Real-Time DPM Ambient Monitoring in Underground Mines

Hsin Wei Wu[1], A.D.S. Gillies[2], J. D Volkwein[3] and J Noll[4]

[1] Director, Gillies Wu Mining Technology, h.wu@minserve.com.au
[2] Union Pacific/Rocky Mountain Energy Professor Missouri University of Science and Technology, gilliesst@mst.edu
[3] Research Physical Scientist, Pittsburgh Research Laboratories, National Institute of Occupational Health and Safety, jdv1@cdc.gov
[4] Research Scientist, Pittsburgh Research Laboratories, National Institute of Occupational Health and Safety, jin1@cdc.gov

ABSTRACT

A real-time Diesel Particulate Matter (DPM) monitor has been developed on the base of the successful National Institute of Occupational Health and Safety (NIOSH) designed Personal Dust Monitor (PDM) unit. The objectives of a recently completed Australian Coal Association Research Program (ACARP) study were to modify the PDM to measure the submicrometre fraction of the aerosol in a real-time monitoring underground instrument. Mine testing focused on use of the monitor in engineering evaluations to determine how conditions can be improved. Studies, including a selection during Longwall (LW) moves as described in this paper, demonstrated how DPM concentrations from vehicles fluctuate under varying ventilation and operational conditions. Correlation between the current SKC DPM measurement system and real-time DPM monitors were conducted and results from six mines show a correlation between elemental carbon (EC) and the new monitor DPM mass ranging from .51 to .81 with R^2 >.90. This differences in suspected to be due to variations from mine to mine in aspects such as mine atmospheric contamination, vehicle fleet variations, fuel type, engine maintenance, engine combustion efficiency, engine behaviour or interference from other submicrometre aerosol..Real-time monitoring readily reflects the movement of individual diesel vehicles and allows pin-pointing of high exposure zones such as those encountered where various vehicles work in areas of constrained or difficult ventilation. 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. Identification of high DPM concentration zones allows efficient modification of mine ventilation, operator positioning and other work practices to reduce miners' exposures without waiting for laboratory analysis results.

KEYWORDS: Longwall, Real-time DPM, Total Carbon, Elemental Carbon.

INTRODUCTION

The real-time DPM monitor has been developed on the base of the successful PDM unit for respirable dust monitoring. The objectives of recently completed ACARP study (Gillies and Wu, 2008) has been to finalise the design of a DPM unit, to undertake comprehensive and internationally recognised laboratory testing, to evaluate the new design, and to undertake an underground series of tests to establish the robustness and reliability of the new approach.

The PDM gives real-time readings and is mounted within the miner's cap lamp battery and internally measures the true particle mass of aerosol collected on its filter. Measurements are insensitive to water spray as opposed optically based measurement approaches. It has been recognised that the PDM's unique measurement approach has application to allow real-time atmospheric DPM monitoring. The industry has no real-time direct reading atmospheric DPM monitor at present. Under the project Thermo Fisher Scientific has undertaken structural changes to the PDM to convert it to a DPM real-time monitoring underground instrument, the D-PDM. The Pennsylvania Pittsburgh Research Laboratories of NIOSH (the group that originally contracted for the PDM development) has undertaken laboratory "calibration or verification" testing. A phase of Australian mine robustness and engineering testing has been undertaken to ensure the instrument can effectively assist mine management to help handle this health issue.

Tests have been undertaken at points of expected high atmospheric DPM such as during LW face moves and in Development Headings. The paper discusses how the monitors have performed within the underground mine environment in evaluating DPM during the various phases of LW moves. The project has closely examined the influence of aspects of the mine ventilation system. Results have been compared to alternative industry pollutant measuring approaches. The outcomes of the project demonstrate a new tool for understanding the atmosphere in the presence of DPM.

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 limits of 0.2 mg/m^3 submicrometre particulate matter, 0.16 mg/m^3 TC particulate and 0.1 mg/m^3 EC particulate. A few prescriptive mining regulations are in force internationally such as those applying to the US metalliferous mining industry from May 2008 based on a DPM limit of 0.16 mg/m^3 TC particulate. The real-time DPM monitor is being developed on the base of the successful PDM unit. Thermo Fisher Scientific has undertaken structural changes to the PDM to convert it to a submicrometre real-time monitoring underground instrument, the D-PDM. The Pittsburgh Research Laboratories of NIOSH (the group that originally contracted for the PDM development) has undertaken laboratory evaluation of the concept. The real time DPM unit continually reports levels of mine atmosphere submicrometre aerosol in mg/m^3 from real-time readings.

The submicrometre size-selective inlet selected for this potential field instrument was the BGI 1-µm sharp-cut cyclone model SCC0.732 followed by a Bureau of Mines (BOM) designed 0.8 micrometre cut point impactor, at a flow rate of 1.7 lpm. Figure 1 shows the size selective configuration.

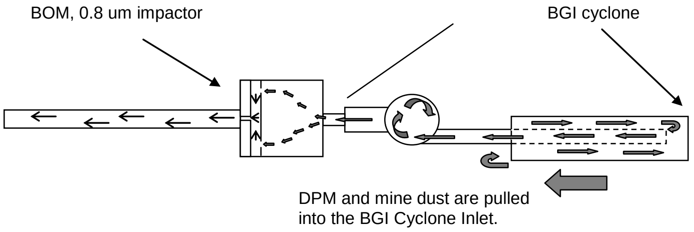


Figure 1 Schematic of prototype D-PDM Sampling Inlet.

The D-PDM instrument is currently at a prototype stage and as with all new technologies will need industry acceptance and support to reach its full potential.

MONITORING OF DIESEL PARTICULATE MATTER

The mine tests by their very nature were restricted to equipment available for testing underground. Six of the mines visited (Mines A to F) focused on LW equipment moves from one panel to another and particularly esamined the various ventilation arrangements used during shield transport to the installation roadway. The real-time DPM monitors successfully evaluated changes during the different tests and between different steps within the individual tests.

Mine A

Mine A testing found it was straight forward to analyse results for arrival and departure times of diesel machines at the face and see whether these matched the arrival of the vehicle exhaust plume. Figure 2 examines one three hour period record of real-time DPM readings as compared to heading air velocity and shield carrier speed. Close examination of results from #108 monitoring the DPM downstream of the main gate (MG) and back road showed that when the shield carriers travel in that in three cases they arrived at the tail gate (TG) end of the face in advance of the peak level of the DPM cloud. This indicated that the carriers were generally travelling at higher average speed than the air velocity. However Carrier #1112 arrived slightly later indicating slower machine travel speed than air velocity. The time difference and the peak concentration depend on the air velocity and shield carriers' travel speeds. Put simply if the shield carrier travels at the same speed as air velocity peak concentration will be extremely high and the carrier will arrive at the same time as the peak. Note that the DPM data has a lag time because it is presented as a rolling average concentration over the previous 10 minutes or 30 minutes.

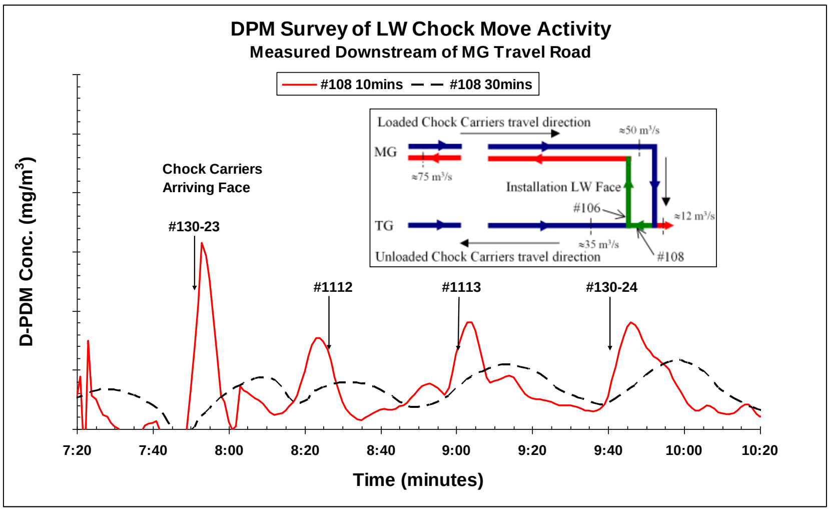


Figure 2 Observations on shield carrier DPM over a three hour period at monitor 108 fixed location.

Mine B

Mine B completed an audit on sources of DPM within a LW installation panel by strategically placing the real-time DPM monitors at points as shown in Table 1. DPM make values account for DPM monitored value in air mg/m^3) and air quantity diluting the exhaust (m^3/s). These values (mg/s) give a value that can be compared for different equipment under varying ventilation and other mine conditions.

Table 1 Sources of DPM identified in the installation LW panel in Mine B.

Location	Sources (μg/s)	%	Comments
MG C & D Hdgs	3.03	18.6	Mains air at MG entrance
Borehole	0.00	0.0	back of LW panel, fresh air
LW Face	4.77	29.2	Shunting Mule or LHDs
TG D Hdg	6.96	42.6	Shield carriers travel way
TG C Hdg	0.00	0.0	No diesel activity
Leakages	1.57	9.6	Mains air; coffin seal & double doors
Measured Total	**16.32**	**100.0**	

Mine C

Mine C examined one 2.5 hour period as a 37 tonne Dozer was brought in to pull the first shield on recovery a LW face as shown in Figure 3. About 51 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 shield but was unsuccessful. It worked hard much of the time at maximum revs. Between 15:32 and 16:00, a Shield Carrier Chariot was chained to the Dozer and together they successfully pulled the first Shield while working hard. A general observation on LW moves was that some high submicrometre 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.

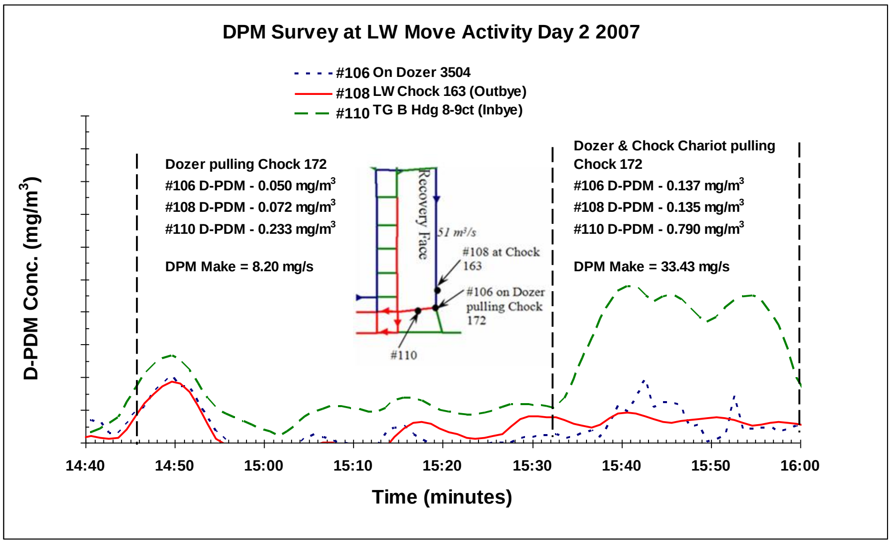
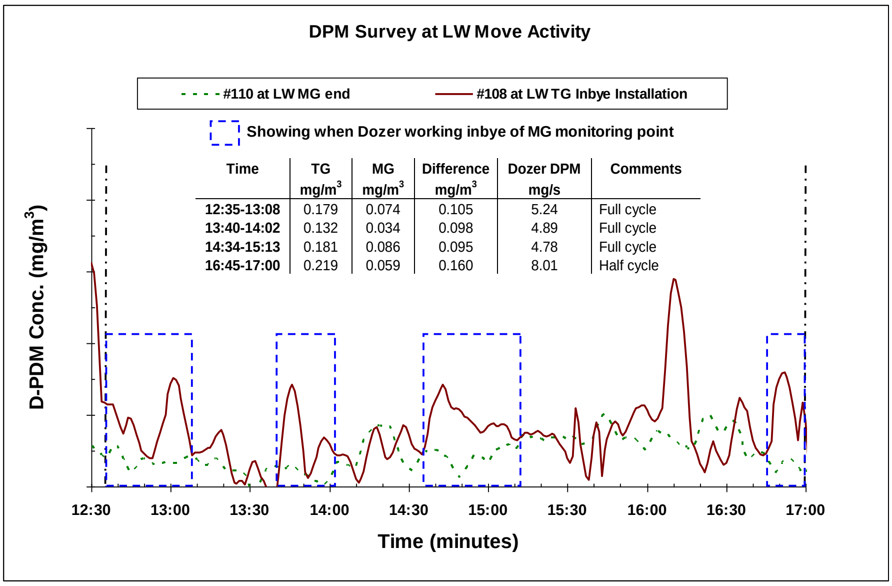


Figure 3 Submicrometre DPM in LW Recovery Face Pulling Shield.

Mine D

Mine D monitored a highwall mine with no underground Mains headings. Ventilation quantity was high and air entered the panel in a clean state. It was found over a number of tests that 62% of DPM within the panel was generated by Carriers hauling Shields in the gateroads and 38% generated by vehicle movement along the LW face.



Time	TG mg/m^3	MG mg/m^3	Difference mg/m^3	Dozer DPM mg/s	Comments
12:35-13:08	0.179	0.074	0.105	5.24	Full cycle
13:40-14:02	0.132	0.034	0.098	4.89	Full cycle
14:34-15:13	0.181	0.086	0.095	4.78	Full cycle
16:45-17:00	0.219	0.059	0.160	8.01	Half cycle

Figure 4 DPM in Mine D LW Installation Face outbye/inbye the face working dozer

Air passing down the segregated belt gateroad reached the face clean and could have been used to better effect on the face where operators were installing newly arrived shields. When planning LW moves mines should evaluate and review alternatives for ventilating shield travel roads to the face. The DPM plots in Figure 4 show variability with the Dozer working as four shields were installed. The difference between LW MG and TG plots clearly shows contributions of the face Dozer..

Mine E

Mine E tests on the recovery face were in a well ventilated situation with clean gateroad belt heading air significantly diluting any DPM pollution from the gateroad travel heading. An electric tracked “mule” moved Shields along the face and did not add DPM pollution. Figure 5 shows influence of DPM make at the installation face with outbye monitored levels subtracted. The close match between times chariots’ face time and DPM pollution levels inbye can clearly be seen. General recommendations were in a planning a LW move it is advantageous to evaluate and review all alternatives for ventilating Shield travel roads to or from the LW recovery and installation faces to reduce peak and average miner exposures.

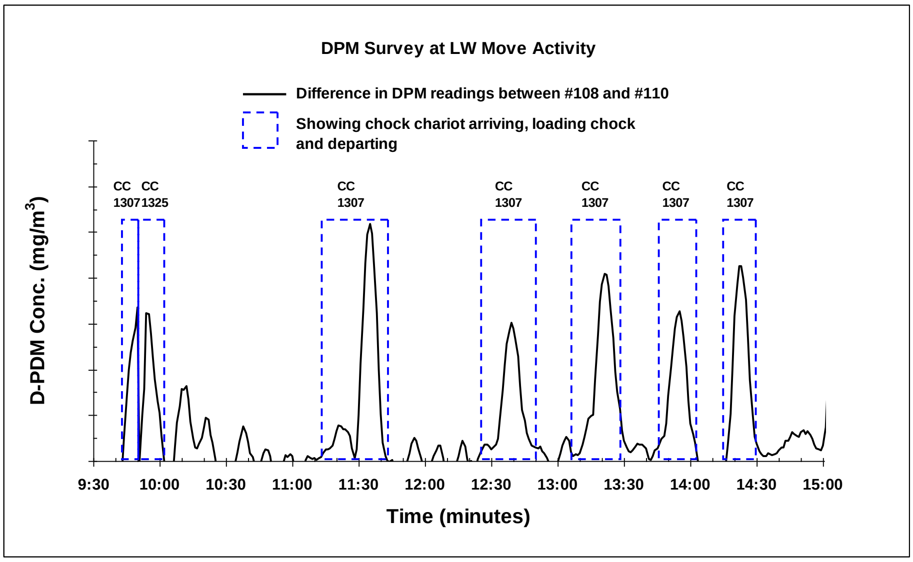


Figure 5 Difference in outbye and inbye DPM in Mine E LW Installation Face

Mine F

Figure 6 shows the influence of DPM make from diesel activities at a LW face with outbye monitored levels subtracted. The close match between time the chariots and

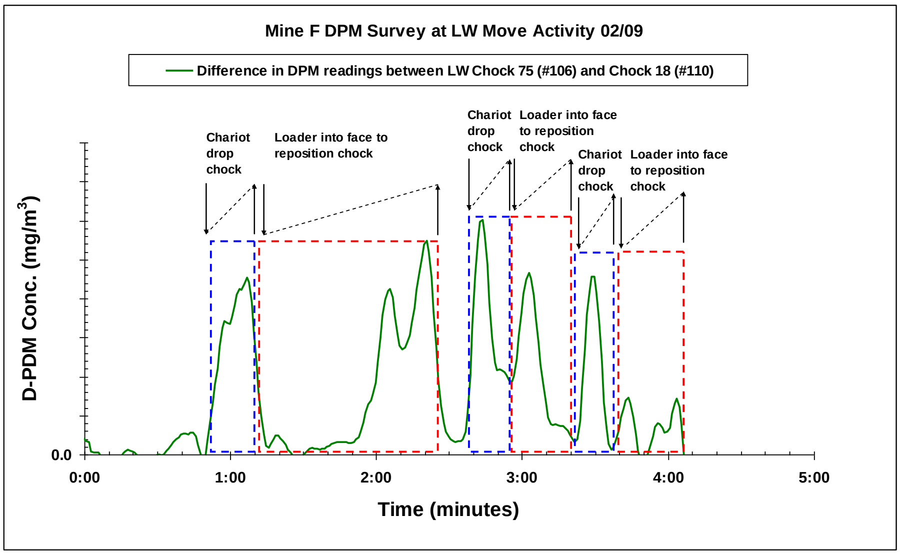


Figure 6 DPM and diesel activities in Mine F LW Installation Face

loader were operating in the face and monitored pollution levels inbye is clearly seen.

An audit was completed on sources of DPM within the LW installation panel by strategic placement of the DPM monitors. It was found that 25% was contributed from outbye diesel activities in Mains, 25% from diesel activities in panel the Travel Road, and 50% from diesel activities within face areas. A good initiative in this mine has been to limit the number of vehicles in the panel by the use of a Tag Board and Traffic controller at the panel travel road entrance. The diesel Tag Board design should consider the diesel loading from outbye Mains diesel activities which account for up to 25% of the total diesel loading for the LW panel. Summary of DPM levels from each shift at points monitored throughout the panel showed increasing levels from influence of additional equipment in series within the ventilation circuit.

SKC MINE COMPARISON TESTS

It is appropriate to compare field results from the real-time DPM monitor with another available measuring instrument .the NIOSH developed SKC impactor system. The SKC system delivers laboratory analysed shift average results and not real-time results. During investigations parallel underground SKC samples have been taken for comparison with the real-time DPM monitored results. These samples came from the same mine atmosphere through use of a “can” with outlets for real-time DPM and SKC monitors. Under the SKC system the sample submicrometre fraction is deposited on a filter after first passing through a respirable cyclone sampler and a 0.8 micrometre impactor that removes most of the mineral fraction of the sample. The sample filter is analysed for EC and (Organic Carbon) OC whose sum is the TC.

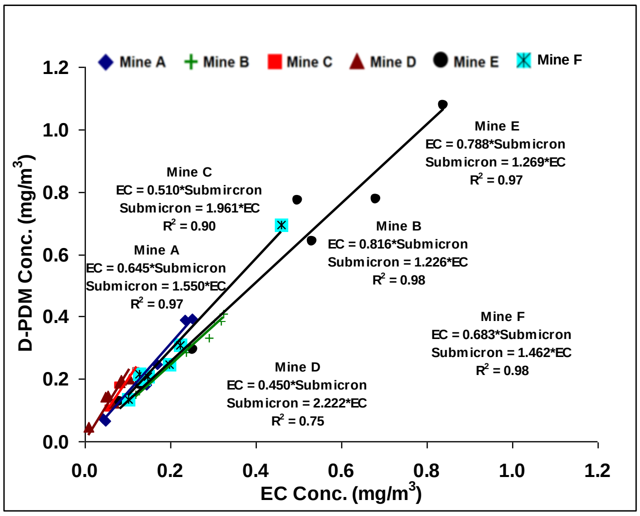


Figure 7 Mine individual relationships between EC and Submicrometre DPM

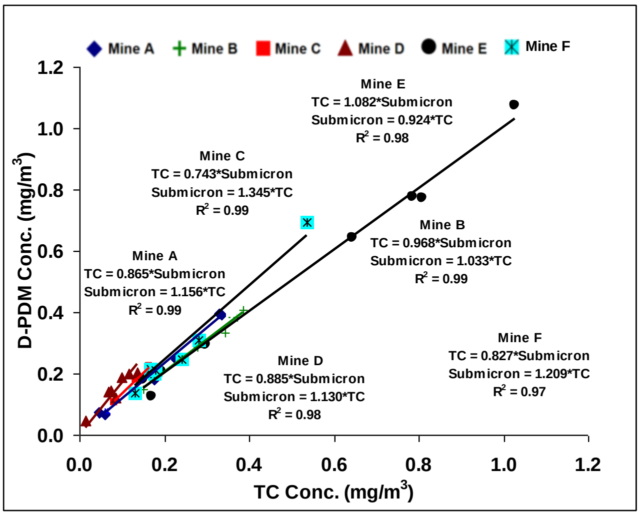


Figure 8 Mine individual relationships between TC and Submicrometre DPM

Figures 7 and 8 show a related set of results, namely those from Mines A to F LW moves..Real-time DPM results (designated as D-PDM measurements) are compared with shift average SKC impactor determinations of EC and TC particulate. Close correlations were found for all cases ($R^2 \geq 0.97$) for TC versus DPM. All EC versus DPM correlations were good ($R^2 \geq 0.90$) except for one set of mine results. The results also demonstrate that relationships (the slopes of the individual mine relationships) vary between mines. This differences in suspected to be due to variations between mines in aspects such as atmospheric contamination, vehicle fleet variations, fuel type, engine maintenance, engine combustion efficiency, engine behaviour, or interference from other submicrometre aerosol.

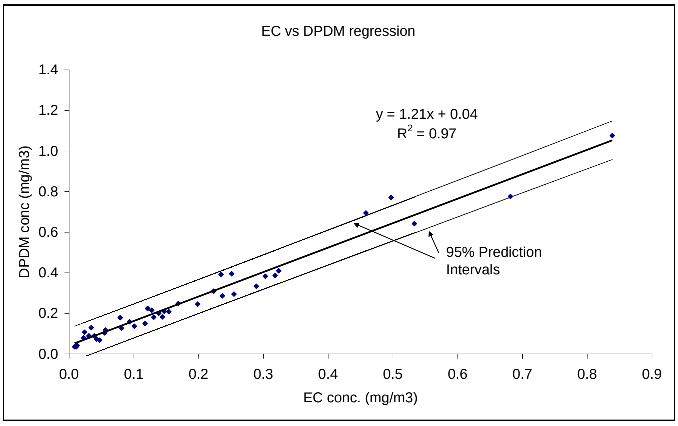


Figure 9 Combined relationships for Six mines between EC and Submicron DPM.

Figure 9 shows combined DPM results from the all mine test series compared with SKC impactor collection determinations of EC particulate shift average results taken in the particular mine at the same time. The distribution shows the calculated upper and lower 95% confidence limits about the regression. The combined mines relationships are close with $R^2 = 0.97$ for EC compared with submicron DPM.

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

CONCLUSIONS

A project on diesel particulate matter real-time monitoring has been discussed. The outcome is that objective testing over different approaches and comparisons with the SKC monitoring lead to the conclusion that this real-time DPM unit provides reasonable results. The principal industrial application of the unit will be to give a greater understanding through real-time information of DPM levels in mine environments and particularly in engineering evaluation exercises. The paper has discussed how the monitor has performed within the underground mine environment in evaluations of LW moves and has closely examined the influence of aspects of the mine ventilation system on underground DPM pollution.

REFERENCES

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

Birch, M.E. and Noll, J.D., 2004. Submicrometre Elemental Carbon as a Selective Measure of Diesel Particulate Matter in Coal Mines. J Environ Monit. 2004, 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 Laboratory, 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.

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