An improved wet-head system:
Prevention of incendive ignitions and dust control

Bharath K Belle ***CSIR: Miningtek,*** *Stephen Clapham* ***Hydra Tools***
SA United Kingdom

Abstract

In the wake of recent methane and coal dust explosions worldwide, the need for the improvements in the existing environment control technology continue to exist. Considerable progress in environment (dust and methane) control in South African mines has indeed been made but they remain a matter of great concern. The introduction of the 1997 Directive on dust exposure levels and face ventilation was a milestone for the South African coal mining industry in improving health and safety standards. These stricter guidelines and the latest dust control technologies are beneficial not only in the long-term health perspective, but also to reduce the risk of methane and coal dust explosions in the short term. The paper discusses the results of the recent tests on the newly developed and improved wet head system. Water transfer to the cutter heads is now by a single cartridge giving obvious advantages over the original three-cartridge system.

Introduction

Coal mining is one of the major economic activities in most of the developed and developing countries. Coal mining operations present both safety and health implications for the workers. Two of the important hazards recognized in underground coal mining are methane and coal dust explosions as safety hazard and dust inhalation as a health hazard. The seriousness of methane ignitions and the resulting explosions is illustrated by the recent series of explosions in mines in China, South Africa, Ukraine and USA. The potential of coal mine dust inhalation resulting in disabling pneumoconiosis has long been recognized but research now suggests that pneumoconiosis is not the only respiratory hazard linked to coal mining. Over the past 30 years evidence has accumulated that an excessive number of miners also experience chronic obstructive pulmonary disease (COPD), and this has led the British and German governments to classify chronic bronchitis and emphysema in coal miners as an occupational disease for which industrial injuries' benefit can be paid (Coggan and Taylor, 1998). In the light of these events, the seriousness of health and safety measures in today's coal mining industry still needs attention.

Background

The original concept of the wet head system on CMs was centered on water sprays being emitted from nozzles mounted on the rotating drum head and close to each bit. This differs from conventional external sprays as water is sprayed continuously (or in a phased manner) to the bit and its vicinity as it cuts the coal. The water is strategically placed in the Pick Back Flushing Mode (PBF) position to reduce the probability of incendive ignitions. The concept was developed in the 1970s by the former United States Bureau of Mines (USBM), the Bituminous Coal Research National Laboratory (BCRL) and various manufacturers (Merritt, 1987). The early tests showed reductions in dust levels from as much as 56 % to 13 %, except for one machine which displayed an increase in liberated dust levels. The early evaluations identified two critical problems with the wet head system, viz.,

1. The water seals were unreliable and resulted in considerable leakage,
2. The nozzles were prone to blockage because of the poor mine water quality, lack of adequate filtration and rust and metal particles in the contaminated mine water circuit - even after it had been filtered.

Despite the interest shown in the wet head technology applied to CMs during both the 1970s and the 1987 trials, there is a lack of further literature indicating progress. This state-of-affairs is, in fact, explained by comments from the machinery manufacturers who have indicated that the high cost of producing and maintaining wet heads (including the cost of sophisticated seals) met with resistance from the coal mining companies, and, despite enquiries during the early 1990's, no wet heads were ordered until late in 1994 (Phillips, 1997).

Incendive ignitions in underground mines are an operational safety threat leading to major explosions. Statistics have indicated that the greatest explosion risk comes from frictional ignitions, and that the most likely site for an ignition to develop into a major incident is in a drivage (Browning and Warwick, 1993). It has been clearly established that frictional ignitions are caused by hot material that is ejected from behind the cutting tool and that water is effective in preventing further propagation. It has also been established that less water is required when it is applied behind the cutting tool instead of in front (Powell and Billings, 1981). A laboratory study by the former USBM at Pittsburgh Research Centre using cutter-drum-mounted water sprays indicated that water sprayed from a carefully designed spray nozzle located behind the bit (PBF mode) during cutting of sandstone, substantially reduced the likelihood of frictional ignitions (Courtney, 1987).

Environmental Monitoring

In order to evaluate the system's effectiveness in controlling dust and diluting methane in the face area, both methane and dust measurements were carried out.

A recent South African study (Phillips, 1997) concluded that continuous mining machines with wet heads are now commercially available, either as new machines or as a wet head retrofitted to existing machines. Also, the report indicated that there is world wide interest in wet head mining machines, not only for frictional ignition protection but also because of the opportunity they afford to reduce respirable dust concentrations. Finally, it was recognized that wet head mining machine would have a major impact on dust control strategies.

This paper describes the results of an underground research project carried out in an underground bord and pillar CM section. The study consisted of evaluating the effectiveness of the improved Hydra Tools wet head system as an effective dust suppression system on the Joy HM 17 Continuous Miner (CM). The principal objectives of the project were: to evaluate the performance of the Hydra wet head CM dust control system by determining the ambient Airborne Respirable Dust (ARD) concentrations in the CM section, and to compare the performance of a CM dust control system with and without the Hydra wet head system. The pictorial view of the Hydra wet head system with PBF mode which was evaluated underground is shown in Figure 1.

At the time of underground evaluation, the Hydra* wet head system was the only available CM wet head system that was operational on a trial basis in the South African coal mine. A total of eleven tests were conducted to evaluate the two systems: four tests to evaluate the CM dust control system without the wet head, and seven tests to evaluate the CM dust control system with the wet head.

Airborne Respirable Dust (ARD) sampling definitions

Sampling definitions currently used in the field of occupational hygiene and mine environmental control vary widely and therefore the following definitions have been adopted for this paper:

Personal Sampling: A personal sample is the dust sample collected in the breathing zone of a worker performing occupational duties during a working shift. With this sampling method, the worker wears the sampling train (cyclone, pump, tube, and sample filter) for the entire shift (bank to bank)

Figure 2. *The photographic view of Hydra wet head system on a CM operating underground*

Area or Environmental Sampling: An area or environmental sample is the dust sample taken at a fixed location in the workplace in an environment or area of interest. The dust sample reflects the average concentration in an area of interest and does not reflect the exposure of any worker in that area. The sampling is usually carried out at a fixed location such as at the intake position and section return.

Engineering Sampling: An engineering sample, which is not defined in any of the previous literature, is the dust sample taken at a "predetermined" CM operator's position consis-

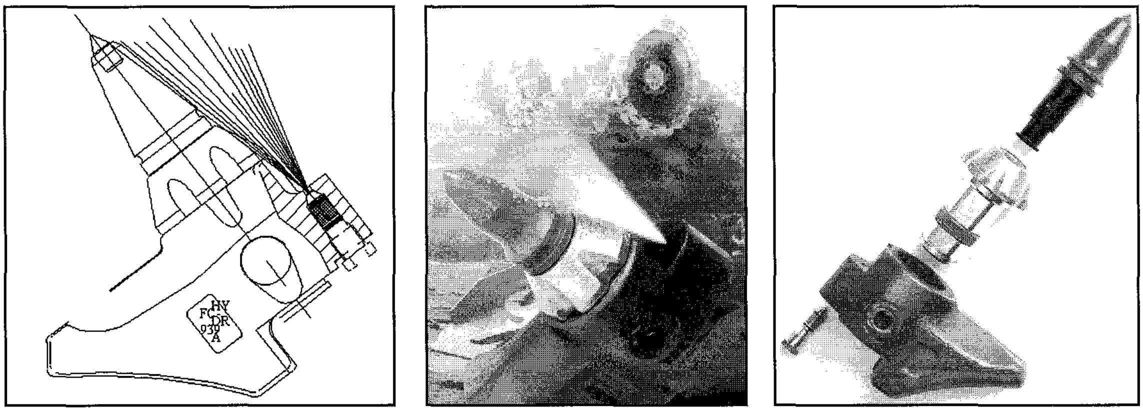

Figure 1. *Hydra wet head system (with pick-based water spray location) in action*

tently. An engineering sample is the dust sample taken to determine the dust concentration near machinery, tipping points, air filters, etc. to characterize the emission source or suppression effectiveness of dust suppression or control measures. The engineering sampler is switched on at the face area at the beginning of the shift at its pre-determined position and is switched off before leaving the face area at the end of the shift. The engineering sample is therefore not collected for the entire eight-hour or shift period since travel time is excluded. The engineering sample enables determination of the effectiveness of dust control and ventilation systems in the section. Furthermore, this sample is aimed at evaluating both the management (administrative effectiveness) of the dust control measures as well as the effectiveness of the dust control system (engineering). The South African DME directive of 1997 requires the engineering dust concentration at the CM operator position to be less than 5 mg/m3. In this study, the engineering sample was collected at the CM Operator's position.

Dust instrumentation

The sampling set-up consisted of two gravimetric samplers, i.e. a Higgins-Dewell-type cyclone (GME 008 cyclone) and a Hund tyndallometer. A gravimetric sampler was positioned at the section intake. Two gravimetric samplers and a real-time respirable dust monitor (Hund tyndallometer) were located at the operator's position and at the section return,. Also, the personal exposure of the CM operator was measured using the personal sampling method. The average gravimetric respirable dust concentration determined for the sampling period was used to convert the Hund readings to mass concentrations (mg/m^3). The dust samplers consisted of an air pump drawing 2.2 L/min of air through a mini-cyclone, which separates the airborne dust and collects only the fraction of respirable dust (< 10 μm) on a pre-weighed filter disc.

The gravimetric samplers were operated at a flow rate of 2.2 L/min according to the new ISO/CEN/ACGIH respirable curve with a D_{50} of 4 μm. Filters from the samplers were weighed on an analytical electronic balance readable at 0.0001 mg. The procedure for determining the particulate mass was followed as per the DME guidelines (1994). Well-maintained pumps were used to avoid the effect of pump pulsations and fluctuations in the flow rate.

Methane monitoring

During the test series, a Crowcon Custodian type methane sensor was used to monitor the methane levels around the CM. The sensor was equipped with data-logging facilities and the recording interval was set to 10 seconds. To protect the methane sensors from the harsh environment around an active CM, the Custodian sensors were placed in polycarbonate boxes. The sensors were exposed to the environment by drilling 70 holes each 3 mm in diameter drilled into the lid of each of the protective boxes. By enclosing the sensors in the box, the response time (T_{90}) was increased from 20 to 35 seconds and a representative indication of the general methane conditions around the CM was determined from the data. During the first week of testing, both Custodian sensors were placed in protective boxes. However, due to the low methane levels recorded, it was decided to remove the protective box from the sensors to reduce the response time (T_{90}).

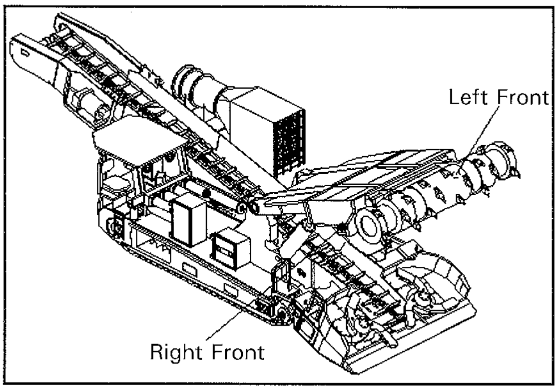

Figure 3. *Methane monitoring positions on the CM*

The methane levels around the CM were monitored at two locations on the CM during the test series. At the beginning of a test shift, the methane sensors were switched on and the time was noted. The Custodian methane sensors were then placed on the CM, one on the intake-air side of the boom and the other one on the return-air side of the boom (Figure 3). The sensors are approximately 2.5 m from the face during cutting. During the test period, the CM activity and location were monitored and any possible major influences on the ventilation conditions, i.e. methane levels, were noted against time.

After completion of the test shift, the sensors were removed from the CM, switched off and the time was noted. The stored data from the sensors was downloaded on surface, and the pre-test procedure as described above was applied. The downloaded data was imported into a spreadsheet for data analysis. Any "abnormal" peaks or lows were checked against the time study log to explain the occurrence.

Data analysis

The dust concentrations presented throughout this paper reflect respirable dust measurements taken over a full production period (from the beginning of the shift to the end of the shift). During any of the test shifts, this production period was never greater than eight-hours. Approximately an hour of the time was spent on traveling to and from the face area of the section to the surface. Real-time dust-sampling results allow the comparison of face-area dust concentrations under different ventilation and mining conditions. Using the mass of dust collected on the filters, the sample dust concentration was obtained. Since the dust sampling is carried out for the entire production period of the shift (excluding travel time), an eight-hour time-weighted average dust concentration (TWA-8 hr) is estimated.

Underground test results

System 1: CM dust control system without the Hydra wet head

A total of four tests were conducted on the CM dust control system without the Hydra wet head. The system consisted of a total of 20 external sprays operating at a pressure of 20 bar and a flow rate of 63 L/min. During the test period, the water pressure was in the range of 2 000 to 2 500 kPa (20 to 25 bar) for the entire spray system. The average sampling time during the four test trials was 390 minutes. The real-time concentration plots showed constant high frequency peak dust concentration levels reaching at the CM operator position, indicating the poor performance of the system. During the test periods, a force fan connected to a column placed on the floor was used as an auxiliary ventilation system.

The calculated average dust concentration levels (Tests 1 to 4) at the intake, operator's position, face out bye and return for the sampling period were 2.29 mg/m^3, 19.34 mg/m^3, 5.88 mg/m3 and 4.56 mg/m^3, respectively. Similarly, the determined TWA (8-hr) dust-concentration levels at the section intake, operator's position, face out bye and section return for the sampling period were 1.82 mg/m3, 15.10 mg/m^3, 4.89 mg/m^3 and 3.74 mg/m^3, respectively.

Results and discussions

The plots of the concentration levels for the sampling period at the identified positions during the trials without the Hydra wet head system is shown in Figure 4. The average coal production for the four production shifts was 1 145 tons with a maximum production of 1 400 tons.

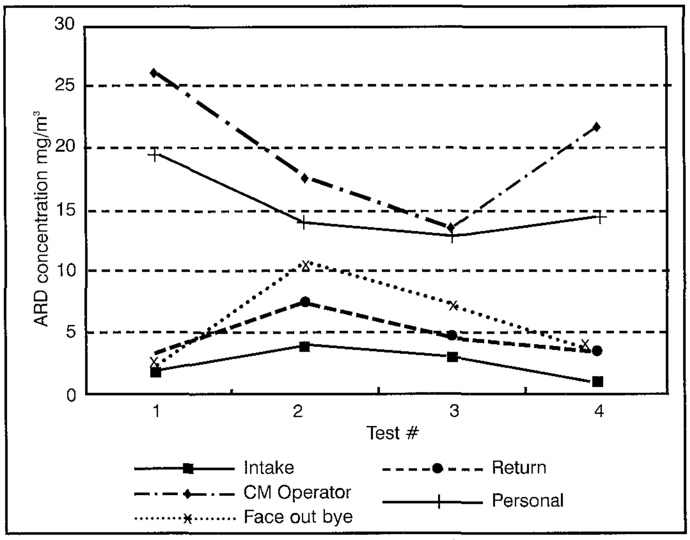

Figure 4. *Dust concentration levels for the CM dust control without the Hydra wet head*

During the test series, the gravimetric dust sampler was worn by the CM operator during the cutting shift for personal exposure assessment. The average sampling period while measuring the personal exposure was 372 minutes and an 8-hr personal exposure was estimated assuming zero dust concentration for the period that was not sampled. The average CM operator personal exposure dust concentration levels for the sampling period and 8-hr estimated exposure levels were 13.63 mg/m^3 and 11.70 mg/m^3, respectively. The average section return velocity level during tests 1 to 4 was 1.02 m/s with a maximum section return velocity of 1.28 m/s.

System 2: CM dust control system with the Hydra wet head

RA total of seven tests were conducted on the CM dust control system with the Hydra wet head system. During this evaluation, a total of 15 external sprays operated at a pressure of 12 bar (1 200 kPa). However, during Test # 7, the L-spray block was not operational, and therefore a total of only 10 sprays were operational. The total water flow through the external sprays at a pressure of 12 bar was approximately 45 L/min. In addition to the external sprays, the Hydra wet head system consumed nearly 65 L/min. During the test period, the water pressure was in the range of 1 000 to 1 200 kPa (10 to 12 bar) for the entire system. The water pressure available to the Hydra wet head was varied from 2.5 bar (250 kPa) on the left hand drum, 3.5 bar (350 kPa) on the center and 7 bar (700 kPa) on the right hand drum as a consequence of booster pump limitations. The evaluation water pressure on the wet head drum was well below the designed water pressure of 10 bar (1 000 kPa). The average sampling period for System 2 was 434 minutes.

The calculated average dust concentration levels (Tests 5 to 11) at the intake, operator's position, face out bye and return for the sampling period were 1.01 mg/m^3, 6.81 mg/m^3, 2.23 mg/m^3 and 2.23 mg/m^3, respectively. Similarly, the determined TWA (8-hr) dust-concentration levels at the intake, operator's position, face out bye and return for the sampling period were 0.88 mg/m^3, 6.12 mg/m^3, 1.98 mg/m^3 and 1.98 mg/m^3, respectively.

Results and discussions

The plots of the concentration levels for the sampling period at the identified sampling locations during the trials without the Hydra wet head system is shown in Figure 5. The average sampling period while measuring the personal exposure was 444 minutes and an 8-hr personal exposure was estimated assuming zero dust concentration for the period that was not sampled. The average coal production for the seven production shifts was 990 tons with a maximum production of 1 460 tons.

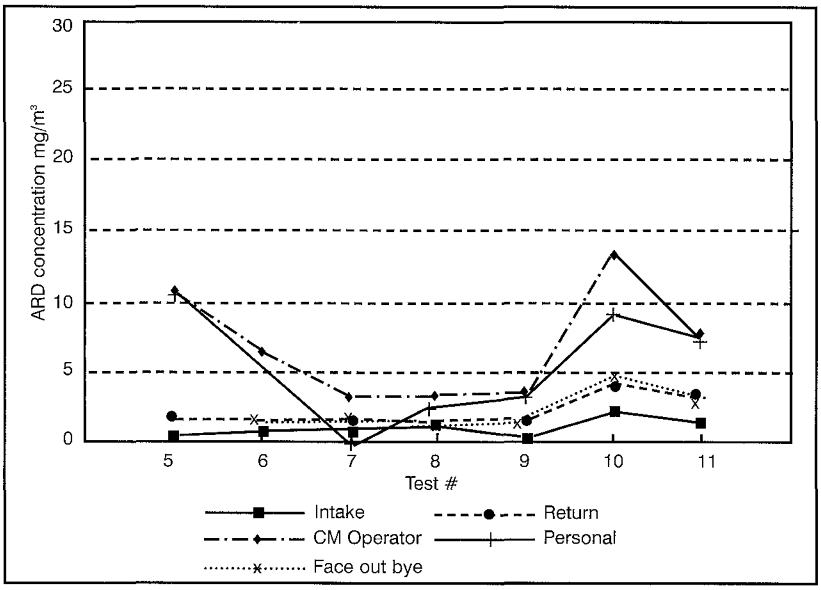

__Figure 5.__ Dust concentration levels for the CM dust control with the Hydra wet head

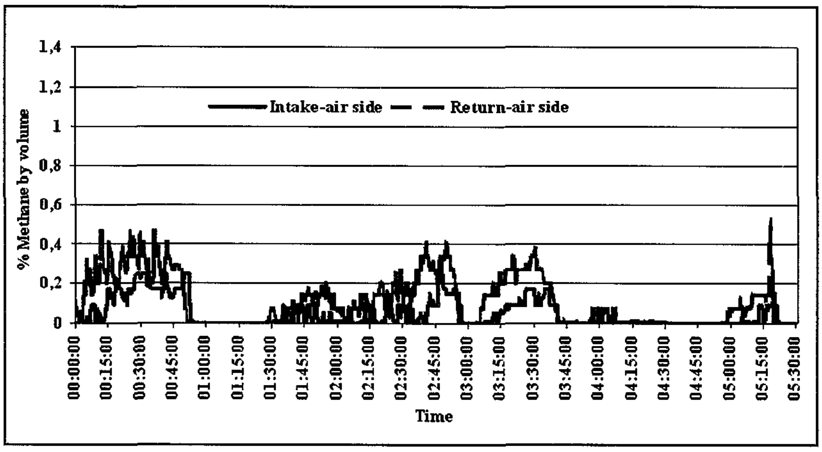

__Figure 6.__ Recoded methane levels during the CM dust control without the Hydra wet head system

The average CM operator personal exposure dust concentration levels for the sampling period and 8-hr estimated exposure levels were 6.46 mg/m^3 and 5.86 mg/m^3, respectively. It is to be noted that from Test # 8 to Test # 11 the personal sampling train was hung inside the CM operator cabin as the CM operator was not willing to wear the sampler after the loss of the personal gravimetric sampling train during Test # 7.

The average section return velocity level during tests 5 to 11 was 1.49 m/s with maximum and minimum section return velocities of 1.70 m/s and 1.30 m/s, respectively. The above dust concentration levels show a significant improvement at the CM operator position despite the Hydra wet head operating well below the designed water pressure and flow rates.

Methane concentration results

A total of 10 shifts were monitored for methane levels during the underground evaluation, viz., four shifts with the wet head switched off and six with the Hydra wet head system active. During the first four tests, the CM was cutting in normal mining conditions, in the absence of any general seam anomalies such as dykes, burnt coal deposits, etc. For the four shifts without the Hydra wet head system, the maximum methane levels recorded were below 0.6 % by volume, which is well below the allowable level of 1.4 % by volume. The average methane levels recorded during the cutting cycles of these shifts were in the region of 0.2 % by volume, with a few peaks of up to 0.5 % and one of 0.6 % by volume being recorded. Based on the methane data, it is clear that the ventilation system is capable of diluting the methane liberated from the cutting process to within acceptable levels for the specific conditions.

The next two tests (Tests 5 and 6) were conducted with the Hydra wet head system activated. The peak levels recorded for these two tests were in the region of 0.7 % by volume. The average methane levels recorded during the cutting cycles for these tests are low with definite sharp peaks present. The plot of methane concentration levels recorded around the CM for the system without the Hydra wet head and with the Hydra wet head are shown in Figures 6 and 7 respectively. From the recorded methane data, we observe that the Hydra wet head system is still able to keep the methane below the allowable limit of 1.4 % by volume.

Comparison of dust control systems with and without the Hydra wet head

In order to relate the effect of different variables in the variation of dust concentration data, adjustments were made for performance comparison of the Hydra wet head system in controlling the respirable dust levels in and around the CM operator's position for the test conditions. The parameters which were identified and considered as having a potentially significant impact on the dust generation and on it becoming airborne during cutting operations were: coal production, sampling time, intake dust concentration levels, section return velocity, and water flow rate to the system. From the above parameters, the Normalized Airborne Respirable Dust (NARD) in the CM operator's position was calculated.

In order to make a comparison among different shifts with varying air quantity, a baseline return air velocity for the measured airflow was chosen. The proportion of air quantity to the base-case number was defined as the scaled air quantity. Since the comparison is made across the dataset, the "sample mean" was the best choice for the base-case section return velocity or section air quantity. Cutting time adjustments were made by employing the tons/minute approach while determining the NARD.

The NARD was calculated considering the actual respirable mass of dust generated and becoming airborne during the sampling period. The factors 0.0022, 1.324 and 90 are applied to the sampling rate, average section return velocity (VA), and average water flow rate (WA) respectively.

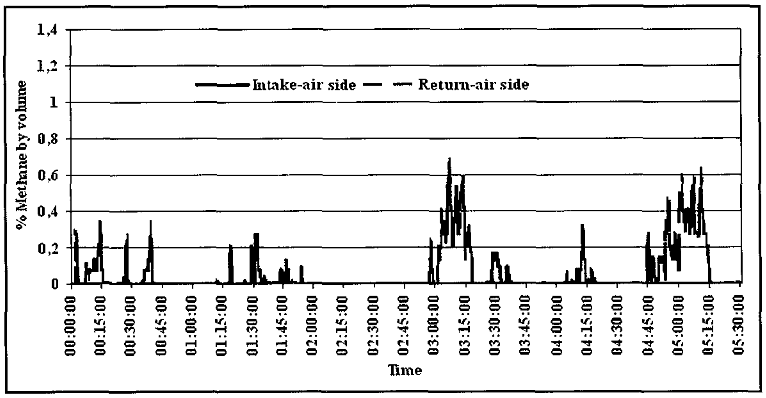

Figure 7. *Recoded methane levels during the CM dust control with the Hydra wet head system*

These adjustments were necessary to compare the amount of respirable dust generated which could not be suppressed with the dust control system and the mining process across the sections, headings with widely varying air quantities, water flow rates, cutting times and test conditions. Incorporating the above-mentioned factors, the NARD generated is calculated below:

$$NARD = \left(\frac{(C_O - C_I) \times 0.0022 \times S_T \times C_T \times V_A \times W_A}{P_S \times V_R \times W_M} \right) \quad (1)$$

where:

C_O = Concentration at the operator (mg/m³)
C_I = Concentration at the intake in mg/m³
S_T = Sampling time (min)
C_T = Cutting time (min)
V_A = Average return velocity during the test period (1.324 m/s)
V_R = Average return velocity during the shift (m/s)
W_A = Average water flow rate to the machine (90 L/min)
W_M = Water flow rate to the machine during the shift L/min.
P_S = Average production during the shift (tons)

Figure 8 shows the CM operator dust concentration levels (both engineering and personal) for an estimated eight-hour period. From the plot it is observed that the Hydra wet head system performed better than the CM dust control without the Hydra wet head system. At the CM operator's position (engineering concentration), the average 8-hr sample concentration for the CM dust control without the Hydra wet head system was 15.1 mg/m³ (4 tests) With the Hydra wet head system this was 6.12 mg/m³ (7 tests) This indicates a reduction of approximately 60%. Similarly, an estimated 8-hr CM operator personal exposure level for the CM dust control without the Hydra wet head system was 11.70 mg/m³ (4 tests) and 5.86 mg/m³ (6 tests) with the Hydra wet head system (a reduction of approximately 50 %).

During the second phase of the evaluation tests, the section passed through a dyke, resulting in long headings, changes in the airflow pattern in the LTR and reduced production levels. Furthermore, this affected the positioning of the face out bye sampler. Therefore, the face out bye sampling values were not used for comparison purposes of the two systems, as this was not a representative sample. Also, during the evaluation period, communication with the CM operators indicated that the coalface was more "visible" while cutting with the CM dust control system with the Hydra wet head system than without.

The normalized airborne respirable dust (NARD) levels at the CM operator position (mg/ton) are plotted in Figure 9. The average NARD level for System 1 (Tests 1 to 4) was 0.498 mg/ton of coal. Similarly, the average NARD level for System 2 (Test 5, 6, 10 and 11) was 0.079 mg/ton of coal. From the results we can infer that the performance ratio of dust control systems without and with the Hydra wet head system for the underground test conditions was 6.24: 1, representing a significant improvement, despite the wet head system operating well below its designed parameters.

Conclusion

In summary, the systems evaluated underground were:

- System 1: CM dust control system without the Hydra wet head
- System 2: CM dust control system with the Hydra wet head

For the scenarios tested in this particular section of the mine, the wet head results for the conditions tested showed an improvement when compared to those obtained without the wet head system. The average dust concentration results at the CM operator position for the two systems tested are shown in Table 1.

The Hydra wet head system showed significant improvements in dust levels despite the wet head operating below it's designed water pressure and flow rates, due to the unavailability of the

Test System	No. of tests	Average Sampling period dust concentration mg/m³	Average 8-hr period dust concentration mg/m³	Average 8-hr personal dust concentration, mg/m³	NARD mg/ton
Wet head off	4	19.34	15.41	11.70	0.498
Wet head on	7	6.81	6.12	5.86	0.079
Improvement		65 %	60 %	50 %	84 %

Table 1. *Summary of test results*

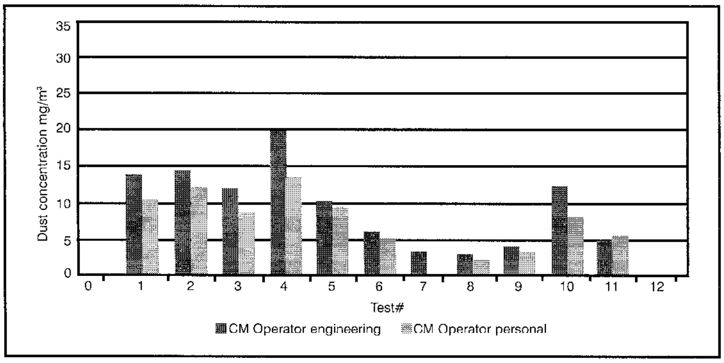

Figure 8. *Dust concentration levels (8-hr period) during the CM dust control without (Test # 1 to 4) and with the (Test # 5 to 11) Hydra wet head system.*

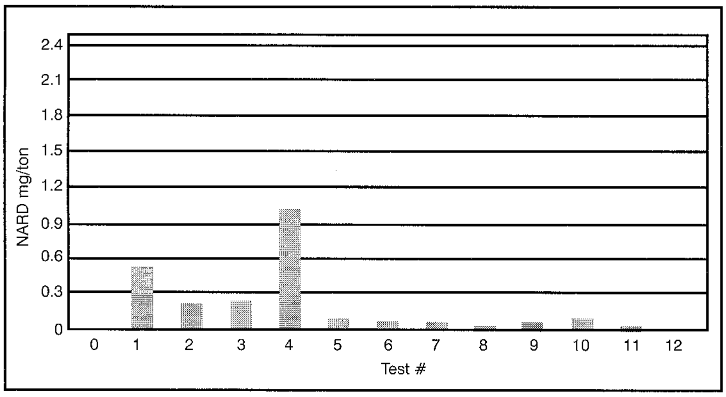

Figure 9. *The Normalized Airborne Respirable Dust levels (mg/ton) at the CM operator position.*

recommended booster pump. For the normal test conditions, the methane hazard was well under control with peak levels never exceeding 0.8 % - well below the maximum permitted concentration of 1.4% CH_4 per volume. Also, due to the low methane concentrations recorded below the accuracy levels for pellistor-type sensors, and the changes in the mining conditions while evaluating the two systems, it was difficult to determine whether significant changes in the methane gas behavior occured when comparing the two systems.

The tests tend to confirm the previous research studies in considering the critical elements of the total dust control system, viz., water flow rate, external spray configuration, Pick Back Flushing (PBF) mode for wet head system, individual components of the dust control system and section ventilation to be extremely important in order to reduce the dust levels below the legal limits (Belle and Du Plessis, 1999). It was noted that the designed water pressure and flow rates recommended for the Hydra wet head were never attained due to the use of an underrated booster pump on the continuous miner.

Hydra management are confident that the Hydra wet head would meet the requirements of the DME directive of 1997, i.e. engineering concentration levels of less than 5 mg/m3 when an appropriate booster pump is fitted capable of delivering 10 bar of pressure across the wet head.

Furthermore, the comments from the CM operator indicated that the visibility in the cutting zone was much improved with the wet head system operational. It is believed that this will lead to safer working conditions and improved production rates. The spray systems on the Hydra wet head are integrated with the tool holder and spray in the Pick Back Flushing (PBF) mode known to be essential to reduce the incidence of incendive ignitions (Browning, 1993; Courtney, 1987; Powell and Billinge, 1981).

Acknowledgments

The authors wishes to express their sincere gratitude and appreciation to Sarel W. Pretorius, and Kobus Van Zyl for their contribution to the field tests and assistance; The Manager, Koornfontein mines, for their help with the experimental set-up and their assistance with the test-section facilities; Claude Haven, of Koornfontein mines; Brian Bell of Hydra SA, and Reinhard Jahn of Joy SA for assisting with the machine set-up and for their valuable contributions to the accomplishment of this work.

References

- Belle, B.K., and Du Plessis, J. J. L., 1999, "Evaluation of a Continuous Miner Half-Curtain Dust Control System in a South African Underground Coal Mine," Proceedings of the 8th U.S. Mine Ventilation Symposium, Editor: Jerry C. Tien, Rolla, Missouri, pp 195-201.
- Browning, E.J., and Warwick, J.S., 1993, "Ignition Prevention," Mining Engineer, Vol. 152, No. 376, pp. 204-212.
- Courtney, W.G., 1987, "Prevention of Frictional Ignition with Ripper-Type Continuous Mining Machines Using Water Sprays," Proceedings of the 3rd US Mine Ventilation Symposium, Pennsylvania State University, USA, Chapter 17, pp. 126-131.
- DME, Parent Document, 1994, "Guidelines for the gravimetric sampling of airborne particulates for risk assessment in terms of the occupational diseases in mines and works act no 78 of 1973," South Africa.
- Merritt, P. C., 1987, "The Wet Head Miner Comes Back," Coal Age, pp. 44-46, South Africa.
- Mine Health and Safety Act, 1996, South Africa.
- Phillips, H.R., 1997, "To establish the current status of research, development and operational experience of wet head cutting drums for the prevention of frictional ignitions, " SIMRAC Report, COL 426, South Africa.
- Powell, F., and Billinge, K., 1981, "The Use of Water in the Prevention of Ignitions Caused by Machine Picks," Mining Engineer, Vol. 141, No. 239, pp. 81-85.
- South African Department of Minerals and Energy Directive, 1997, South Africa.
- Kenny, L., Baldwin, P.E.J., and Maynard, A. D., 1998, "Respirable Dust Sampling at Very High Concentrations," HSE Report, UK.

* Reference to specific trade names is made for identification only and does not imply endorsement by the CSIR-Miningtek.