventilation by employing ventilation curtains and brattice wings to reduce the amount of air going passed the maingate chock, over pressurising the goaf and returning somewhere further along the face with contamination. Longwall face ventilation quantities in Australian mines range typically from 40 m^3/s up to over 100 m^3/s depending upon the production and gas dilution requirements.

While the development of longwall mining has led to high productivity records, the consequent production of high amounts of airborne dust has placed even more stringent demands on dust controls. Extensive studies have shown that high dust exposures on longwall mining operations are mainly due to:

- Inadequate air volume and velocity;
- Insufficient water quantity and pressure;
- Poorly designed external water spray systems;
- Lack of dust control at the stage loader and crusher;
- Dust generated during support movement; and
- Cutting sequences that position face workers downwind of the cutting machine.

Dust Monitoring

The current personal dust monitoring regime in Australia provides the mine tested with a single figure for shift average respirable dust exposure levels for five samples taken over a minimum of four hours during a production shift. The majority of dust sampling to date has been carried out with cyclone separation and collection of the sized particles for weighing, generally over the period of a full shift. Although this method provides an accurate measurement for the total dust exposure for the period sampled, it does not always accurately reflect the source, quantity and timing of respirable dust entering the longwall from different sources, hence presents difficulties in determining the relative effectiveness of the different control technologies in use. Tests based on this methodology also have a number of limitations including limited information from the results and the large number of invalid samples due to over-exposure to dust levels.

Since 1st February 2016, US mine operators have been required to use the Continuous Personal Dust Monitor (CPDM) to sample for respirable coal mine dust on working sections of underground coal mines and other areas. In addition, the CPDM must be used to sample air for all Part 90 miners (miners who have evidence of Black Lung), and may be used for sampling at surface mines if approved. From on 1st August 2016 (24 months after the effective date) concentration limits for respirable coal mine dust will be reduced. The overall respirable dust standard in coal mines is reduced from 2.0 to 1.5 mg/m^3 of air. The standard for Part 90 miners and for air used to ventilate places where miners work is being reduced from 1.0 to 0.5 mg/m^3 of air.

The CPDM is a belt-wearable, computerized device that measures and displays the real-time, accumulated and full-shift exposure to respirable coal mine dust as shown in the Figure 1. Reporting dust concentrations in real-time empowers miners and operators to take immediate action to avoid excessive airborne dust levels that can injure miners' lungs. Unlike the samples from existing dust sampling devices that require several days to collect, ship and process, the CPDM's measurement of respirable dust provides more immediate, full-shift exposure data. This device, which represents a major improvement in respirable dust sampling technology, was approved for use by both MSHA and NIOSH.

Figure 1 MSHA respirable dust rule - Phase II continuous personal dust monitor

Real-time respirable dust sampling technique has particular application for determining high source locations, efficiency of engineering means of suppression and other approaches to handling the problem. The following sections give an overview of case studies where real-time respirable dust monitoring were utilised to optimise dust control strategies at various Australian and US mines.

Case Studies

Over the last 12 years, 24 real time respirable dust surveys have been undertaken at eight Australian underground longwall mines with 135 series of PDM measurements in their longwall production and development faces. Several real-time dust surveys were also undertaken in US metal and nonmetal mines.

A number of examples are given in the following sections to illustrate real-time dust monitoring in Australian coal and US metal and nonmetal mines to identify dust sources and to optimise duct controls. Results from dust monitoring using real-time PDM instruments are shown from two Australian coal mines with a particular emphasis given to the longwall dust sources and controls in place. Dust control strategies utilised by these mines are also described.

Mine A

Mine A is a gassy longwall mine with seam and extraction thickness of about 4.0 m with typical longwall panels were 200 m wide using 114 two-leg chock shields and 2.8 to 3.8 km panel lengths. Ventilation air quantities at longwall production faces were ranging from 70 to 90 m^3/s. The longwall panel has a number of potential dust sources. A detailed survey is able to assist in evaluating the contribution of each component dust source, show the contribution from a number of major sources and the cumulative dust level faced by a miner at different points throughout the panel. The particular longwall panel ran from Chock No 1 at the Main Gate (MG) to Chock No 114 at the Tail Gate (TG) with four operators, namely MG operator, MG Shearer operator, TG Shearer operator and Chock operator. For conformity of approach a number of reading sequences were taken just inbye the MG at Chock No 8 or just outbye the TG at Chock No 110. Dust readings for a number of measurements sequences are set down and average values calculated.

Tests were also carried out to monitor the dust suppression efficiency of sprays in the BSL and at the belt transfer point where the longwall belt and the main trunk belt met. For the BSL test, one PDM was placed outbye of BSL, the second PDM was placed on top of the BSL inbye of the spray and the third PDM further inbye of the BSL at Chock No 8. During the test, BSL sprays were on initially and then disconnected for about 30 minutes and then reconnected again.

The results showed that with the water sprays off dust concentration levels downstream of the BSL were dramatically increased to more than 1.0 mg/m^3 while the dust concentration level upstream of BSL remained constant (0.2 - 0.3 mg/m^3) with little variations. It was found that the fluctuations in dust levels measured by the PDM upstream of the BSL correlated well with whether there is coal loaded on the moving conveyor belt or not. When there is no coal loaded on the belt the dust levels of intake air upstream of the BSL were measured at around 0.2 mg/m^3. It is possible to draw a horizontal line as shown in Figure 2 to indicate whether there is coal on the belt or not.

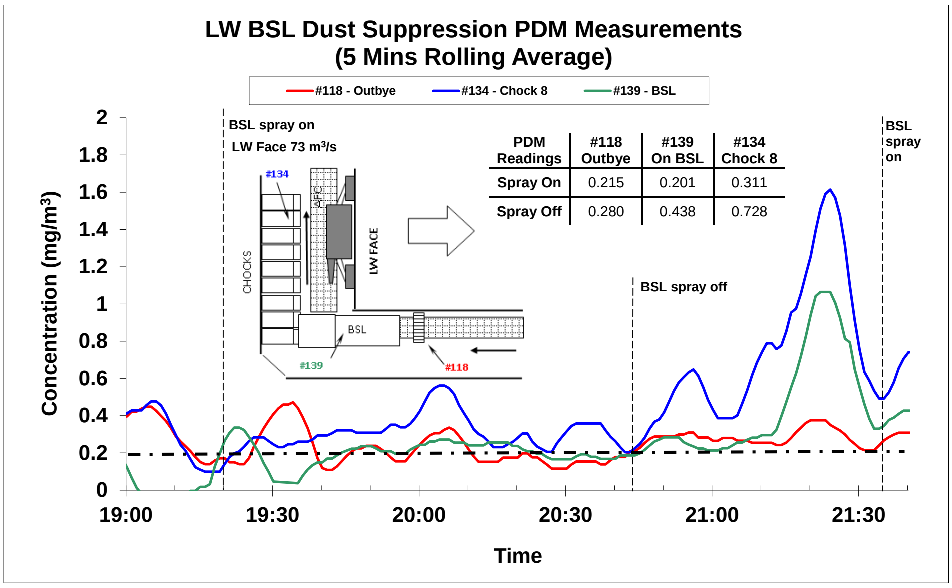

Figure 2 Real-time PDM dust readings across a Longwall BSL with sprays on and off

In undertaking longwall studies it is important to maintain consistency with measurement conditions along the face activities. Figure 3 examines studies undertaken over the majority of a shift. The shearer position data was downloaded from the mine monitoring system. A cutting sequence took on average slightly less than an hour. It can be seen in the figure that seven cutting cycles occurred across the 7 hour study time period with good regularity. One early period of 45 minutes of cutting was lost to belt structure removal. Measurements were carried out at LW face positions monitoring the dust levels experienced by shearer and chock operators in a unidirectional mining cutting sequence. Results of these tests for various operator position combinations are analysed and summarised as shown Table 2.

Table 2 Dust readings across different sources within a longwall panel

Test No	Chock #8	MG Operator	TG Operater	Chock Operator	Inbye Chock Operator	Chock #110	Comments
1		1.00	1.12				Shadowing operators
2		1.11		1.52			Shadowing operators
3						3.90	Fixed position test
4		1.53				4.57	Shearer Clearer off
5		1.58				4.65	Shearer Clearer off
6	0.89	1.29					AFC dust only
7	1.12	1.62					AFC and Bank Push dust
8	1.64				4.26		AFC, Shearer & Chock dust
9		1.51			3.18		Shearer & Chock dusts
10			1.53				Outside airstream (5 min ave)
11			1.47				Outside airstream (30 min ave)
Average	**1.22**	**1.38**	**1.37**	**1.52**	**3.72**	**4.37**	

Figure 3 also illustrates monitoring dust make across the length of a shearer when cutting from MG to TG and then back to MG between 15:30 and 16:17 as shown by the shearer position data downloaded from the mine monitoring system. One PDM unit (#134) was worn by a person who shadowed the MG shearer operator for a cutting cycle during unidirectional cutting with average dust level of 1.05 mg/m^3 recorded. The other PDM unit (#139) was worn shadowing the TG operator with average dust level of 2.09 mg/m^3 over the same period. The results showed an increase (1.04 mg/m^3) in dust exposure faced by the TG operator over the MG operator. The unusual anomalous “bump” in the PDM 139 result trace at about 15:45 is put down to a significant face-slabbing fall which very obvious to those nearby.

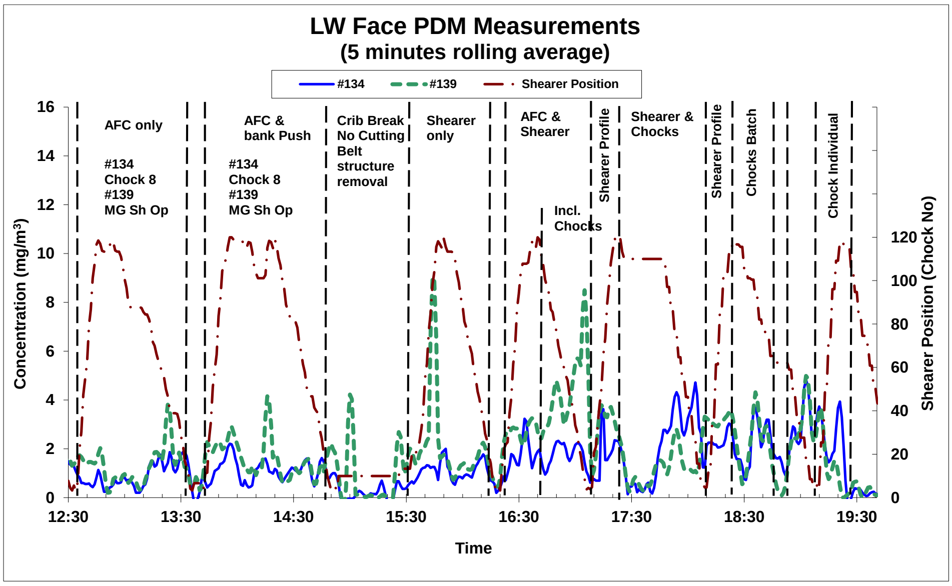

Figure 3 Real-time dust surveys with shearer positions and dust levels

Mine B

Mine B is also a gassy longwall mine with mining heights ranging from 4.1 to 4.5 m. Typical longwall panels are 250 m wide using 151 two-leg large and heavy chock shields and about 2.5 to 4.0 km long with twin heading gate roads. Over a period of five years, eight series of real-time dust surveys at Mine B's longwall faces to assess the baseline dust situations and to optimise the effectiveness of various dust controls were implemented.

Performance audit of the BSL Dust Scrubber for respirable dust reduction has been undertaken. The first part of the surveys evaluated the scrubber operating normally for a period of extensive face cutting with the scrubber sprays alternatively off and on. A second part of the surveys was undertaken with the aim to monitor dust along the face with the scrubber on and compare with a similar situation with the scrubber off. Face coal cutting activity and shearer position on the face was recorded during both tests.

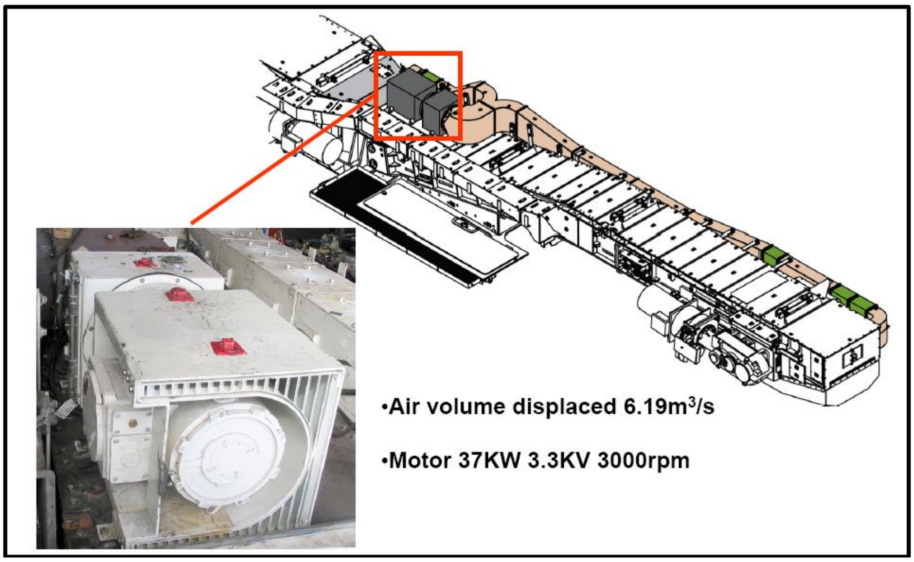

Figure 4 Schematic and photographic view of the electrically driven dust scrubber

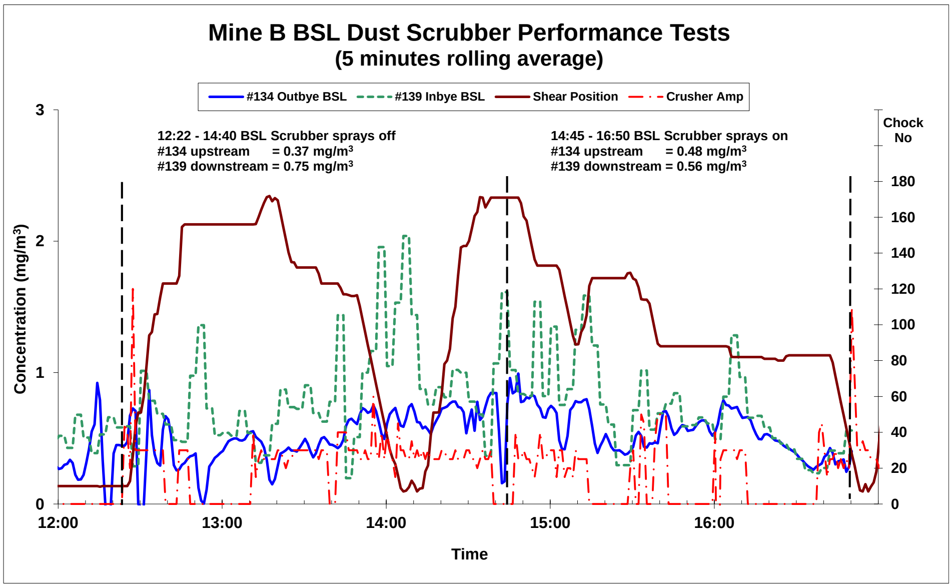

Figure 5 BSL Dust Scrubber performance test PDM results

The BSL Dust Scrubber survey was undertaken in consecutive tests with the scrubber water sprays off and on. With an air quantity of 36.7 m^3/s flowing through the BSL, it is possible to calculate the dust make from the BSL and crusher. Results were evaluated depending on whether face cutting was occurring or not. The results demonstrated that the overall average filtration efficiency of the BSL Dust Scrubber is about 47% with mining active or not active. However, when mining was active, the dust filtration efficiency of the scrubber is reduced to about 21%. When mining is not active, the filtration efficiency of the scrubber is increased to about 78%.

Higher level of efficiency occurred when the scrubber was not “working hard”. This indicates that with active mining the scrubber was overloaded and a lesser proportion of the dust is impacted or captured by water droplets. It is clear that the dust scrubber performs effectively at low dust loads but not as effectively as at higher loads. It was recommended that consideration be given to using two independent scrubber units with one drawing air from the crusher and the other from under the hood at the outbye BSL end where coal passes onto the panel conveyor belt.

Several real-time longwall dust surveys were conducted at Mine B to evaluate the dust situations with various dust controls implemented over the years. The following table gives dust levels at various manning positions in the longwall production area recorded.

Table 3 Summary of three survey series of dust results at various manning positions

Average Dust Levels (mg/m^3)	Face Q m^3/s	Outbye	MG Chock #8	MG Shearer Operator
Baseline - Standard	63.4	0.28	2.54*	1.91
Improved Condition 1	71.2	0.30	1.16	1.33
Improved Condition 2	70.5	0.30	0.62	0.91

** Unusual local high dust level experienced was a direct result of additional dust created by strata stress loaded MG chocks (No 1 to 5) advancements.*

During the initial longwall dust survey (Baseline - Standard), standard dust controls and strategies were implemented. The results from the survey formed the baseline data. In the next two series of dust surveys undertaken about four and 12 months after the initial surveys, improved dust controls and strategies were applied. Improved and additional dust controls and strategies which contributed lower dust levels at various longwall positions in the second series of the dust surveys were as follows.

1. Improved face air quantity,
2. New finer shearer sprays (50%) installed,
3. New sails installed on the top of MG Drive,
4. Good housekeeping - washing away loose coal on platoons in the face walkway.

Further improved and additional dust controls and strategies which contributed lower dust levels at various longwall positions in the third series of the dust surveys were

1. Full finer shearer sprays installation completed,
2. Water Mist Venturi system installed at Chock #6 with three sprays in the front at 45 degree angle and one at the back with 10 degree angle to the face line.

Mine C

Real-time dust sampling was performed in a US nonmetal mine entry of a longwall mining operation. PDM unit was installed in the conveyor belt entry in order to assess the effect of belt operation on dust accumulation. The peak dust value based on 15 and 30 minutes concentrations were 7.0 mg/m^3 and 6.4 mg/m^3 respectively. The belt was not operating at the beginning of measurement. This can also be observed in Figure 6 as dust concentrations were very low before the time of 9:45 am. The belt operation started at 9:45 am, since then an exponential increase in the dust concentration is observed. This can be seen in Figure 6.

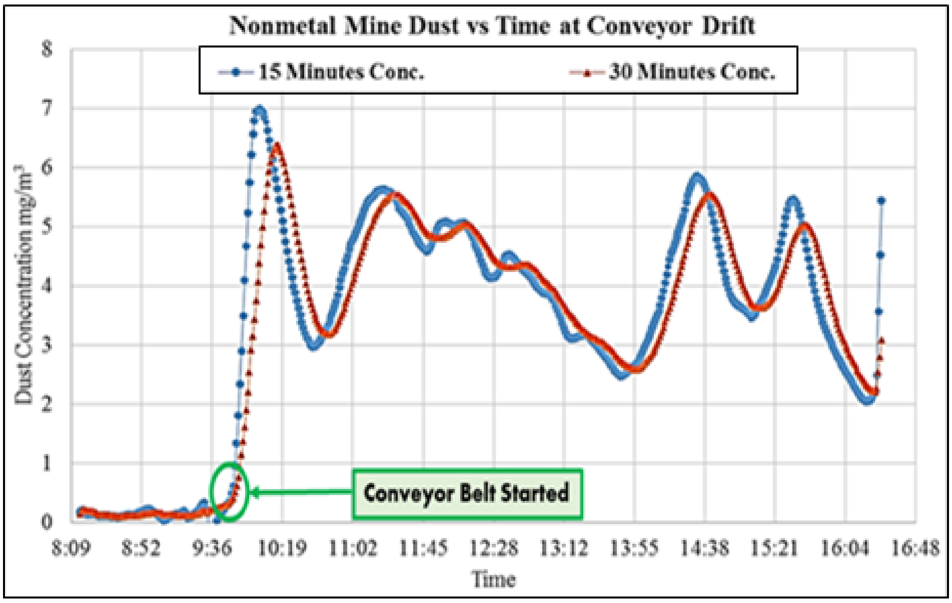

Figure 6 Real-time dust concentrations versus time over 15 and 30 minutes

Mine D

A real-time dust sample was collected during face drilling in a US metal mine by using the PDM. During the monitoring period all activities of vehicles or machinery in the area of monitoring were noted. A 224 kW jumbo drill was operating at the monitoring face. One 97 kW diesel powered hydraulic mechanical scalar was working in a nearby entry. Low dust values were recorded at the commencement of monitoring as no major work was being carried out during that time. Drilling operation started at 10:25 am when a sudden increase in dust concentration can be seen in Figure 7.

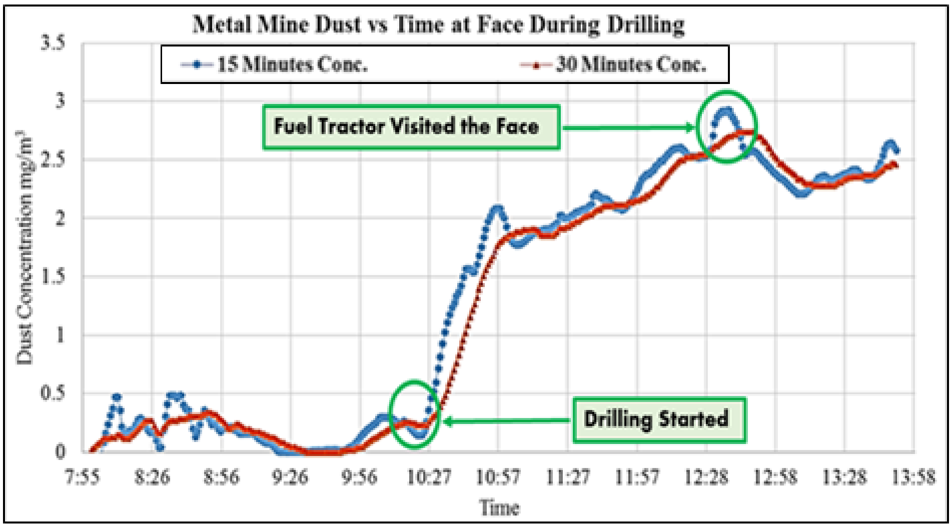

Figure 7 Real-time dust concentrations versus time over 15 and 30 minutes

The recorded peak dust value based on 15 minutes rolling average was 2.9 mg/m^3 and based on 30 minutes rolling average the peak recorded value was 2.7 mg/m^3. At the face the air velocity was quite low so the dust started accumulating with time. Both 15 and 30 minutes dust concentrations were plotted against time.

Conclusions and Recommendations

Summaries of case studies and discussions about the benefits of real-time dust monitoring over the statuary shift averaged monitoring were presented. This is with particular emphases on the real-time dust monitoring as an engineering tool that can effectively and efficiently assess impacts of dust controls and/or strategies implemented at mines. Statuary shift-averaged monitoring will still have its roles to identify whether there is a dust issue or not at this stage but it will not be able to assist the optimisation of dust mitigation in a practical way.

Australian longwall mining experience has indicated that the efficiency of some of the existing dust control methods reduces significantly in thick coal seams and under high production environments. High dust concentrations were observed in a US nonmetal mine and belt conveyor was identified as the main source of dust in a US nonmetal mine. As the current trend in the industry is to substantially increase the face production levels and to extract more thick coal seams, there is an urgent need for detailed investigation of various dust control options and development of appropriate dust management strategies.

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