KLOPPERSBOS HEALTH AND SAFETY RESEARCH IN THE SOUTH AFRICAN COAL INDUSTRY

J J L du Plessis and B K Belle

CSIR Division of Mining Technology, South Africa

ABSTRACT

The increase in production, and the technologies used to obtain this goal, in the South African coal mining industry has led to various problems. These can be attributed to a number causes, some related to human beings and others to technology. The 1995 report of the Leon Commission of Inquiry into Safety and Health in the South African Mining Industry (Leon *et al.*, 1995) led to the promulgation of the Mine Health and Safety Act of 1996. The Act placed the emphasis on the safety and health of the workers and made this the responsibility of the owner of the company or his representative. The increase in concern about health and safety-related issues has in turn made mine operators intensify their efforts in this regard and caused them to take a fresh look at their current strategies.

This paper presents a summary of recent advances in health and safety technologies in the coal mining industry in South Africa. The topics discussed are wide-ranging and serve to illustrate how diverse the current research activities being undertaken in South Africa are.

INTRODUCTION

The South African coal mining industry has grown rapidly over the past two decades. Annual coal production is currently of the order of 210 million saleable tons, of which approximately 60 million tons are exported. Coal is produced mainly by three methods, viz. surface mining, and underground mining using conventional mechanized methods or mechanical miners. The nature of the international coal markets and the volatility of the coal price necessitate continuous improvements in the methods used to exploit coal. Some of the current inherent features of South African mines are: long headings up to 35 m, and the increased use of highly mechanized equipment.

During 1999 alone, there were 4 466 recorded mine accidents in the entire mining industry. The causes of these accidents were: failure to comply with recognized safety standards, good practice and good procedures; lack of caution or alertness; and inadequate examinations, inspections or tests (Ensor and Xako, 1999). To keep up with the technological changes in the production methods, it is essential to be innovative with regard to safety methods and techniques and these are being investigated.

ADVANCES IN HEALTH AND SAFETY

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 South African underground coal mines in the early 1970s. The sheer size and power of these machines gave rise to a number of problems, some of which related to health and safety and are still being investigated today. A combination of rapid advance rates, roof stability problems, and dust- and noise-related disease still forms the basis of continued research aimed at creating safe working environments. Approximately 300 mechanical miners are currently used in exploiting coal from underground reserves in South Africa.

This paper highlights the following aspects of research relating to the currently available health and safety technologies that are being implemented in the mines:

?? Dust control technologies

?? Dust measurement

?? Underground explosion control

?? Methane monitoring

?? Integrated escape and rescue strategies

?? Self-Contained Self-Rescuers (SCSRs)

DUST-CONTROL TECHNOLOGIES

The dust hazard to miners was first specifically recognized and made the subject of intensive study in South Africa during the early years of the 20th century. Inhaling excessive amounts of respirable coal mine dust causes pneumoconiosis, commonly known as “black lung”. The occurrence of the disease can be prevented by lowering dust-exposure levels in the workplaces. Several sampling strategies have evolved over the years and there are various sampling methods for defining the standard levels in various countries. The samples taken can be divided into:

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

Engineering Sample: An engineering sample is the dust sample taken at a pre-determined position of the continuous mining machine operator for control purposes. Engineering samples help to determine the effectiveness of the dust control and ventilation systems in the section.

Concerns were raised through recent studies by British scientists and by NIOSH, which indicated that the risk of developing pneumoconiosis at the present exposure-level standard (2 mg/m^3) is higher than had been previously believed. However, the Australians have reported that they have found no evidence of pneumoconiosis at levels greater than the 2 mg/m^3 standard (US Federal Register, 1995).

A Directive (1997) of the South African Department of Minerals and Energy (DME) to reduce the engineering sample concentration levels to below 5 mg/m^3 resulted in a research project entitled “Underground Mechanical Miner Environment Control.” These studies focused on reducing respirable dust so as to ensure lower worker-exposure levels.

Extensive simulation studies in the ventilation tunnel (Figure 1) at the CSIR have resulted in a new Kloppersbos Spray System (Du Plessis and Belle, 1998) and the development of new dust-control systems. They are the half-curtain, the retrofitted hood system, double scrubber system and the integrated hood system.

A project team from the CSIR Division of Mining technology (Miningtek) successfully evaluated these new dust-control systems under the auspices of the Safety in Mines Research Advisory Committee. Dust levels below those prescribed in the Directive were easily achieved during a four-month underground trial at Matla No. 3 Colliery (Belle and du Plessis, 1998).

Currently, the systems are being operated in more than 80% of the mines in South Africa. Of all the systems tested, the half-curtain dust-control system was the most successful. In the half-curtain tests, methane levels never exceeded the maximum concentration of 1.4% CH_4 per volume and it was proved that dust concentrations were kept below 5 mg/m^3 at the operator’s position by following the recommendations made in the study.

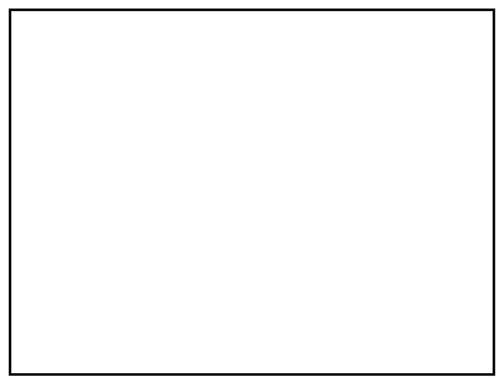

Figure 1: Ventilation Simulation Tunnel at CSIR Miningtek, Kloppersbos, South Africa

A typical half-curtain dust-control system (see Figure 2) is fitted with:

?? New hollow-cone spray nozzles (1.6 mm inlet and 2.0 mm outlet diameter)

?? A directional spray system

?? Air movers fitted over the flight conveyor

?? An extended scrubber intake, with an inlet cone fitted

?? A physical air curtain.

Recent tests carried out on the half-curtain system in the Kloppersbos ventilation simulation tunnel showed that the system effectively dilutes the methane released at the face at a rate of 600 L/min (Van Zyl *et al.*, 1999).

In South Africa, several of the mining houses have succeeded in complying with the DME Directive (1997) and have shown extra enthusiasm and taken individual responsibility for enhancing the mine environment by several means.

Figure 2: A half-curtain dust-control system installed underground

DUST MEASUREMENT

One of the South African mining industry's goals is to find a standard measurement procedure using sampling instruments with minimal resources, without compromising the health of mine workers. An initial study by CSIR Miningtek (Oberholzer *et al.*, 1998) indicated that there were discrepancies in the dust-concentration results between individual gravimetric dust samplers. In the study that followed, alternative instruments or methods were sought. It was recommended by the HSL in the UK that a cowl (shield) arrangement, together with a sampling rate equivalent to the CEN/ISO standard, be used to minimize oversampling. Subsequently, the CEN/ISO recommended sampling rate of 2.2 L/min was used.

Field experience of dust measurement in South African coal mines has suggested that when samplers for respirable dust such as cyclones are used in conditions of very high dust concentrations, they can become overloaded. To provide a practicable means of avoiding this problem, a large cowl was fitted over the entire cyclone. Measurement of the size-selection characteristics of the South African cyclones tested in the UK confirmed that they are similar to the Higgins-Dewell designs commonly used in the UK and elsewhere in Europe (Kenny *et al.*, 1998).

In South Africa, fears were expressed that the additional shield surrounding the cyclone would inevitably result in lower measured dust concentrations. However, in the study conducted by Kenny *et al.* (1998) at the HSE laboratory (UK), it was shown that cowl samplers performed similarly to Higgins-Dewell-type samplers. Informal opinions solicited from world experts in this field have suggested that the use of a cowl should not influence cyclone performance at high dust concentrations (Oberholzer *et al.*, 1998). A BGI stainless steel cyclone sampler and a Higgins-Dewell-type sampler with a cowl arrangement were therefore studied in South African mines (Figure 3).

Figure 3: Higgins-Dewell cowl-type and BGI-type dust samplers

Analysis of the data collected in this way (Belle *et al.*, 1999) indicated that the gravimetric measurements at the section intake, continuous miner (CM) operator position and section return were not significantly affected by the difference in the two samplers. Although the two instruments differ in terms of their design, cost and ease of use, the results demonstrated that there was no significant difference (95% level) between the relative mean concentration values measured in the section. However, at the operator position, the mean dust-concentration level from the BGI sampler was generally higher than that from the cowl sampler. This was not the case for the section intake and section return sampling positions where the concentration value obtained by the BGI sampler was lower than that from the cowl sampler.

A comparison of the individual regression lines derived from the data from the different sampling locations shows that, on average, the cowl sampler undersampled by approximately 7%. This undersampling appears to occur with the samplers located at the operator position and in the section return. It could therefore be concluded from these regression lines that adding the cowl to the sampler biases the measurement by about 7%. It is hoped that a further study in which various pairs of Higgins-Dewell cyclone samplers, used with or without a shield, will be placed side-by-side underground may provide answers to the questions raised.

Currently, in the holistic approach, research and development in the area of dust and emission control are directed towards:

?? Respirable dust measurement and instrumentation

?? A review of existing dust-measurement strategies.

UNDERGROUND EXPLOSION CONTROL

The Safety in Mines Research Advisory Committee (SIMRAC) has made a sizeable investment in investigating a number of alternative and new explosion-protection controls. The most recent research focus has been on techniques for preventing coal dust explosions. A number of these research projects are briefly described below.

Active On-board Explosion-suppression System

The major ignition source for methane and coal dust explosions results from the action of the cutting pick of the tunnelling machine on small quartz and sandstone inclusions in the coal seam. To help reduce the risk of these ignitions, the picks of the machine are cooled with water sprays, methane detectors are mounted at the face to monitor methane concentrations, and ventilation is used to prevent methane build-up at the face. However, even with these and other precautions, ignitions still occur.

Active on-board explosion-suppression systems are mounted on CM machines and detect the presence of a methane ignition by means of light sensors. The electronic signals from the sensors trigger the suppression system which creates a barrier of flame-suppressing material, thus containing the flame in the immediate vicinity of the ignition and so preventing further development and propagation of a coal dust/methane explosion.

A South African test protocol (Du Plessis and Bryden, 1997) was established for these systems and a 20-m rectangular test tunnel was developed at Kloppersbos. The objective of the protocol test is to determine whether a system or configuration is able to fulfil the acceptable criteria for various cutter head positions, methane concentrations and roadway heights.

Several active suppression systems have been tested in the Kloppersbos explosion tunnel. Recently, in response to an approach from the French research institute INERIS, which required further precautionary measures for their collieries, an on-board active suppression system, "Explo-Stop®", was adapted in South Africa for their requirements (Figure 4). This project involved four different companies – Centrocen, the CSIR, INERIS and HBCM – the French mine in which the system was to be installed subsequent to the success of the tests (Van Dijk *et al.*, 1999).

The results of the tests showed that the system managed to suppress stoichiometric methane mixtures (a volume of 180 m^3 of a 9% methane concentration). This was achieved with a temperature rise of less than 100°C at the operator's cab and no flame was detected at the operator's cab. Active suppression systems can therefore be used in conjunction with 'traditional' methods of explosion prevention.

Figure 4: The Explo-Stop® on-board active suppression system on a Dosco 1300H

Bagged Stone Dust Barrier System Technology

The bagged stone dust barrier system (Figure 5), in various configurations, makes use of the concept of containing stone dust in a bag but incorporates a new method of rupturing the bag based on material properties, relative volumes and a patented suspension device (Du Plessis and Vassard, 1997). Evaluation tests were conducted over a period of four years to establish the design, materials specifications and installation configurations for suppressing dust explosions.

Both distributed and concentrated installation configurations have been devised. Tests at Kloppersbos and in the underground test facility at DMT Tremonia (Margenburg and Du Plessis, 1996) have indicated that a minimum dynamic pressure of 3 kPa is required for bag rupture and that coal dust/methane explosions are effectively stopped with a stone dust loading of 100 kg/m^2 of cross-sectional area (Michelis, 1998; DME, 1997). In South Africa, more than 80% of the collieries have fully implemented such systems. Similarly, the system is currently being implemented in Australian mines.

METHANE MONITORING

Since the late 1960s and early 1970s, significant advances have been made in the area of methane-monitoring techniques for mechanical miners. Determining the amount of methane released into the working face during mining is an important aspect in the effective control of methane levels. An increase in the methane levels around mechanized mining machines during operation has also been established.

A recent study indicated that to minimize the risk of methane ignitions, gas levels must be measured within 2 m of the cutting face. To achieve this and make it acceptable to industry, it is necessary to develop a sensor or sensor-protection system that can withstand the unforgiving environment near a cutter head, give accurate readings and that will only need low maintenance.

Figure 5: Bagged stone dust barrier system

To provide a simple method of quantifying methane release rates, a unique model has been developed to simulate in-coal gas flow behaviour in terms of gas desorption rate and content. To apply this model, a new prototype system has been developed; this is shown in Figure 6 (Van Zyl, 1999). This system overcomes the problems associated with current direct test methods and improves reliability and manoeuvrability. The first design relies on sensitive pressure and temperature transducers which monitor the conditions as methane desorbs from a sample in a sealed vessel containing 12 to 15 kg of freshly cut coal, while the second relies on a constant stream of fresh air from a compressed air cylinder across a coal sample of a similar mass.

The pressure versus time curve obtained is then used to determine the gas content and flow behaviour of the coal sample. Stand-alone software for data analysis has been developed, but the data-processing manipulation for the pressure and temperature transducer system still needs to be streamlined.

Figure 6: Methane release rate-quantification system

INTEGRATED ESCAPE AND RESCUE STRATEGIES

Owing to the high concentrations of carbon monoxide present in mines, escape in the irrespirable atmosphere that results from an underground explosion or fire is dependent on the use of an artificial breathing apparatus. Self-Contained Self-Rescuers (SCSRs) thus form the basis of any escape and rescue strategy. However, although SCSRs form the core technology, they are largely ineffective unless they are integrated into an overall escape and rescue strategy compromising escape routes, guidance systems, refuge bays, hazards identification and communications systems.

The performance of SCSRs is determined by many factors, including the physiological characteristics of the wearer and the nature of the escape route. In this regard studies have been conducted to determine the effects of inclination, reduced roof height and zero visibility on the speed at which escape routes can be negotiated, as well as safe travelling distances. It was ascertained that, typically, safe escape distances are reduced from 1 500 m, based on a breathing criterion, to a maximum of 750 m when adverse condition criteria are applied. Mines are currently using this information to determine the location of back-up facilities and refuge bays.

One of the integral parts of an escape and rescue strategy is the design and positioning of refuge bays. The fundamental requirement of a refuge bay is that it should prevent the ingress of gases and fumes following an explosion. Based on this rationale, considerable effort has been directed towards defining the overall strength and viability of refuge bays for use in the event of fires/explosions. It has been found that current refuge bay designs in South Africa are more than adequate in the event of fire. Based on the probability of human survival at various explosion overpressures, investigations have revealed that a criterion of 140 kPa should be applied in the design of refuge bay bulkheads.

In deciding on the placement of refuge bays, the first criterion is that they should be within practicable reach of the workers that they serve. Based on an evaluation of the performance of SCSRs under zero visibility conditions, refuge bays should not be further than 750 m from the workplace. The development of the Mobile Air Rescue Station (MARS) arose from the need to provide an economical, intermediate staging point and breathing station at a distance of less than 750 m from the workplace, which could be readily integrated with the design and positioning of existing refuge bays. The MARS is an easy-to-operate mobile life-support system for underground workers, developed in conjunction with MSA-South Africa.

SELF-CONTAINED SELF-RESCUERS (SCSRs)

In South Africa, the concept of a body-worn SCSR was still novel 12 years ago and much of the research in this area is still ongoing. The South African mining industry could, in fact, be regarded as having pioneered this innovation and the deployment of body-worn SCSRs world-wide. A total number of approximately 100 000 belt-worn SCSRs are at present used underground in South African mines. There are six different makes of SCSRs: the MSA/AUER SSR 30/100, the Drager Oxyboks K, the Fenzy Spiral 1, the Ocenco M20, the Afroxpac 30 and the Size Moya. Three of these makes have been deployed for longer than 11 years and the remaining three for five years. However, the SCSRs used in overseas mines do not necessarily function adequately under South African mining conditions.

The South African mining industry's track record, history and the incidents that have occurred over the past 12 years in terms of the performance of the different body-worn SCSRs were critically scrutinized by Schreiber and Unsted (1999). In 1996, an industry-wide SCSR monitoring programme was established in a collaborative effort between the DME, mining houses, trade unions and CSIR Miningtek. The goal of the programme is to compile a database and to provide a forum for feedback on the test results to all interested parties. A protocol for SCSR selection procedures, structural test procedures and functional performance has been drawn up and is contained in a comprehensive document. All the necessary test equipment and gas analysers, as well as two lung-breathing simulators, have been commissioned to assist with the scientific and objective testing of SCSR units at the CSIR Miningtek facility.

From the initial tests on SCSRs carried out by the Accredited Testing Authority (ATA) at CSIR Miningtek, it was found that the functional performance of 11% of the SCSRs had deteriorated to the extent that they had reached the rejection limit. The relationship between casing leakage and functional deterioration was also established. Some of the major findings and conclusions derived to date are (Schreiber and Unsted, 1999):

?? The ongoing SCSR monitoring programme allows any functional, material and structural deterioration in SCSRs to be identified and recorded.

?? Although new SCSR units may initially meet the required design and performance criteria, several years of daily handling and of exposure to bumps and knocks will eventually lead to some deterioration of their materials and components, which will compromise their reliability.

?? In the last few years, normal symptoms of wear and tear and the deterioration of functional performance are not the only faults that have been identified. Material failures, structural faults and design weaknesses have also been found.

?? There have been other initiatives as well, relating to the ergonomics of SCSRs and the development of a nose-clip design to cater for the low-ridge noses typical of most of the South African mine workforce. This nose clip is currently being retrofitted to several types of SCSR.

?? The SCSR test facility is unique to the Southern African Development Community (SADC) and it also serves as a training and education centre for the mine inspectorates, industry professionals and mine workers.

CONCLUSIONS

The rapid changes in the coal mining industry have resulted in various new problems and associated risks. The major identified health and safety risks are dust-related health problems, noise and the risk of explosions. These risks have been addressed through a number of research contracts and independent consultancies by both local and international companies. A wealth of information has been obtained and is now available both locally and internationally, resulting in the achievement of a definite and consistent downward trend in the accident and fatality rates. Future work will therefore be more closely directed towards the development of site-specific technologies that can resolve a specific need in as short a time as possible. CSIR Miningtek is playing a leading role in providing for most of southern Africa's mining needs through its multi-disciplinary approach to the solution of health and safety problems. The organisation is recognised by the Department of Minerals and Energy (DME), the Safety in Mines Research Advisory Committee (SIMRAC), the DEEPMINE project, mining houses, mines and equipment manufacturers for its quality fundamental and applied research.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the financial support of the CSIR and its Division of Mining Technology. Gratitude is also expressed to their colleagues, Kobus van Zyl and Wilfred Schreiber, and to Robert van Dijk of Centrocen, South Africa, for his input on the Active Suppression System.

REFERENCES

Belle, B.K. and du Plessis, J.J.L., 1998, "Summary Report on Underground Mechanical Miner Environmental Control," SIMRAC Report, South Africa.

Belle, B.K., du Plessis, J.J.L. and Oberholzer, J., 1999, "Evaluation of BGI and Cowl-type Gravimetric Samplers in South African Underground Coal Mines," Paper submitted to the *Journal of the South African Mine Ventilation Society*.

Du Plessis, J.J.L. and Vassard, P.S., 1997, "Assessment of the Dispersed Stone Dust Barrier," SIMRAC Report, South Africa.

Du Plessis, J.J.L. and Belle, B.K., 1998, "Evaluation of Ventilation and Dust Control Systems in a South African Ventilation Simulation Tunnel," *Proc. 2nd International Symposium on Mine Environmental Engineering*, Brunel University, UK, pp 100-107.

Du Plessis, J.J.L., and Bryden, D., 1997, "Systems to Limit Coal Dust and Methane Explosions in Coal Mines," SIMRAC Report, South Africa.

Ensor, L. and Xako, S., 1999, "Mine Accidents this Year Total 4466," *Business Day*, South Africa.

Kenny, L., Baldwin, P.E.J. and Maynard, A.D., 1998, "Respirable Dust Sampling at Very High Concentrations," HSL, UK.

Leon, R.N., Salamon, MD.G., Davies, A.W. and Davies, J.C.A., 1995, "Commission of Inquiry into Safety and Health in the Mining Industry," South Africa.

Margenburg, B. and du Plessis, J.J.L, 1996, "Explosion Tests with Distributed Stone Dust Bags (RSA) in the Explosion Gallery of the Tremonia Experimental Mine," Germany.

Michelis, J., 1998, "Explosionsschutz im Bergbau unter Tage," Gluckauf-Betriebsbucher Band 38 DMT, Verlag Gluckauf GmbH Essen, Germany.

Oberholzer, J.W., du Plessis, J.J.L., Belle, B.K. and Eroglu, N., 1998, "Gravimetric Monitoring of Excessively High Dust Levels", Paper presented at a SIMRAC Symposium, South Africa.

Schreiber, W.L. and Unsted, A.D., 1999, "Self-Contained Self-Rescuers in the South African Mining Industry - Life Saver or Necessary Evil"?, *Journal of the Mine Ventilation Society of South Africa*, January/March, pp 4-10.

South African Department of Minerals and Energy Directive, 1997.

South African Department of Minerals and Energy, 1997, "Guidelines for the Compilation of a Mandatory Code of Practice for the Prevention of Coal Dust Explosions in Underground Coal Mines".

US Federal Register Notices, 1995, Vol. 60, No. 20, January 31.

Van Dijk, R.L.S., du Plessis, J.J.L. and Bryden, D.J., 1999, "Testing of Onboard Active Suppression System for French Mining Conditions," CSIR Division of Mining Technology, unpublished report.

Van Zyl, K., Belle, B.K. and du Plessis, J.J.L., 1999, "The Quantification of Methane Behaviour in Continuous Miner Headings using a Controlled Environment," SIMRAC Report, South Africa.

Van Zyl, K., 1999, Personal Communication, South Africa.