Recent advances in dust control technology on South African underground coal mines

Bharath K Belle CSIR Miningtek, Jan Du Plessis Gold Fields Limited

Abstract

Despite the much-heralded arrival of the new millennium, improving mine health and safety remains an enormous challenge. Considerable progress with environmental (dust and methane) control in South African mines has indeed been made but it remains a matter of great concern to all parties, i.e. mine management, labor and the government. The introduction of the 1997 Directive on dust exposure and mine 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 in terms of controlling methane and coal dust explosions (high-risk) in the short term.

Over the past two years, CSIR: Miningtek personnel developed new dust control systems through various Safety In Mines Research Advisory Committee (SIMRAC) funded projects and successfully implemented them in underground coal mines. Currently, it can be confidently claimed that the new and proven dust control systems are being effectively operated in more than 80% of the bord and pillar sections in South Africa. This paper highlights the critical components of the new dust control systems evaluated underground, viz., the half-curtain system, the retrofitted hood system, the double scrubber system and the integrated hood system for continuous miners, and the road header dust control system. The status of wet head dust control systems and the challenges facing high seam longwall mines are also presented in the paper. The relative effectiveness of various dust control systems are discussed and the relevant test results are given in the paper. It concludes with a discussion of the progress made and challenges facing the coal mining industry in reducing workers' exposure to respirable dust.

Introduction

Coal production of the South African mining industry has evolved from manual mining (hand-got, pick and shovel, tubs, rails and endless rope haulages) of 1940s to mechanized mining, the first unit (10 RU coal cutter, 2´32D shuttle cars and an 11 BU loader) being introduced in 1948 (Whitefield, 2000). South Africa's run-of-mine coal production for the year 1998 was 289.6 Mt, of which approximately 70 Mt were exported, with an annual income of R21 billion and the coal industry employing 53,752 miners on average. The South African coal industry production is an almost even split with the ratio between opencast and underground mining is 48% to 52%, respectively.

The rapid growth in the industry has led to the acceptance of both new and proven technologies. The first continuous mining machines were introduced into the South African underground coalmines in the early 1970s. Currently, approximately 300 mechanical miners are used to extract coal from underground reserves in South Africa. The sheer size and power of these machines to increase the production gave rise to a number of problems, some of which are related to the health and safety of workers.

The 1995 report of the Leon commission of enquiry in to the mine health and safety procedures indicated that there is a serious lack of control measures and techniques available to control respirable dust in mines (Leon et al., 1995). This led to the promulgation of the Mine Health and Safety Act of 1996. The Act placed a clear emphasis on the safety and health of the workers and made the onus of responsibility on the owner of the company or his representative. The increased concern over health and safety-related issues has resulted in intensified efforts by all the interested parties to re-look at their current environmental control strategies. It was reported that, during the period 1996-97, a total compensation amount of R43 million was paid to mine workers in South Africa who had been identified positively with pneumoconiosis.

Background

The dust hazard to miners was first recognised and made the subject of intensive study in South Africa during the early years of the 20th century. Inhaling excessive amounts of respirable coal dust causes pneumoconiosis, commonly known as "black lung." The link between exposure to dust and pneumoconiosis, and the increased risk to workers exposed to high levels of dust for a longer period of time as opposed to workers who are exposed to lower dust levels for shorter periods, were studied principally by Beadle (1967). Lowering dust-exposure levels in the workplaces can prevent the development of pneumoconiosis. In South Africa, the current personal dust exposure level standard is 2 mg/m^3 for an 8-hr period.

Dust measurements in South Africa

In most South African mines, various dust samplers (Casella 10 mm cyclone, Gillian cyclones, MSA cyclones, and CIP10 samplers) are being used by both the mine operators and the inspectors of Department of Minerals and Energy Affairs (DME). These samplers are operated at a flow rate ranging from 1.9 L/min to 10.0 L/min in agreement with the BMRC respirable convention (BMRC, 1952). However, according to the new ISO/CEN/ACGIH respirable dust curve with a d50 of 4 μm, the recommended flow rate is 2.2 L/min (Kenny, Baldwin and Maynard, 1998). The new flow rate confers an immediate advantage in sensitivity since, presently, the South African cyclones sample 16% less air per minute. At present, no changes are being recommended by the DME for switching over to the new respirable curve.

According to the DME guidelines, individual mines are also obliged to submit "engineering samples" to the DME, where respirable samples are collected at the operator's cabin position on a continuous mining machines on every shift. In addition to this, the DME separately collects bi-yearly "personal samples" from all controlled mines for risk determination purposes. Varying sampling definitions are currently used in the fields of occupational hygiene and mine environmental control in South Africa and are discussed hereafter:

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

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 is the dust sample taken at a "predetermined" continuous mining machine operator's position, which is not defined in any of the previous literature. 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 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 enables the determination of the effectiveness of dust control and ventilation systems in the section. Further, it aims at evaluating both the management (administrative effectiveness) of the dust control system as well as effectiveness of the dust control system (engineering).

Dust control technologies

The critical conditions in the South African underground coal mining sections influencing environmental control (dust and methane) are:

1. South African mining conditions and ventilation dynamics are different from those in mines elsewhere.
2. The most commonly used ventilation and dust-control systems are on-board scrubbers, water sprays and auxiliary ventilation devices such as brattices, jet fans and force fans.
3. The ventilation systems used in the South African long development headings (sometimes up to 36 m and under supervised operations up to 65 m), and the resulting airflow patterns, are more complex than those reported in the literature on mines in other countries.
4. The rate of advance per shift in headings in the South African mines is comparatively greater than those in European or US mines. Thus, dust and methane control requires special provisions to ensure effective dust control and face ventilation systems.

In 1997, the South African Department of Minerals and Energy (DME) sent out a directive to reduce the engineering dust concentration level (engineering sampling) to below five mg/m^3 at the operator's position. This was achieved through multi-party involvement in various SIMRAC sponsored projects. These projects involved tests on a model continuous miner in a ventilation simulation tunnel at the CSIR's Kloppersbos Research Facility. The systems tested needed to comply with two main criteria: adequate methane dilution at the face and keeping the respirable dust-concentration levels below five mg/m^3.

Continuous Miner (CM) dust control systems

New CM dust control systems developed and successfully applied underground are: the half-curtain system, the retrofitted hood system, the double scrubber system and the integrated hood system. Currently, these dust control system types are being effectively operated in more than 80% of the mines in South Africa. Of all the systems tested, the half-curtain dust control system proved to be the most successful for continuous miners (see Figure 1). Details of the systems are discussed in the SIMRAC research reports COL518 and COL 619.

Elements of a typical half-curtain dust-control system are:

- A hollow-cone spray nozzle (1.6 mm inlet/2.0 mm outlet diameter) with a Kloppersbos directional spray system
- Air movers fitted over the flight conveyor
- An extended scrubber intake, with an inlet cone fitted
- A physical half-curtain.

The methane levels during the underground tests never exceeded the maximum permitted concentration (Minerals Act and Regulations, 1991) of 1.4% CH_4 per volume for the dust control systems. Doubts about the system's effectiveness in diluting methane at very high face methane releases were alleviated by the tests carried out on the same dust control systems in the Kloppersbos simulation ventilation tunnel at a face methane release rate of 600 L/min (Van Zyl and Belle, 1999). At such high methane release rates, the measured methane concentration levels did not exceed 1.0 % level in the face area.

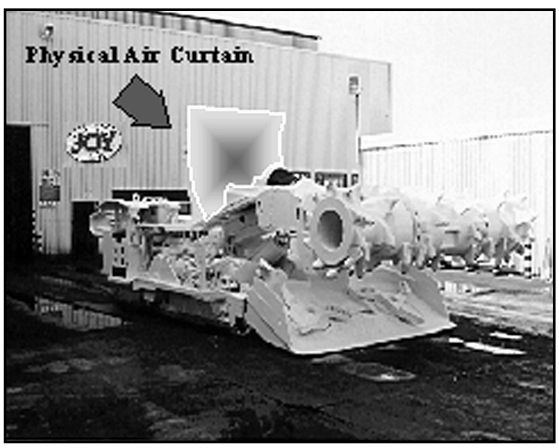

Figure 1. A half-curtain dust-control system installed on the Joy CM (Courtesy: Joy SA)

Road Header (RH) dust control system

With their inherent advantages over CMs, road-heading machines are the preferred extraction systems of many of the coal operators. In South Africa, the road headers are being used for development sections for seam heights up to 5.9 m. Despite the production benefits, the road header sections pose a unique and complex dynamic environment in terms of controlling dust, unlike CM sections.

The extensive use of road headers in South Africa has meant that research on improving face ventilation and dust-control systems has been emphasised. Due to the design of RHs and the severe conditions under which they operate, the dust-control strategies that have already been developed for the CM may not be universally applicable. Also, ventilating the face area while a RH is cutting is more complex than with a CM because of the physical layout of the machine and the nature of the movement of the boom.

Faced with these enormous challenges, during 1999-2000, CSIR: Miningtek successfully developed a dust control system, which was able to contain the engineering dust concentration levels at the operator's cabin position to less than five mg/m3 in a mining seam height of 5.2 m. The successfully developed system was initially simulated at the IMCL gallery in the UK and was later modified underground in a South African coal mine by CSIR: Miningtek.

In high seam coal mining headings, the control of total dust is difficult as the water sprays or air movers alone will not be able to contain the roll-back of dust towards the operator. The main feature of the new dust control system incorporated a 'concave spade plate,' which prevented the roll-back of total dust from the falling coal, and the containing of it in the face area, while at the same time guiding in a smooth airflow to and across the face area.

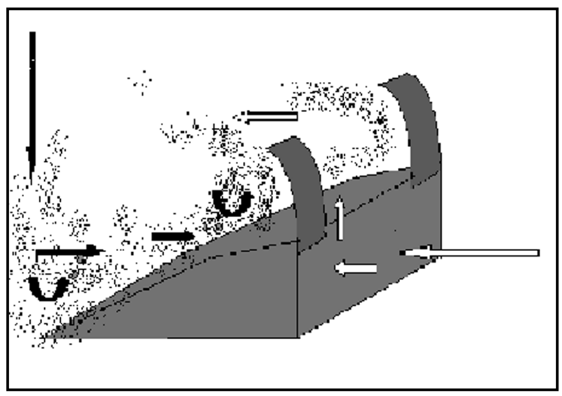

Figure 2. Concave spade plate operation principle on a road heading machine

The principle of operation of the concave spade plate, as shown in Figure 2, is as follows: the spade plate is approximately 30 inches high and 22 inches wide and is positioned at the spade. The concave shape of the plate prevents or slows down the momentum of falling dust cloud or rollback dust, and prevents further traveling towards the operator's cabin, acting as a physical shield. As the falling dust rolls towards the spade area, due to its concave shape, the dust travels backwards towards the face. On the other hand, when auxiliary ventilation such as a jet fan and column are used, the concave shape of the spade plate does not act as a shield and rather guides the fresh air to reach the face area.

The typical spray configuration of the cutter head of the RH machine is shown in Figure 3. The critical elements of the RH Dust Control System are as follows:

- Hollow-cone single-inlet nozzle - 1.6 mm (inlet)/2.0 mm (outlet) with a new spray configuration (Figure 3)
- Physical half-curtain covering an area from the scrubber on the left hand side (LHS) of the machine to the middle of the machine over the flight conveyor. This curtain consists of a conveyor belt positioned approximately one meter from the scrubber inlet
- Air movers on the flight conveyor and on the LHS of the operator
- Jib sprays on the LHS and concave spade plates
- Flight conveyor discharge cover
- 45° scrubber deflector plate, and
- Operating water spray pressure ranging from 15 to 20 bar at a flow rate of 3.0 to 3.5 L/min/nozzle.

Wet Head dust control system

The original concept of wet head system on the CM's was based on water sprays emitted from nozzles mounted on the rotating drum head and nearby each bit. This differs from conventional external sprays, by water being sprayed continuously to the bit and its vicinity as it cut the coal. The concept was developed in the 1970s by the former USBM, Bituminous Coal Research National Laboratory, and various manufacturers (Merritt, 1987). The early tests showed reductions in dust levels from as much as 56 % to as low as 13%, with one machine actually showing an increased dust make. The tests also identified two problems with wet head drilling:

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

Despite the interest in both the 1970s and the 1987 trials of wet head continuous miners, there is a total 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 wet heads (including the cost of sophisticated seals) met with resistance from the coal mining companies. Despite enquiries during the early 1990's no wet heads were ordered until late in 1994 (Phillips, 1997). A recent SIMRAC report concluded that CMs with wet heads are now commercially available, either as new machines

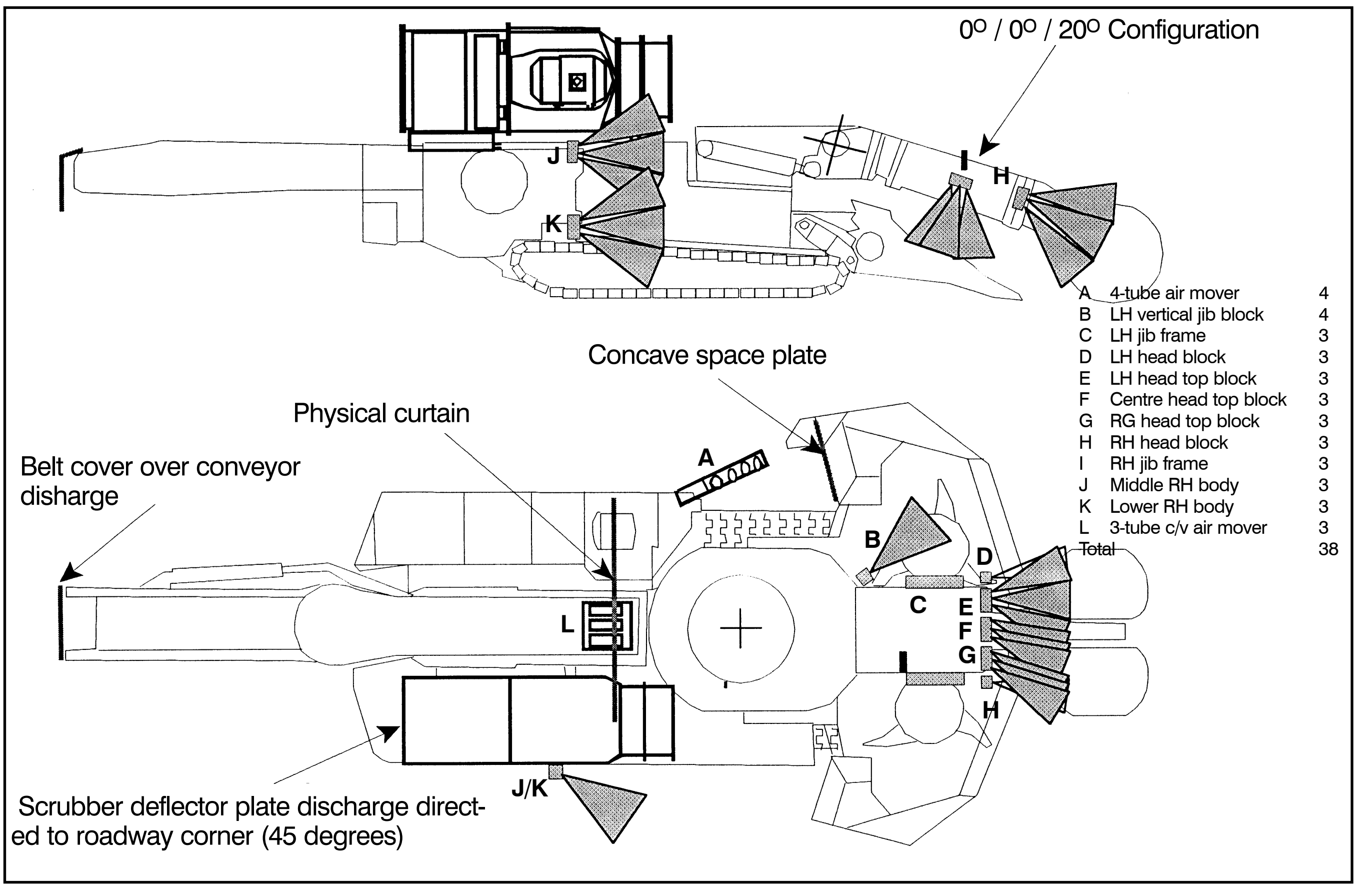

Figure 3. Final configuration of the Bank 2000 RH dust control system

or as a wet head retrofitted to existing machines. Also, the report indicated that there is world-wide interest in wet head continuous miners, 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 continuous miners will have a major impact on dust control strategies.

CSIR: Miningtek evaluated a Hydra Tool wet head system in one of the South African coal mines. This wet head system was the only operating system on a trial basis in South Africa. Water transfer to the cutter heads is now by a single cartridge giving obvious advantages over the original three-cartridge system. The results of tests on the newly developed and improved wet head system is discussed elsewhere (Belle and Clapham, 2002).

Longwall dust control system

Currently, only a handful of longwall faces are operational in South Africa, unlike US operations where longwall production accounts for 50% of the underground coal production (Fiscor, 1997). Longwall coal mining operations confer several major benefits for underground coal mining operations. The most important of these are the almost total extraction of the coal deposit compared to extraction of the order of 60% with conventional and CM bord and pillar operations.

A South African study of personal dust exposure data from underground coalmines indicated that, in coal mines, the highest dust concentrations were experienced in 'longwall mining sections.' Exposure to high respirable dust concentrations, even in the absence of a high quartz concentration, was identified as a major problem in coalmines.

However, the cutting height is a major obstacle to the successful implementation of longwall techniques developed for overseas coal mines in order to control dust levels within acceptable limits. In fact, the Department of Minerals and Energy has indicated that it would close down existing longwall operations unless new technology is developed which makes it practical to maintain acceptable worker exposure levels. While technology exists for use in the narrower coal seams encountered in other parts of the world, no such systems are applicable for South African conditions. Considerable technical challenges and R&D is required to enable the design of equipment appropriate to these circumstances.

Extensive research was carried out in the USA in the last century on longwall dust control. A wide variety of techniques for the control of shearer-generated dust were developed in the US for low seam longwall mines (seam heights up to 2.5 m). The research study by Organiscak and Colinet (1999) indicated that face ventilation and water application are essential elements in controlling longwall dust levels. Application of these US developed techniques are limited to South African longwall conditions where the seam heights vary from 4.1 m to 5.9 m. Augmenting the existing dust control problems in South African coal mines is the fact that the primary respirable dust generation rates of South African coal seams were higher than those of the US coal seams (Ramani and Srikanth, 1996), thus posing a more serious health and safety threat to the underground coal mine workers.

Future dust control research should be in the area of high seam longwall dust control as nowhere in the world does the technology exist to control dust generated for planned seam heights of nearly 5.9 m, mined by longwall shearers.

Auxiliary ventilation

Auxiliary ventilation in the face area of any mining section is a critical factor in a successful environmental control system. A combination of force and exhaust ventilation systems are universally believed to represent the optimum system, combining the advantages of the high velocities from force systems for dispersing methane with those of exhaust systems for dust capture. However, there is considerable conflict between the two systems, requiring strict control of the effect of the force system to allow the successful capture of dust by the exhaust system at the face. The following critical observations were made on the most effective methane and dust control practices adhered to in continuous mining sections in South Africa:

- The right and left cuts of the first 12 m should not be force-ventilated. Depending on the section ventilation, beyond 20 m from the last through road, the force column ventilation should be such as to ensure that air velocities over the operator do not exceed 1.0 m/s.
- Auxiliary fans (force or jet) positioned on the floor should be used in conjunction with the columns on the intake side of the machine (CM operator's side).
- Because of their robustness and capacity, jet fans with columns would be better auxiliary ventilation devices than large force fans, unless controls were set up to ensure that the required discharge velocity from the outlet of the column was between 10 m/s and 12 m/s.

Critical elements in control technologies

Researchers worldwide have repeatedly stressed the need for effective ventilation and water application in any environment control (dust and methane) technology. The sensitivity of the dust and methane control system to water flow rates and pressures was clearly demonstrated during various underground trials. Some of the interesting results are shown in the plots hereafter. The relationship between water flow rate and the concentration level at the operators' cabin position is shown in Figure 4. We can observe that, by increasing water flow rate or maintaining the optimum water flow rate to the spray system, the dust concentration below the compliance level can be achieved.

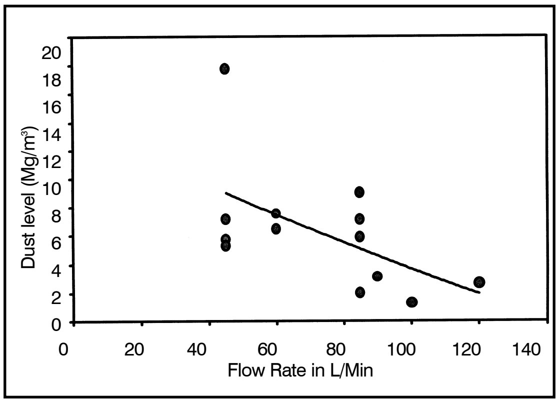

Figure 4. Relationship between dust concentration and water flow rate to the spray system

Similarly, Figure 5 shows the influence on the methane levels with and without operating the booster pump on the CM. The correct operation of the pump resulted in a reduction in the methane levels measured, despite the normal production. Prior to this the methane sensor saturated at 4% CH_4 per volume. From this, one can infer that the sweeping action of the directional spray system will be severely hampered if the design water pressure and flow rate are not adhered to.

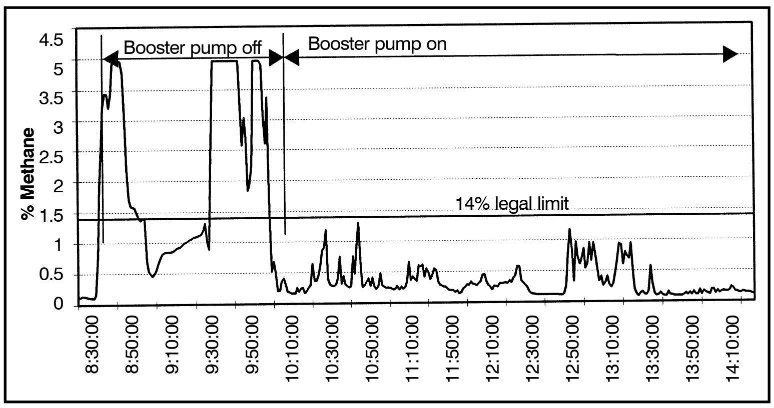

Figure 5. Influence of water spray system on methane concentration

Approach for dust control

Extracting high seam coal seams, while maintaining the health and safety of workers, is a challenge facing the South African mining fraternity. Since their inception in the control of dust and methane, water sprays and ventilation have played an effective role in the mining industry. As discussed above, a wide range of engineering controls are available to the industry for dust control. The two fundamental strategies adopted by the industry for controlling worker exposure to respirable dust are the engineering control and administrative control.

The effectiveness of the various engineering controls depends on basic variables such as operational technique, mining machines, coal characteristics and the ventilation parameters of the workplace. In summary, the engineering dust control techniques will include an effective ventilation system (main and auxiliary), effective water application and a combination of various dust-extraction systems. Maintaining engineering controls and following effective control procedures will protect the workers from being exposed to high levels of dust concentration.

From an administrative (management) control perspective, experiences have shown that the proper maintenance of all dust-suppression components, i.e. spray nozzles, spray blocks, air movers and scrubbers, is absolute essential. Flushing of the water filters prior to cutting, together with checking of the water flow and pressures, is recommended at the start of every shift. Regular changing of worn-out bits greatly contributed to the reduced dust levels at the face, especially while cutting a bad roof. It was also observed during the field visits that it is essential to train and educate the miner about the sampling objective, sampling procedure and the resulting dust-related decisions based on the samples collected underground. Finally, the introduction of "achieving compliance dust levels" as a component of the "production bonus" could be the "future management carrot" for the creation of safe and healthy environment by the worker ownership in the exercise.

Conclusions

The improvement of the underground working environment through proper control of the environment will result in an improvement in mine worker health. The problem has been addressed in lower seam operations in the USA but, due to the South African coal seam heights, systems able to meet the different seam characteristics are crucial.

Through joint partnerships with the industry and labour, CSIR: Miningtek has been successful in reducing dust levels and effectively controlling methane levels below the regulatory limits in continuous miner and road header sections in seam heights up to 5.2 m. Few of these concepts are particularly innovative or new and they are generally already widely appreciated within the South African mining industry. Efforts are being made for the effective control of dust in longwalls of heights up to 4.0 m and challenges lie ahead for "super walls" of up to 6.0 m in height. More widespread, successful control of dust in longwall mining could extend the remaining lives of South Africa's major coalfields and thereby positively affect economic activity.

In the context of global change in technology, further research is still required. This is particularly urgent as the required dust levels to prevent dust related illnesses are continuously decreasing. It is the authors' opinion that, through research partnerships and international collaboration, we can effectively address the future requirements and challenges of our industry.

The rapid changes in the coal mining industry have resulted in various new problems and associated health risks. The major identified health and safety risks are related to dust exposure, noise and explosions. Both local and international agencies have addressed these risks through a number of research contracts. Advances in dust research worldwide and the continued support of the South African mining industry in abating the dust problems will achieve a definite and consistent downward trend in the incidence of pneumoconiosis. The development of site-specific dust control technologies will be able to resolve the specific needs of individual mines within as short a time as possible.

Acknowledgments

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ERRATUM

The title of the presentation by HJM Rose, in the conference programme published in the July/September edition of the Journal was printed incorrectly.

The correct title is MANAGING THE DUST CONTROL PROBLEM AT THE VERTICAL ROCK HANDLING SYSTEM AT TAU LEKOA GOLD MINE.

We apologise for this error.