



Comparison of diesel particulate matter ambient monitoring practices in underground mines in Australia, the United States and South Africa

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ABSTRACT: Exposure to the microscopic particles in diesel engine exhaust can lead to serious health problems including incidence of cancers, heart disease and increased susceptibility to respiratory ailments of pneumonia, bronchitis, and asthma. Different ambient monitoring approaches being used in Australia, the United States and South Africa are examined. The options for the treatment and reduction of diesel emissions have become a major area of concern for many mine operators. The study compares various DPM ambient monitoring practices used currently in underground mines in Australia, the US and South Africa. Measurements undertaken in the three countries are examined. DPM monitoring approaches have been available for some time based on shift average measurement practices but these have limitations in leading to understanding of DPM levels over short time periods. Real time monitoring produces data that is required for engineering evaluation exercises and often highlights mine situations where DPM levels are relatively high for substantial time periods.

1 INTRODUCTION

Exposure to the microscopic particles in diesel engine exhaust can lead to serious health problems including the incidence of cancers, heart disease and increased susceptibility to respiratory ailments of pneumonia, bronchitis, and asthma. Different diesel particulate matter ambient monitoring approaches being used in Australia, the United States and South Africa are examined. The options for the treatment and reduction of diesel emissions have become a major area of concern for many mine operators. The basis for any complete Diesel Particulate Matter (DPM) compliance strategy should be a comprehensive baseline study of the DPM present in the mine atmosphere including ambient air monitoring, analysis of monitored data, and development of a realistic plan for ambient DPM reduction. It is important that studies are taken on a real time basis to allow important sources of DPM in the mine atmosphere to be prioritized.

NIOSH has been closely involved in development of instruments for measurement of airborne DPM for more than 20 years. The earliest approaches focused on shift average determinations with development of the SKC approach. Two real time DPM monitors have been developed since. The first, the D-PDM was developed on the base of the successful Person-

al Dust Monitor (PDM) unit. The heart of the PDM is a miniaturized direct mass measuring sensor that measures mine dust. Changes were undertaken to the PDM (Gillies and Wu, 2008) to convert it to a DPM particulate submicrometer real time monitoring underground instrument which was named the D-PDM. The real time DPM unit continually reports levels of mine atmosphere submicrometer aerosol. The D-PDM results have been correlated with parallel SKC system DPM evaluations (Gillies, 2011). A phase of robustness and engineering testing has been undertaken to ensure the instrument can effectively assist mine management.

Another real time DPM measurement instrument, the FLIR Airtec, became commercially available in 2011 (Janisko and Noll, 2008; Noll and Janisko, 2007). It measures the Elemental Carbon (EC) component of DPM by a laser scattering approach. Both new instruments have been evaluated underground in robustness and reliability testing in coal and metal/non-metal mines.

The study compares various DPM ambient monitoring practices used currently in underground mines in Australia, the US and South Africa. Approaches from the three countries are examined. DPM monitoring approaches based on shift average monitoring have been available for some time but these have limitations in leading to understanding of DPM levels

over short time periods. Real time monitoring produces data that is required for engineering evaluation exercises and often high-lights mine situations where DPM levels are relatively high for substantial time periods. There are limits to the tools available to improve mine face conditions. One of these is increasing airflow ventilation in the working area. Another is to carefully control position of miners to upstream of working filters designed to capture DPM.

Modern large mines use hundreds of diesel vehicles. Real time DPM monitoring allows the industry to pin-point high exposure zones such as those where various vehicles work in areas of constrained or difficult ventilation. Identification of high concentration zones allows efficient modification of local mine ventilation, operator positioning, work practices and introduction of exhaust filters and other engineering tools to reduce exposures.

2 AUSTRALIAN DEVELOPMENTS

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

2.1 Ventilation Considerations in Handling DPM

One point of high DPM generation that is found in coal longwall (LW) moves occurs once every 12 to 14 months for a period of up to a month. The move relies on use of high powered shield transporters that produces high levels of exhaust pollutants of gases and DPM. Many mines find it a challenge to meet DPM recommended or target limits during all phases of operational moves. Issues that should be considered in optimizing design of strategies to minimize atmospheric DPM include:

- Maximize air quantity where LW face equipment recovery, movement or installation occurs.
- Have all moving equipment (at least loaded machinery) travel in opposite direction to air flow.
- Ensure that air velocity exceeds machine speed to ensure a plume of exhaust does not hang over travelling equipment.
- Have parallel transport roads so that movement occurs in a circuit of loaded machines travelling inbye on one road and outbye on a parallel one.

- Ensure that miners are working upstream of machinery and particularly machinery that is working on faces loading or unloading.
- Divide available air so that majority is passing along the headings used by loaded machinery.
- Monitor DPM with real time instruments so that points where “Target” limits are not being met are identified and improvements are made during current LW move or planned for the next.

Mine atmosphere measurements of DPM in Australian mines have occurred systematically since the early 2000s. Regulatory guidelines are starting to emerge in Australia and the individual states are generally moving to acknowledge DPM metal/non-metal mine limits in use in the US of 0.2 mg/m³ full submicrometer particulate matter, 0.16 mg/m³ TC particulate and 0.10 mg/m³ EC particulate. Examples of coal mine measurement real time DPM measurement are shown.

2.2 Monitoring of Diesel Particulate Matter using the D-PDM

2.2.1 Mine A

Results from DPM monitoring using D-DPM instruments are shown from three coal mines. Mine A examined one 2.5 hour period as a 37 tonne dozer was brought in to pull the first shield on recovering a LW face as shown in Figure 1. About 50 m³/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 engine power.

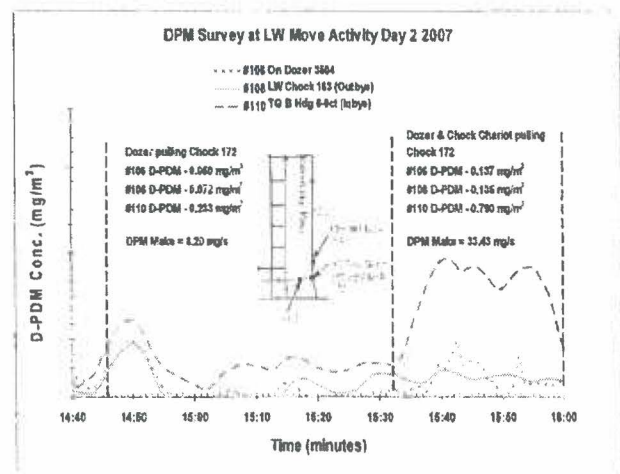


Figure 1. Submicrometer DPM in LW Recovery Face Pulling Shield.

Between 15:32 and 16:00 a shield 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 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 inby 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.

2.2.2 Mine B

Mine B monitored a highwall mine with no underground Mains headings. Ventilation quantity was high. The main diesel activities were at the LW installation face. A total of seven Chock Shields were installed during the survey period as shown in Figure 2. For the seven peaks or higher levels of DPM, cycle time and DPM make were identified. The DPM makes varied from 7.6 to 14.8 g/cycle with individual cycles time ranging from 25 to 54 minutes. This compared well with other mines' data. For example LW moves in one neighboring mine showed DPM makes ranging from 3.0 to 22.4 g/cycle and cycle times from 16 to 29 minutes for operations of Shield chariots (arrived, unloaded shields and departed) and EMICO 936 (into face, repositioned shields and out of face). The short cycle times in the other mine were due to the chariots only needing to travel half the length of the LW panel.

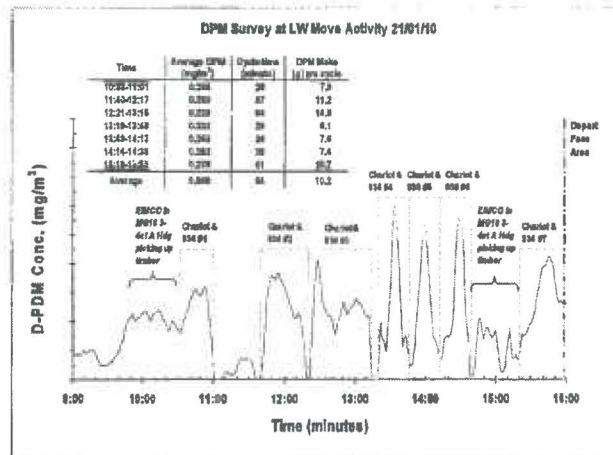


Figure 2. Submicrometer DPM of a Chariot transporting shield to installation face.

2.2.3 Mine C

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

- Chariot was working under load thus more exhaust generated.
- Chariot was travelling in the same direction as the ventilation air flow thus reducing the effective air velocity over the engine exhaust.

- Chariot was blocking much of the cross-sectional area of B Heading thus increasing airway resistance and forcing more air flow through A Heading and as a consequence leaving less air available to dilute chariot exhaust.

A computer ventilation simulation (Ventsim) model was created to demonstrate the last point with chariot travelling in tailgate B Heading. Figure 3 shows the effect of the chariot in B Heading on the ventilation air split between A and B Headings.

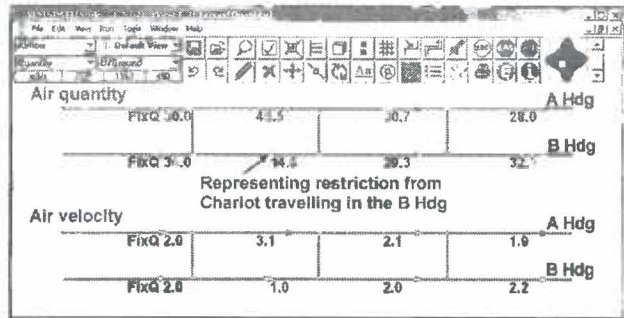


Figure 3. Simplified Ventsim model showing the effects of Chariot travel on air split.

A total of 60 m³/s was available in the TG between A and B Headings and it was assumed that air split evenly between A and B Headings. A restriction of 67% of the cross-sectional area in the B Heading by the chariot loaded shield was assumed. This restriction had reduced airflow in B Heading from 30 m³/s down to 14.5 m³/s and air velocity from 2.0 m/s to 1.0 m/s. It should be noted that actual air split between A and B Heading near the installation face was measured at 28 and 32 m³/s for A and B Headings during the surveys.

A chariot took one hour to travel from B Heading near the Recovery Face to the Installation Face (over about 3.0km (and thus at an average speed of 0.83 m/s). Therefore, a relative velocity of 0.17 m/s (about 2.5 m³/s with 14.5 m² area) across the chariot's engine exhaust can be calculated. The small amount of available air had caused buildup of DPM around the chariot while travelling inby carrying a shield which was evidenced by the high exposure level measured by the D-PDM unit on board.

3 UNITED STATES DEVELOPMENTS

The US DPM Personal Exposure Limit (PEL) was adopted in May 2008. This rule limits the Total Carbon (TC) on a shift average basis to 0.16 mg/m³. Research is continuing by NIOSH on what is an equivalent or acceptable PEL limit in terms of EC. The Airtec DPM monitor measures the EC component of DPM by a laser scattering approach (Noll and Janisko, 2007). Results from the Airtec can be compared directly with SKC system DPM

evaluations. Both the D-PDM and Airtec new instruments have been evaluated underground in robustness and reliability testing in coal and metal/non-metal mines. Two Airtec units were used and results were compared against SKC method.

A DPM survey was conducted at Mine D, a metal-liferous mine, during mucking. Downstream and upstream underground stations were selected to install real time Airtec units. Two SKC units were also installed next to the Airtec units to measure time weighted average DPM concentrations. Monitoring was conducted for 5.5 hours. Vehicle passing the points were monitored; data logged consisted of time, vehicle type and direction of travel. It was noted that almost 65 equipment units passed during the duration of monitoring. High EC content was observed whenever there was high vehicle frequency. The Airtec instrument which was installed downstream showed overall higher EC values compared to the other one upstream. The Airtec instrument which was installed upstream failed after 4.2 hours. There was a junction in between both measuring points. Air quantity downstream was 84.5 m³/s and upstream was 79.8 m³/s.

Table 1. Elemental Carbon, Organic Carbon and Total Carbon measured by SKC NIOSH 5040

Mucking	EC (µg/m ³)	OC (µg/m ³)	TC (µg/m ³)
Downstream	130	42	170
Upstream	97	27	120

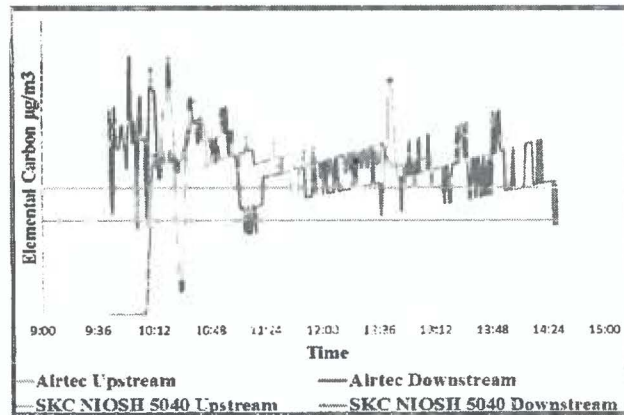


Figure 4. Time versus Real time EC by Airtec and SKC

The peak value of EC observed at the upstream Airtec was 0.220 mg/m³ after 1.7 hours. The peak value of EC observed at the downstream Airtec was 0.263 mg/m³ at 0.95 and 1.2 hours. Table 1 gives the EC, Organic Carbon (OC) and TC by SKC. Figure 4 shows comparisons between each of the Airtec and SKC units for upstream and downstream stations.

3.1 Front End Loader Cab Tests

The second set of DPM measurements at Mine E, a metalliferous mine, was based around Front End Loader (FEL) activities during a normal working operation. The aim was to check the effectiveness of the FEL operator's cab for decreasing DPM exposure and this was achieved by measurement at locations both inside and outside of the cab. Monitoring was conducted for 285 minute including 90 minutes idle time (break time) near the middle. From 9:40 to 13:06 FEL was working inside the mine at two locations. Airtec and SKC DPM monitors were used at both measuring stations and placed inside and outside the cab.

A count was made of the number of 300 kW powered haul dumpers being loaded by a FEL. Other equipment passing by the FEL was noted. A total of three different dumpers were involved in mucking operations. During the measurement period 42 dumpers were loaded by the FEL. Table 2, below gives the Elemental Carbon, Organic Carbon and Total Carbon measured by the SKC.

Table 2. TWA, Elemental Carbon, Organic Carbon & Total Carbon measured by SKC NIOSH 5040

FEL Cab	EC (µg/m ³)	OC (µg/m ³)	TC (µg/m ³)
Inside	85	5	85
Outside	300	150	450

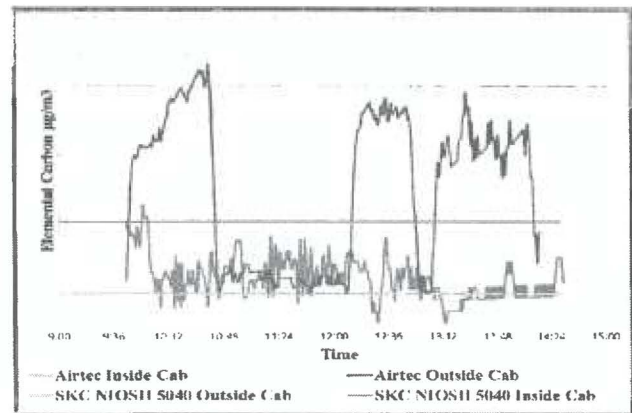


Figure 5. Time versus inside and outside real time Airtec EC and SKC measurements.

Airtec Inside the Operator's Cab: The Airtec which was installed inside the operator's cab shows quite high EC values. Before break time the peak EC was 0.352 mg/m³. Even during break time the EC content was higher than 0.1 mg/m³. The reason for this is the movements of vehicles in the workshop during lunch time, as the dumper was parked near the underground shop during break time. On resuming the loading activity the EC values increased again. Very high, consistent and alarming EC values were observed. During most of the measuring time the EC values are consistently higher than

0.1 mg/m³. An EC versus time graph for Airtec and SKC instruments installed inside FEL operator's cab is shown in Figure 5.

Airtec Outside the Operators' Cab: Before break time almost all EC values on the Airtec were above 0.5 mg/m³, which is much higher than MSHA prescribed value. During break time (10:50 to 12:20) the EC values range from 0.08 to 0.167 mg/m³. This is due to the vehicles movement in the shop during lunch time as the FEL was parked near the underground shop during break time. On resuming the work at about 12:25, the EC values raised again. The value was consistently higher than 0.6 mg/m³. At about 13:06 the loader has moved to another location, Section 9 Undercut for loading and the EC values has decreased rapidly to about 0.1 mg/m³. Once loading operation started at the new location, EC value has increased rapidly. These values are found to be higher than 0.4 mg/m³ all the time and once peak at 0.685 mg/m³. EC versus time graph for both Airtec and SKC which were installed outside the FEL operator's cab is shown in Figure 5.

3.2 Diesel Powered Drilling Jumbo Tests

A third set of DPM measurements were taken at Mine F, also a metalliferous mine. A 224 kW jumbo drill was measured during its normal operation. The aim was to measure DPM output from jumbo drilling operation and also to check the effectiveness of the jumbo drill operator's cab in reducing DPM content by taking atmospheric measurements at locations both inside and outside the cab. Monitoring was conducted for almost 4 hours inside and outside of the operator's cab. As before Airtec real time DPM monitors were placed with SKC time weighted average units.

During the monitoring period any additional activity of diesel vehicles or machinery in the area were observed and noted. One 97 kW diesel powered hydraulic mechanical scalar (Getman Model S330) was also working during the whole monitoring time in the nearby entry or at another face.

Table 3. TWA, Elemental Carbon, Organic Carbon & Total Carbon measured by SKC NIOSH 5040

Jumbo Drill Cab	EC (µg/m ³)	OC (µg/m ³)	TC (µg/m ³)
Inside	6	6	10
Outside	470	230	700

Table 3 gives the EC, OC and TC recorded by SKC units. Airtec inside the Operators' Cab gave very much lower EC values (Fig. 6). The values were very low and sometimes not even measureable. During most of the measuring time, the EC value was found to be less than 0.06 mg/m³ and it is apparent that the cabin reduced DPM content significantly.

The consistency of trend needs to be tested by more measurements.

An Airtec monitor was installed outside the drill jumbo. These recorded very high, consistent EC value. The value of EC increases gradually during drilling and reached up to a maximum of 1.06 mg/m³ which is high. This particular peak in the plotted graph was due to the movement of one Load Haul Dump machine which was loading and hauling the broken rock material at a nearby face. During most of the measuring period EC values were found to be more than 0.4 mg/m³ which indicates need for serious remedial measures. Figure 6 shows a comparison of readings from Airtec and SKC units for inside and outside stations.

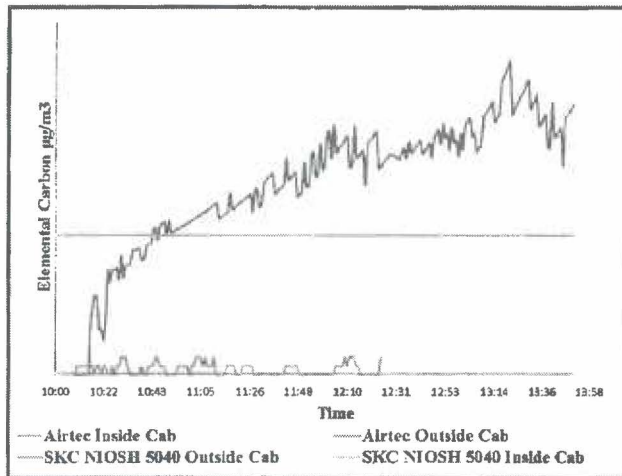


Figure 6. Time versus Real time EC by Airtec and TWA EC by SKC.

4 SOUTH AFRICAN DEVELOPMENTS

After the recent re-classification of DPM as a Group 1 Human carcinogen by the International Agency for Research on Cancer in June 2012, efforts to establish an Occupational Exposure Limit (OEL) is becoming a necessary reality.

The use of diesel engine locomotives in South African mines can be traced to Van Dyk Consolidated Mines Ltd on the Witwatersrand gold mines in 1928 as a replacement for battery locomotives (Belle, 2008). The advantages and disadvantages were recognized in those days, and surprisingly, there are no significant additions to this list, but only refinements. The recognized advantages were minimum installation costs, high mobility and greater power. The disadvantages were heat input into the air, noxious gases exhausted into the air, danger of explosions (in coal mines) and fires. The mining regulations at the time required that the proportion of CO and CO₂ should not be more than 0.01% and 0.1% respectively. This translated to a dilution factor of 0.017 m³/s/kW for the diesel engines used at the

time. Unlike gold and platinum mines which are generally at low levels of diesel mechanization, coal mines use large numbers of diesel vehicles for transportation, materials handling and other support operations like LW and bord and pillar section belt moves. In recent years small diesel vehicles are commonly used for worker transportation from surface to underground. DPM research in the 1990s was focused on exhaust and control measures in underground workings (Haase, Unsted and Denysschen, 1995; Unsted, 1996). Advances in DPM measurement technology have resulted in OELs being set in some areas such as for metal mines in the US.

Considerable research on DPM has been conducted in Australia, Canada, Germany and the USA. In some Canadian provinces respirable combustible dust (RCD) has been used as a measure of the exposure of miners to DPM. RCD is that portion of a respirable dust sample (collected with a cyclone pre-separator) that can be burnt off a silver membrane filter when exposed to a temperature of 400°C for two hours. The filter is weighed before and after heating with the amount of material being lost deemed RCD.

NIOSH researchers in conjunction with Sunset Laboratories developed a thermo-optical technique for the analysis of the EC fraction of DPM, which is now the commonly accepted analytical method - known as NIOSH Method 5040 (first published in 1999). CSIR in South Africa is the only laboratory facility that carries out DPM analyses in accordance with the NIOSH 5040 method.

4.1 *South Africa Occupational Exposure Limit Position*

Currently there are no regulatory mechanisms (such as OELs) that specifically address DPM limits. No mention is made of DPM in the regulations of either the Mine Health and Safety Act or the Occupational Health and Safety Act. Employers are obliged to conduct risk assessments on all hazards that may affect the health and safety of employees and initiate appropriate risk mitigation measures. There are references that some metal mine ventilation designs consider 0.12 m³/s/kW dilution rate to manage and dilute exhaust and particularly gases produced. A value of 2 mg/m³ has been generally accepted as being an appropriate OEL for DPM (Unsted, 1996).

DPM research into exposure to diesel engine emissions has been primarily through the Mine Health and Safety Council, the Chamber of Mines Research Organization or privately funded activities of mining houses into exposure levels (base lining) and control methods. A DPM study (Gen 010) by Haase, Unsted and Denysschen (1995) concluded that the critical components of diesel exhaust emissions were NO₂ (peak exposures) and DPM (time

averaged exposures). It was stated that DPM should be considered critical in the light of the stringent Threshold Level Values that had been announced at the time by the American Conference of Governmental Industrial Hygienists. It was found that DPM emissions were sensitive to engine maintenance and it could be conveniently measured with gravimetric dust samplers. Also of note was that operators of diesel-powered vehicles and persons in headings with low or no ventilation experienced the highest exposure levels.

In a DPM study (Gen 208) by Unsted (1996), it was noted that size selective sampling would not be appropriate due to the large fraction of sub-microns particulates that would conceal any DPM emissions, which are mainly submicrometer in size. The project concluded that there was no technical justification to advocate the use of low emissions diesel fuel, as emissions levels could be better and more effectively controlled by an engine maintenance program than by a change in fuel formulation. However, it is important to note that DPM definition was not known at the time (NIOSH 5040) and mines used to measure gaseous component of diesel exhaust, which was stopped for unknown reasons with the promulgation of 1996 Mine Health and Safety Act.

There has been a SIMRAC research study which was attempting to estimate DPM emissions in coal and platinum mines. The study failed to provide clarity on the DPM sampling methodology used, for instance sampling flow rate, personal or area sampling or location of samples or if it indeed sampled DPM. For example, one of the data suggested a personal DPM value of over 4.5 mg/m³ which is remotely unlikely. The reason for the disagreement is that if the DPM is of 4.5 mg/m³, then the respirable dust would be of the value of 50 mg/m³ and total dust would be in the order of 500 mg/m³ which is not a possibility in a metal (gold or platinum) mine work area. Therefore, use of the research report or the data at its face value needs to be reviewed prior to perpetuating misleading and alarming levels of exposures.

With the impending legislation surrounding DPM in South Africa and in the absence of any previous work specific to DPM measurement, the above section of the paper discusses the ongoing South African journey of measurement and limitations of exposure data for ventilation planning and regulatory purposes. Unfortunately, discussion on setting up an OEL limit has been going on for over a decade to date.

In South Africa currently the Department of Minerals and Energy (DME) and Department of Labor (DoL) listings of OELs do not include an OEL for DPM but the DME is currently investigating this possibility. In Australia, currently accepted DPM limit is 0.1 mg/m³ measured as EC) to avoid the complicated TC/EC ratios associated

with the measured DPM values (Belle, 2008, 2013). Figure 7 shows the complexity of these ratios highlighting differences for various mined commodities.

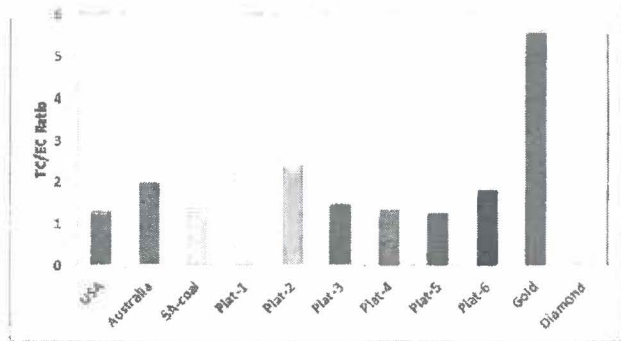


Figure 7. DPM TC/EC ratios in various mining commodities (Belle, 2013)

4.2 Monitoring of Diesel Particulate Matter

Belle (2008) revealed that TC versus EC ratios measured in South African mines have shown the limitations associated with the adoption of international standards because the median TC/EC ratio for underground platinum mines in South Africa is 1.8, with a range of 1.2 to 5.8. Measurements in coal mines have shown a median ratio of 1.44, with a range of 1.25 to 2.13. Both of these commodity measurements differ from established international TC/EC ratios. This makes it difficult to duplicate existing international OELs to regulate DPM in South African mines. Further investigation may be necessary at a globe level to address the differences in TC/EC ratios and its use in setting up OELs.

Further to the adoption of an appropriate OEL, the tripartite working parties compiled a guideline for the preparation of a mandatory code of practice or guidance note on the use of diesel engines in all mines to address and manage health aspects (occupational exposure to diesel emissions).

Figure 8 shows a photographic view of the South African gold, diamond, platinum and coal mine DPM samples (soot coloured) prior to carrying out NIOSH 5040 analyses.

Figure 9 shows the typical real time coal dust and DPM level trends recorded during a belt move-shift (data is not adjusted for any correction factors) using PDR real time dust monitor. The DPM measurement data in coal mines indicate that in surface mines or under normal underground mining conditions, the DPM exposure is well below the overseas DPM compliance limits, unlike underground belt or section or LW moves. The reasons for high DPM exposures can be attributed to the increased number of diesel operating engines, diesel vehicle conditions, engine maintenance and loaded engines during the belt moves and continuous idling of diesel engines underground sections. Also, the disruptions in sec-

tion ventilation layout during belt moves may also have contributed to the high DPM exposure.

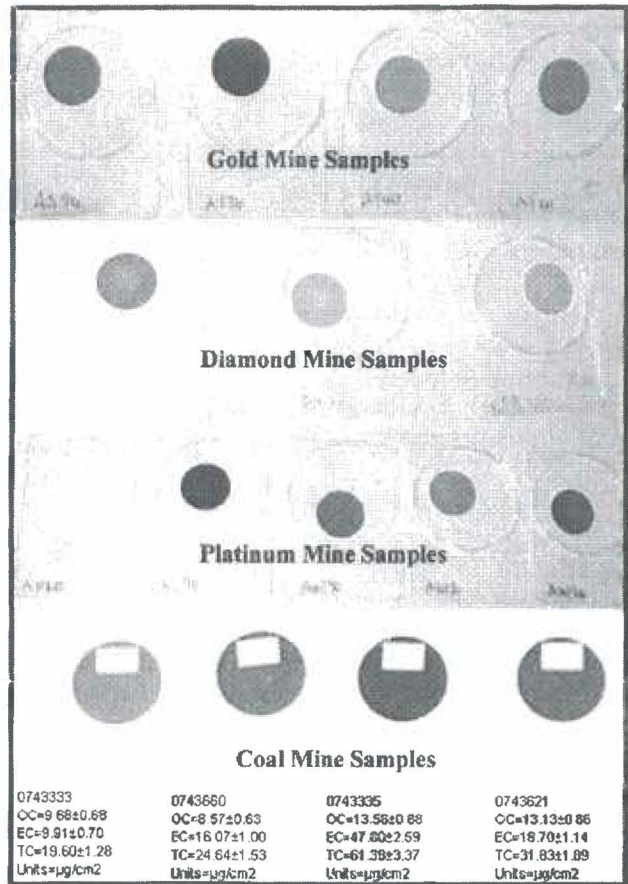


Figure 8. Various mine samples sent for NIOSH 5040 analysis (Belle, 2002)

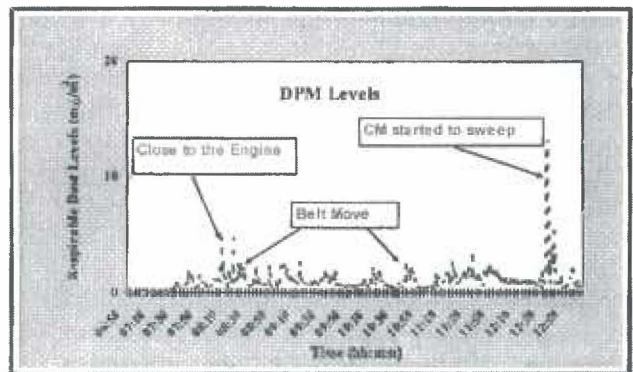


Figure 9. Typical real time DPM/Dust trend levels (unadjusted) during coal mine belt extension shift.

It is understood that all of the diesel engines use water-cooled scrubber filtration systems, which do not have any readily available records of their maintenance. It was noted that all the coal mines use low-sulphur diesel fuel supplied by a central depot (up to 500 ppm sulphur unlike overseas mines with sulphur levels of 10 ppm). However, the validation of the sulphur levels in the supplied diesel to the mines could not be found in all mines. Overall, a comparison of the exposure data indicates that there

is a significant difference in the range of DPM values between surface and underground mines. For example it was observed a section still contained measurable DPM levels even though there was no diesel equipment present during the normal coal cutting operations. As an example a Continuous Miner section where there was no LHD present during the shift had measured EC levels of 0.027 mg/m³.

Currently in the absence in South Africa of regulated limits some local mining companies have adopted an EC DPM OEL of 0.1 mg/m³ or 0.2 mg/m³ sampled as the submicron fraction (TC). It is envisaged that adoption of continuous monitoring practiced overseas during diesel intensive and infrequent mining operations in South Africa would assist in effective management of DPM in mines.

5 SUMMARY AND CONCLUSIONS

Various DPM approaches, regulations and ambient monitoring practices currently used in underground mines in Australia, South Africa and the US have been discussed and compared. Some monitored results undertaken in the three countries have been examined. DPM monitoring approaches have been available for some time based on shift average monitoring. This approach has limitations in gaining a full understanding of DPM levels over short time periods. Real time monitoring produces data that is required for engineering evaluation exercises or to control effectiveness. Real time monitoring often highlights situations where DPM levels are relatively high for substantial time periods.

There are limits to the tools available to improve mine face conditions. One of these is increasing airflow ventilation in the working area. Another is to carefully control the position of miners to upstream of working diesel machines. A third is to carefully introduce use of exhaust DPM filters designed to capture DPM and a fourth is to make use of electric equipment where practical.

Modern large mines may use hundreds of diesel powered vehicles. Real time DPM monitoring allows the industry to pinpoint 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 local mine ventilation, operator positioning, work practices, introduction of exhaust filters and other engineering tools to reduce exposures.

Based on the findings of the study, it is concluded that real time DPM ambient monitoring practices in underground mines are gradually being accepted as an engineering tool to optimize the DPM control strategies in the mining industries of the countries under study. However, statutory monitoring still re-

lies on shift average monitoring for determination of personal exposure levels.

6 ACKNOWLEDGEMENTS

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