

3. Mine dusts

Evaluation of a new real time personal dust meter for engineering studies

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ABSTRACT: A new personal respirable dust monitor developed by Thermo Electro Corporation under a project funded by the National Institute of Safety and Health (NIOSH) has generated promising results in underground coal mine testing. An Australian Coal Association Research Project (ACARP) funded study has been undertaken to evaluate the new real-time personal respirable dust monitor particularly in engineering studies. It can quickly highlight high dust situations and allow the situation to be corrected. The instrument has been tested for robustness and potential to be used as an engineering tool to evaluate the effectiveness of dust control strategies. This project has evaluated the personal dust monitor's (PDM) ability to quickly and accurately measure changes to longwall dust levels after implementation of an improvement. This has been done at two Australian longwall underground mines. Results of the tests demonstrate the ability of the instrument to increase understanding of the respirable dust exposure levels faced at underground manned points.

1 INTRODUCTION

A new personal respirable dust monitor developed by the company Rupperecht and Patashnick in the US under a project funded by National Institute of Safety and Health (NIOSH) has generated promising results in underground coal mine testing performed in the US recently (Volkwein et al. 2004a & 2004b).

The study described in this paper has been undertaken to evaluate this realtime personal dust monitor (PDM) using the tapered element oscillating microbalance (TEOM[®] system) for personal respirable dust evaluation particularly in engineering studies. The study is part of an international program of evaluation being undertaken by NIOSH in the US.

The technology that forms the heart of the PDM, the TEOM[®] system, is unique in its ability to collect suspended particles on a filter while simultaneously determining the accumulated mass. The monitor internally measures the true particle mass collected on its filter and results do not exhibit the same sensitivity to water spray as optically based measurement approaches. The technique achieves microgram level mass resolution even in the hostile mine environment, and reports dust loading data on a continuous basis. Using the device, miners and mine operators have the ability to view both the cumulative and projected end-of-shift mass concentration values, as well as a short-term 15 or 30 minute running average. It is believed to be the first personal dust monitor instrument that reliably delivers a near-real-time reading. It can quickly highlight high dust situations and allow the situation to be corrected.

The instrument has potential to be used as an engineering tool to evaluate the effectiveness of dust control strategies. In a US evaluation performed by Consol Energy the mine operator evaluated the benefit of a proposed new water spray-based dust control system. Engineers measured the dust concentration upstream and downstream of a production location under different dust control scenarios using two of the personal dust monitor units. By evaluating the change in the dust loading between the upstream and downstream monitoring sites, the company was able to determine in a few hours which hardware configuration would yield the greatest benefit to the workplace environment.

Being a personal dust monitor, the instrument measures the airborne dust from the breathing zone region and so has many advantages over instruments that measure from a fixed-point location. It delivers a near-real-time reading and so can quickly highlight high dust situations and allow the situation to be corrected.

A recent ACARP supported research project completed by one of the authors, (Gillies 2001) entitled "Dust Measurement and Control in Thick Seam Mining" ACARP C9002 has highlighted some areas for new approaches and research to allow improvement of dust conditions within extraction panels within Australia's emerging thick seam coal industry. Industry, management, technical engineering staff and the workforce all give strong recognition to the challenge of dust as an increasing hazard particularly as higher production levels are achieved.

The underground workplace particularly along the longwall face is an environment with varying

respirable dust conditions due to aspects such as ventilation conditions and air velocity, shearer activity and design, chock movement, AFC movement, manning position, face time of individual personnel, outbye conditions and dust levels in intake air and measurement instrument behaviour.

The objective of this study is to evaluate the new PDM in its capability as an engineering tool to quickly and accurately measure changes to longwall dust levels at manned points after implementation of an improvement. This has been done in conjunction with the support of mining companies through measurement at two longwall mines.

Many mines have observed a lack of repeatability in dust monitoring that is not easily explained. This study has evaluated the instrument as an engineering tool that can assess the effectiveness of one change to improve dust levels in sufficiently short a time that other aspects have not changed.

The measurement program on the longwall face has focused on recognised areas for improvement through different engineering approaches such as spray usage and man positioning. The project aims to assist in developing an approach to sampling measurement that is reliable and repeatable and can ascertain efficiency or effectiveness of engineering improvements.

The project was undertaken over four months from April to July 2005. Some preliminary activities occurred before this period. To ensure reliability of testing for the international evaluation program training in use of the TEOM® system, PDM instruments was given by Rupprecht and Patashnick personnel in April 2005. Some technology transfer from the project has taken place in publications, workshops and conference deliveries during and after the project.

2 EVALUATION OF THE PDM AS AN ENGINEERING TOOL

In the US the incidence of coal workers pneumoconiosis (CWP) has been declining for the past 35 years. Production levels at mines have been continually increasing and the development of dust control technologies to protect workers has become more difficult and complex. Improved dust monitoring of coal mine dust concentrations offers a new means of protecting miners' health by more quickly identifying anomalous dust conditions.

Despite the decline in CWP, coal mine dust is still implicated in the US in the premature deaths of miners. In response, the US Secretary of Labour and the Federal Advisory Committee on the Elimination of Pneumoconiosis among Coal Mine Workers recommended that better monitoring of coal miner dust exposures be used as a method to improve miner health. In consultation with labour, industry, and government, NIOSH issued a contract to Rupprecht & Patashnick Co., Inc.

(R&P), to develop a one-piece PDM. The objective of this work was to miniaturise the TEOM® technology into a form suitable for a person-wearable monitor that would enable accurate end-of-shift dust exposure information to be available to miners. Furthermore, any person-wearable dust monitor should minimize the burden to the wearer by incorporating the monitor into the mine worker's cap lamp battery, with exposure data continually displayed during the shift to enable workers and management to react to changes in dust exposure.

The PDM is configured to provide accurate respirable dust personal exposure information in a form that is convenient to wear by a miner. Respirable dust exposure data displayed by the device has two main objectives:

- Providing the miner and mine operator with timely values to avoid overexposure to dust by making any necessary changes during the course of a work shift, and
- Computing an accurate end-of-shift statistic for a miner's average respirable dust exposure.

The mass sensor in the PDM, holds the key to the accurate, time-resolved dust concentration measurements. The inertial, gravimetric-equivalent, mass measurement technique used in the device typically provides a limit of detection on par with that of the most sensitive laboratory-based microbalances. Similar to the integrated sampling method, the PDM contains a sampling system that collects particles on a filter located downstream of a respirable cyclone. In contrast to the current lapel worn personal method, however, the PDM mass measurement is performed continuously during a working shift in a mine instead of being delayed by the days or weeks required for a laboratory analysis.

The PDM is a respirable dust sampler and a gravimetric equivalent analysis instrument that is part of a belt-worn mine cap lamp battery. The main components of the device include a cap lamp and sample inlet located on the end of an umbilical cable, a belt-mounted enclosure containing the respirable dust cyclone, sampling, and mass measurement system, and a charging and communication module used to transmit data between the monitor and a PC while charging its lithium ion batteries for the next shift. Figure 1 illustrates the components typically carried by the miner. The PDM is designed to withstand the harsh conditions found in the mine environment, with the system designed to meet MSHA intrinsic safety type approval requirements.

A 2.2 litre per minute flow of particle-laden air from the mine atmosphere enters an inlet mounted on the bill of the miner's hard hat, and passes through conductive tubing before reaching the Higgins and Dewell (HD) cyclone at the entrance of the PDM.

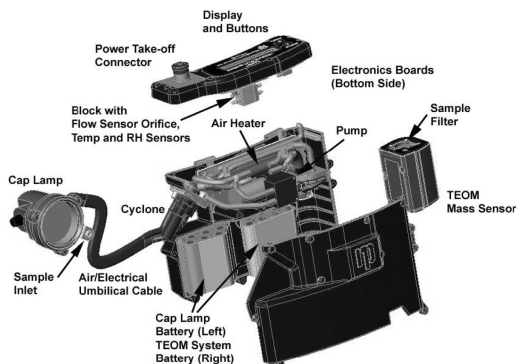


Figure 1. Major components of the PDM.



Figure 2. Installing a sample filter in the mass sensor.

The sample stream with respirable particles that exits from the cyclone is then conditioned in a heated section of tubing to remove excess moisture. As the air stream subsequently passes through the mass sensor, an exchangeable filter cartridge collects the respirable particles. The mass sensor can be removed from the PDM by a mine's dust technician (Fig. 2), who changes its particle collection filter and cleans the unit after the end of each work shift.

Downstream of the mass sensor, the filtered air sample flows through an orifice used in conjunction with a differential pressure measurement to determine the volumetric flow rate. The system computer uses this information to maintain a constant volumetric sample flow by varying the speed of a DC pump.

At the heart of the TEOM mass sensor is a hollow tube called the tapered element that is clamped at its base and is free to oscillate at its narrow end (Fig. 3). The exchangeable filter cartridge mounted on its narrow end collects the respirable particles contained in the air stream that pass from the entrance of the mass sensor through the tapered element. Electronic components positioned around the tapered element cause the tube to oscillate at its natural (or resonant) frequency.

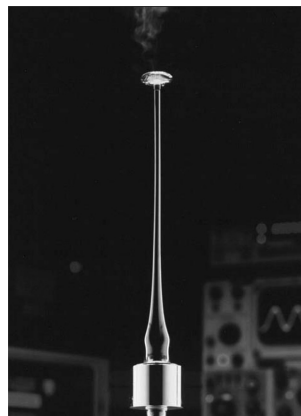


Figure 3. Tapered element with exchangeable filter mounted on narrow end.

As additional mass collects on the sample filter, the natural oscillating frequency decreases as a direct result. This approach uses first principles of physics to determine the mass change of the filter, and is not subject to uncertainties related to particle size, colour, shape or composition.

Built-in sample conditioning to remove excess moisture minimizes the PDM's response to airborne water droplets. The PDM determines the mass concentration of respirable dust in the mine environment by dividing the mass (as determined by the frequency change) collected on its filter over a given period of time by the volume of the air sample that passed through the system during the same time frame.

The two battery packs inside the PDM provide power to the miner's cap lamp and the particle sampling and analysis system. Laboratory and in-mine testing conducted to date indicates a battery lifetime of 12 hours or more for both the cap lamp and mass monitor batteries.

The PDM internally stores the readings from its built-in environmental sensors and mass sensor for later downloading, and provides summary information on a continuous basis to the miner through the display located on top of the battery case. The display continuously shows the latest values for the cumulative mass concentration, the current dust concentration, and the miner's end-of-shift projected exposure. Through this interface, miners can gauge their current dust exposure, as well as the effectiveness of actions taken to reduce the in-mine dust concentration.

The PDM also allows miners and management to initiate secondary dust loading measurements for specific monitoring objectives without affecting the shift-based statistics. The averaging time used for these readings is user-selectable prior to the start of the work shift, and can be set to a time base as short as 15 minutes for maximum instrument responsiveness. This

capability enables the monitor to be a powerful engineering tool to gauge the effectiveness of various dust or ventilation engineering control techniques.

In 2003, NIOSH conducted extensive testing of the PDM to determine its laboratory and in mine performance. In addition, anecdotal data collected in the mines showed several occasions where miners were able to identify situations that were producing high levels of respirable coal mine dust. Volkwein et al. (2004a & 2004b) discussed examples where the PDM's response to unplanned changes resulted in action being taken to keep dust exposures as low as possible.

3 AUSTRALIAN EVALUATION OF THE PDM

The objective of the study was to evaluate the PDM for use particularly in engineering studies to evaluate the effectiveness of dust control strategies. This project was designed to evaluate the ability of the new PDM to quickly and accurately measure changes in mine section dust levels at manned points before and after implementation of a change or an improvement.

3.1 Australian tests – Mine A

Mine A is a Hunter Valley underground longwall mine producing low sulphur bituminous thermal coal exported for power generation and industrial applications. PDM evaluation tests undertaken included operator positions at development faces and longwall face, Beam Stage Loader (BSL) and belt transfer points at various locations.

A total of three PDM units were made available for engineering evaluation tests. Tests were initially undertaken at a development face to monitor the dust exposure levels of various equipment operators. The PDM units give both 15 minutes (MC1) and 30 minute (MC0) rolling averages of dust concentration and it was decided initially that each monitoring test undertaken should last for at least 45 to 60 minutes. PDM units were put on continuous miner (CM), bolter and shuttle car (SC) operators at 8:15 pm. During the tests the face crew was replaced at 9:10 pm by the second crew as the first crews were released for crib break. The results of the PDM tests are shown in Figure 4 as 30 minute average and in Figure 5 as 15 minute average dust levels.

By comparing the dust levels shown in Figures 4 and 5 it is concluded that for the engineering evaluation purpose it is better to use the 15 minute rolling average dust concentration than 30 minute rolling average dust concentration as the 15 minute average gives a quicker response to monitored changes during the test and shows more significant dust concentration variations.

During the tests an unplanned event took place. The end cap of ventilation ducting in the inactive face at A heading of the development section was sucked in

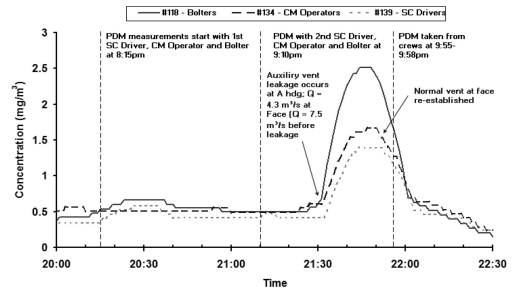


Figure 4. Development Face PDM results – 30 minute average.

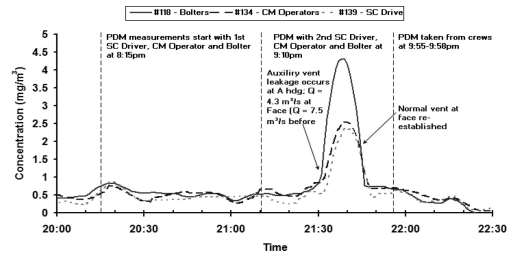


Figure 5. Development Face PDM results – 15 minute average.

and caused reduction in the ventilation air quantity available to the face being monitored from 7.5 m³/s to 4.3 m³/s. This caused a significant loss of suction head in the ventilation ducting at the face resulting in the dust-laden air at the face billowing back onto operators. All PDMs worn by the three operators have registered sharp rises in dust level. In fact this unplanned event was first noticed by one of the operators who had checked the real time display on the PDM he was wearing at the time. The failure of the end cap piece in the inactive face was soon rectified and the normal ventilation flow re-established. Readings from all PDMs show the immediate reduction in dust concentration.

Tests were carried out at Mine A longwall face to monitor the dust suppression efficiency of sprays in the BSL and at a 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. Results of BSL tests are as shown in Figure 6.

During the test, BSL sprays were on initially and then disconnected for about 30 minutes and then connected again. The results show that with the sprays off dust concentration levels downstream of BSL were dramatically increased while the dust concentration level upstream of BSL remained constant with little variations.

It was found that the fluctuations in dust levels measured by the PDM upstream of the BSL correlated well

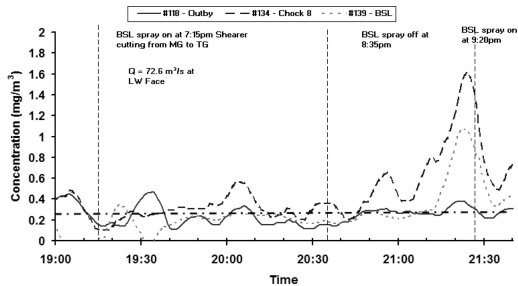


Figure 6. Mine A Longwall BSL PDM results – 15 minute average.

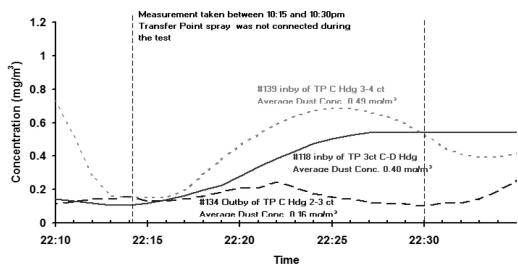


Figure 7. Mine A Longwall belt transfer point PDM results – 15 minute average.

with whether there is coal loaded on the 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 less than 0.2 mg/m^3 . It is possible to draw a horizontal line as shown in Figure 6 to indicate whether there is coal on the belt or not.

Results of Mine A longwall belt transfer point to the mains belt PDM measurements show that an increase in dust levels of more than 0.2 mg/m^3 was observed at a belt transfer point (Fig. 7). This increase doubled the concentration of respirable dust levels in the intake air. At the time of measurements the sprays at the belt transfer point were not connected.

A second evaluation of a belt transfer point occurred where one Mains belt met another Mains belt at 90 degrees. Similar results were observed as with the previous test at the Longwall belt transfer. Dust levels were doubled as air passed across the belt transfer point. Again, there were no dust sprays operating during the test.

Measurements were carried out at Mine A longwall face to monitor the dust level experienced by shearer and chock operators in a unidirectional mining cutting sequence. Results of these tests are shown in Figure 8.

For the shearer operator test, one PDM (Unit #139) was worn by a mine person who shadowed one of the shearer operators for about 30 minutes during unidirectional cutting. The other two PDM were measuring dust levels outbye of the BSL (Unit #118) and at

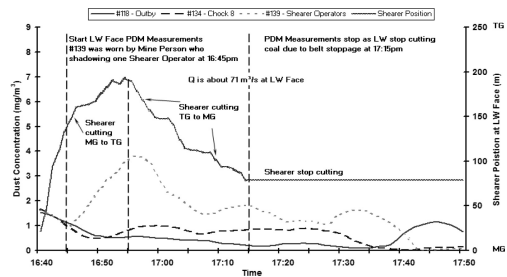


Figure 8. Mine A Longwall shearer operator PDM results under unidirectional cutting.

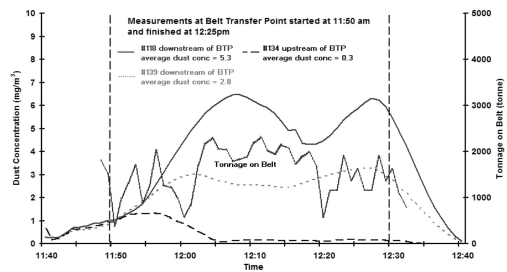


Figure 9. Belt transfer point PDM results – 15 minute average.

Chock No 8 position (Unit #134). The shearer position data was downloaded from the mine monitoring system and indicated that the shearer was cutting from maingate to tailgate first and then cutting from tailgate back to maingate during the test. The results indicated that the shearer operator was subjected to high dust level exposure when cutting from maingate to tailgate. When cutting from tailgate to maingate the dust level experienced by the shearer operator was much lower.

3.2 Australian tests – Mine B

Mine B is also located in the Hunter Valley and is considered to be one of the lowest cost longwall operations of its kind in Australia. Currently Mine B has an annual production of about 6.5 million tonnes. PDM evaluation tests undertaken included operator positions at development faces and longwall face, BSL, belt transfer points and belt tripper drives at various locations. Tests on effectiveness of an air stream helmet for isolation of miners to dusty atmospheres were undertaken.

Results of PDM tests on a belt transfer point are shown in Figure 9. Information about the tonnage on the belt during the tests was also obtained from the mine control and monitoring system. It should be noted that the tonnage was measured about 1 km away from the belt transfer point. Therefore, the tonnage on belt data was shifted horizontally along the timeline to take this into account.

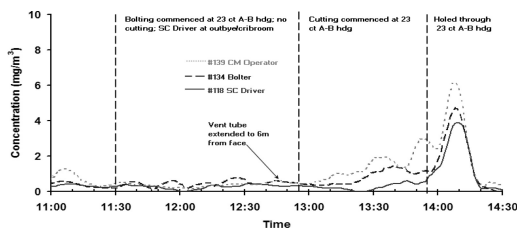


Figure 10. PDM results at development face during cut through holed through.

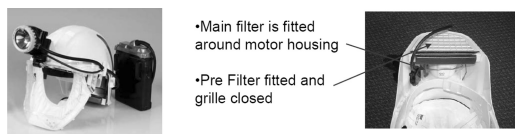


Figure 11. Photographs of air stream helmet and the filters used.

It can be seen that the dust concentration measured correlates well with the amount of coal transported on the belt. The more coal transported on the belt, the higher dust concentration levels resulted at belt transfer point.

Tests were undertaken at a development face to monitor the dust exposure levels of various equipment operators.

During the shift, due to a cable problem with a face shuttle car, cutting was delayed for two hours. Ventilation at the development face was well maintained and dust levels appeared consistent for all face operators. Towards the end of shift, a hole-through in mining the cut through from Heading A to B occurred. Ventilation at the face was disturbed when the hole-through occurred and dust concentration levels experienced by CM operator, bolter and SC driver were increased. These high dust results can be seen in Figure 10.

In Figure 10, it also can be seen that before hole-through, face ventilation condition was deteriorating, as the ventilation ducting was not extended. The dust levels experienced by both CM operator and bolter, as they were standing right behind the machine were gradually increased. However, dust levels experienced by the SC driver remained fairly constant before the hole-through.

Tests on stream helmets were carried out at the belt transfer point discussed previously. Two air stream helmets were used with one worn under normal operating condition and the other worn with both the pre and main filters (as shown in Fig. 11) removed. All three PDMs were used, one sampling the background atmospheric dust level and the other two sampling the air inside the two test air stream helmets. The results of the air stream helmet tests are shown in Figure 12.

An average dust concentration of 0.05 mg/m^3 was measured inside the normal operating air stream

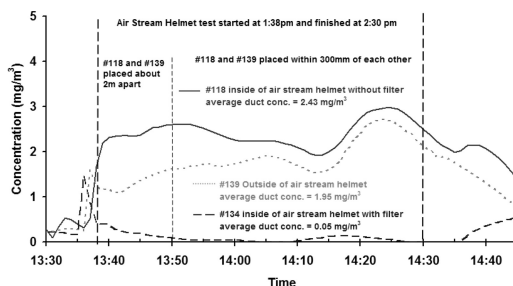


Figure 12. Air stream helmet PDM results – 15 minute average.

helmet during the 40 minutes test period. This demonstrates that the filters used by air stream helmet can filter out most of the respirable dust. Without the filters in place, average dust concentration inside the air stream helmet was similar to that of the outside atmospheric were consistently higher than the dust levels measured in background atmosphere. A similar phenomenon was reported by others when attempting to measure dust levels inside and outside air conditional cabs (Volkwein 2005). It was concluded that an enclosed space acts as a dust trap when a jet stream injects dust laden air into a constrained space leading to higher than background dust level. In addition the jet stream in the enclosed space would keep the dust suspending longer.

Caplan et al. (1973) maintain that in air streams with velocities up to 1.5 m/s neither the air velocity nor the cyclone inlet orientation has any impact on the dust concentration measured by a sampler. However, at air velocities over 1.5 m/s , both the air velocity and the cyclone inlet orientation have an impact. Cecala et al. (1983) found that when the Dorr-Oliver cyclone inlet is pointed directly into the wind, it over samples when the air velocity exceeds 4 m/s . At very high velocities of 10 m/s it over-samples by 35 percent. When the cyclone inlet is at a right angle to the wind or pointed downwind it under-samples when the air velocity exceeds 1.5 m/s .

Cecala et al. also tested a shielded cyclone to see if a shield would reduce the over- and under-sampling. The shield was a 25 mm wide strip of aluminum sheet bent into a cylinder. This cylinder was then wrapped around the top of the cyclone and bolted to the hole in the back of the vortex finder clamp. Testing showed that the shield successfully reduced both the over- and under-sampling to within 14 percent of the true value when tested at 10 m/s .

These evaluations were done with the traditional lapel worn personal samplers with ordinary pumps operating across the normal range of flow rates. Flow rates from these pumps are affected by conditions such as the resistance of the filter as it is loaded during sampling and hose arrangement. The pump used by

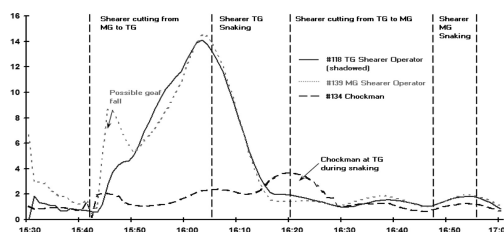


Figure 13. Shearer operators and the chockman PDM results – under bidirectional cutting test 1.

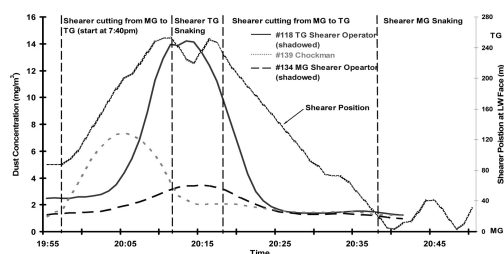


Figure 14. Shearer operators and the chockman PDM results – test 2 (Shearer position plotted).

the PDM has a self regulating flow rate function to correct the response to external conditions and maintains a constant flow rate throughout the measurement period. Examination of flow rates recorded in PDM data files during the air stream helmet tests showed that through out the tests the flow rates of the three PDM units remained at a constant of 2.2 litres per minutes. Therefore it should not be either over or under sampling as suggested by Cecala et al.

Two PDM Tests were undertaken to examine the dust exposure levels of shearer operators and the chockman along longwall face during bidirectional cutting. As shown in both Figures 13 and 14 it was found that when the shearer was cutting from maingate to tailgate, both maingate and tailgate shearer operators can experience higher dust concentration levels than when snaking at either end of the face or when cutting from tailgate to maingate.

In general the chockman experienced less dust than shearer operators during cutting as the chockman usually stands outbye of the shearer. However when snaking at the tailgate end the chockman may experience short periods of high exposure as he stands inbye of the shearer. Advances in automation of shearer cutting and chock advance and reliability of systems will influence man positing and exposure levels.

Measurements were also taken inbye and outbye of the belt tripper drive located about 500 m outbye the longwall face as shown in Figure 15. There was a spray in operation but inappropriately placed for dust control purpose. Spray operation was not affecting dust levels inbye the tripper drive. The results in the following

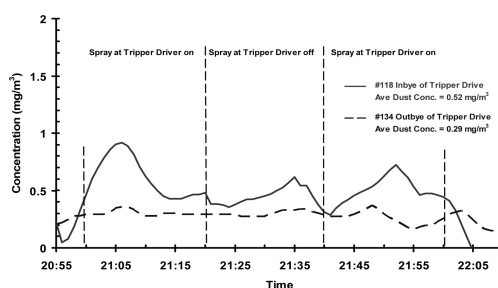


Figure 15. Belt tripper drive PDM results – 15 minutes average.

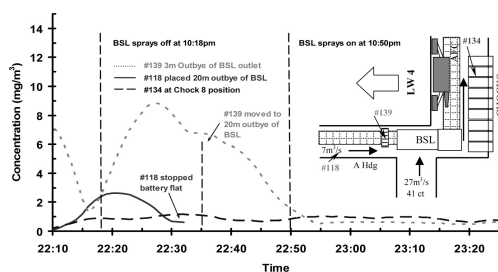


Figure 16. BSL sprays PDM test 1–15 minutes average.

figure showed higher dust level inbye this dust transfer point and the benefits of installing dust control at the tripper drive.

Efforts were also done in examining the effects of sprays installed within the Mine B longwall BSL on dust suppression efficiency. Two tests were undertaken. All three PDMs were used with one placed 20 m outbye the BSL, another at about 1m in front of the BSL outlet and the other at Longwall face Chock No 8 position. The results of measurements around the BSL with spray on and off are as shown in Figure 16.

It was found that as the Longwall face was located near a cut through less than 20 percent of the total Longwall air was passing across the BSL in the A heading and the rest of the intake air flowed directly to Longwall face by the cut through. This dilution led to a very mild increase in dust levels measured at Chock No 8 position with the sprays at the BSL turned off even though the PDM placed close to the BSL outlet had measured a dramatic increase in dust levels after the sprays were turned off.

One of the PDM used ran out of power and switched itself off during the test as the PDMs had been in use for more than 12 hours. A second test on BSL sprays with better placement of the PDM units to take into consideration of intake air split in the cut through was conducted and the results are shown in Figure 17.

It is shown that with the BSL sprays switched off, the dust concentration levels inbye of the BSL have increased dramatically. Dust concentration levels at

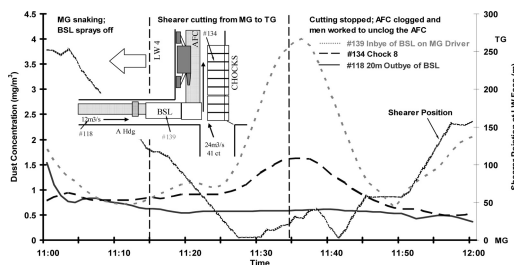


Figure 17. BSL sprays PDM test 2–15 minutes average.

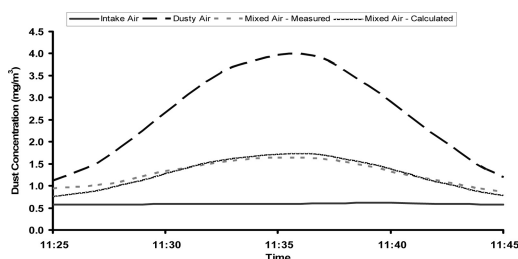


Figure 18. Comparison of measured and calculated dust concentrations at Chock No 8.

Chock No 8 position have also increased but more modestly. This is because the dusty air from the BSL was mixed with about twice the quantity of relatively clean intake air from the cut through.

About one third of the total intake air available to the Longwall face was from A heading across the BSL. Dust concentration levels measured by PDM confirmed the air stream ratio is about 1 to 2. Based on the ratio, it is possible to calculate the expected dust concentration at downstream location (Chock No 8) by knowing the upstream dust levels in intake air (outbye of BSL) and dusty air (inbye of BSL). Figure 18 shows a good correlation between the measured and calculated mixed air dust levels at Chock No 8 position.

4 CONCLUSIONS AND RECOMMENDATIONS

Based on the tests conducted, it is concluded that the PDM has demonstrated its potential use as an engineering tool to locate and assess various sources of dust during normal mining operations. The principles and concepts used to identify and fix some of the higher dust levels are generally common sense and would be easy for most miners to understand.

However, to make the most effective use of this information, training and experience in using this type of technology will be very important. Experience with the data from the unit will help miners gain confidence to use the information to maintain reduced or safe dust

levels during mining. Further in-mine trials are necessary to determine the long term durability, stability and maintenance requirements for this new dust monitor.

Mine managements from several mines have shown interests in obtaining the units when they meet IS standards in Australia and are commercially available.

Possible improvements to PDM for Australian mine applications which could be considered include provision of an option to display histograms of 15 minute instead of or as well as 30 minute results, use of an adaptor to recharge battery through an Australian style cap lamp bracket. Exchange cap lamp for Australian type lamp that can power an Air stream helmet and expand keypad to allow the keying in underground location. Incorporation of “PED” and “Tag” options would also be an advantage.

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