Safety In Mines Research Advisory Committee

Draft Project Report

Strategies to monitor non-homogeneous atmospheres in sealed off panels in coal mines

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Project Number : COL 602

Date: June 2001

Executive Summary

Many South African coal mines contain large areas sealed off from the mine ventilation. These areas contain an atmosphere sampled only at or near the seals. The research described in this report was commissioned to examine whether the current methods of monitoring sealed off areas are adequate, how South African practice compares with the methods used in other countries and whether alternative monitoring systems exist.

The research has shown that monitoring deep into sealed areas is not normally a major concern world-wide and that periphery or near-seal sampling is normal. When circumstances indicate the need for multi-point sampling in sealed areas, the accepted method is the tube bundle system, where samples are drawn through small diameter tubes to a central (usually surface) installation and the atmosphere from each tube is sampled sequentially prior to being analysed for the presence of a range of gases.

Although the report identifies a number of factors which increase the risk of the occurrence of non-homogeneous atmospheres in a sealed off area, the one tube bundle installation in South Africa for which data has been analysed has indicated a remarkably uniform atmosphere, where all the sampling points gave readings very similar to standard near-seal observations.

The alternative to the tube bundle system is to use standard, fixed-point gas sampling apparatus. Because these instruments need a power supply, routine maintenance and regular calibration, their use in a sealed off area cannot be recommended.

No new or novel devices could be identified during this study but two concepts, both using infra red detection of flammable gases, do appear to have potential but would require considerable research and development before they would become viable alternatives to the tube bundle system.

Acknowledgements

The authors would like to thank SIMRAC for the opportunity to undertake this research, which could not have proceeded without their financial support of project COL 602.

The section on current practice in Europe and North America was contributed by Dr D P Creedy. In doing so he drew on the resources of his employer, Wardell Armstrong, and this is gratefully acknowledged.

Information on current practices in Australia was obtained with the assistance of Dr J W Oberholzer, Manager of the Mining Research Centre at SIMTARS and through a visit to Australia undertaken by Mr G Lind of the School of Mining Engineering, University of the Witwatersrand. The contribution of both these gentlemen is acknowledged

During the course of this study several research organizations, Universities and monitoring equipment suppliers were contacted. Their willingness to help and ready assistance made the preparation of this report possible and they are all thanked for their contributions.

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1. Introduction

For over a century the preferred method of excavating South Africa's coal seams has been room and pillar mining. Until 1970 virtually all coal mining was by underground methods and, despite the rapid increase since then in large-scale surface mining, 50 % of coal production is still obtained from underground mines. In recent years bord and pillar mining has accounted for between 75 and 80 % of underground production. This means that most, if not all, underground coal mines in South Africa have current, recent or old bord and pillar panels.

Once mining of a bord and pillar panel has been completed, equipment and material recovery is undertaken and then a fundamental decision must be made on the future of the panel. It can remain part of the mine and continue to be ventilated or it can be sealed off from the mine ventilation system and become an inaccessible part of the mine. The former practice is generally regarded as highly inefficient in its use of ventilation air, while the latter requires the building of seals. Once a panel is sealed off there is the opportunity for a significant volume of the enclosed atmosphere to enter the explosive range and this is the hazard SIMCOM identified and commissioned this research to investigate.

This project looks specifically at bord and pillar mining for two reasons. Firstly, the void created by mining remains sensibly constant once mining has ceased (i.e. there is not a reduction due to caving or the roof lowering) and this void is also at the seam horizon and often adjacent to working panels or currently used roadways. Secondly, by its nature, room and pillar mining is a multi-entry operation and this makes the sealing of panels by explosion proof stoppings expensive and often technically impossible due to the small size of pillars. This investigation, is therefore, intended to review current practice and appropriate technology for the monitoring of atmospheres in sealed panels.

2. Review of international practice

Underground coal mines world-wide all face the same problem of dealing with sealed-off, inaccessible areas. However, the nature of the problem differs according to factors such as mining method, gas content of the seams and depth below surface. Until the 1980's most developments in coal mining technology resulted from large-scale, national research programmes in the northern hemisphere. However, the reduction in the scale of mining in Europe, together with the demise of the United States Bureau of Mines has meant that new developments are currently more likely to occur in the major coal mining countries, such as South Africa and Australia.

In order to gauge best practice in the rest of the world, information has been collected from Europe, the United States and Australia (both Queensland and New South Wales).

2.1 Monitoring of atmospheres in inaccessible areas of coal mines - practices in Europe and North America

2.1.1 Introduction

The hazardous gases which commonly occur in the inaccessible parts of a coal mine are methane, mixtures of carbon dioxide and oxygen deficient air (blackdamp), and carbon monoxide (a product of low temperature oxidation and also spontaneous combustion).

Inaccessible areas in European and US mines can be divided into 3 main categories:

1. Normally accessible areas of a mine temporarily sealed for the treatment of spontaneous combustion or fires.
2. Goaf areas of a working longwall section where access is prohibited by regulations, or access is impracticable.
3. Worked-out areas which are abandoned and permanently sealed.

The requirements for monitoring depend on the perceived hazards, the nature of the coal, the method of working and the compositions of gases likely to be present.

Monitoring of inaccessible areas is usually undertaken to provide information on one or a combination of the following:

- Oxygen (air) leakage into sealed areas
- Products of combustion
- Outflows of hazardous gases to airways
- Explosion risk

Pressure gradients and gas compositions are the principal parameters measured. The monitoring techniques used are focussed mainly on the requirements of longwall mining methods which predominate in Europe and North America. The extensive, open, abandoned roadway networks common in South African bord-and-pillar mines are rarely encountered. Conditions in stooped sections, however, will have some similarities with longwall districts.

Longwall mining methods differ from partial extraction methods in that large volumes of ground are disturbed above and below the worked seam. Any gas-bearing coal seams in the roof and floor disturbed by mining activity will release methane to the workings. These emissions decay over time, but significant accumulations of gas can still occur in worked-out longwall sections that have been sealed. In low-gas content longwall workings, large surface areas of coal in goaf areas generally result in the rapid oxidation of air and generation of blackdamp

Abandoned, gassy longwall districts tend to emit methane at the stoppings during atmospheric pressure falls. Methane concentrations deep within the sealed area will usually be in excess of the upper explosive limit, although flammable mixtures can arise close behind a leaking stopping. This situation contrasts with most South African collieries where, due to typically low methane emission rates, methane air mixtures are likely to accumulate within sealed areas at concentrations below or within the explosive range.

Although coal production is concentrated on longwall faces in both Europe and the US, face layouts differ considerably. Multi-entry systems are used to develop longwall faces in the USA but most European longwalls are accessed using a single intake and return airway. Sealing off is therefore arguably easier in European mines but access around the goaf for monitoring is more difficult than with US longwall layouts.

There is little interest in monitoring deep within sealed areas in the UK and USA during mining operations for the following reasons:

- Stoppings are designed to exclude air and thus prevent the formation of explosive mixtures in sealed areas. Gas testing at stoppings, and from pipes passing through them generally provides sufficient data to assess their adequacy;
- Information on the compositions of gases is not usually a major safety issue as the likelihood of methane ignitions occurring in sealed areas is considered remote in most countries although experience in Germany indicates a finite risk in some longwall goafs.

2.1.2 Monitoring techniques

Gas compositional information can be obtained using either remote instruments or by extracting a gas sample for analysis using a hand pump or an automatic sampling system connected to the surface (a "tube bundle" system).

The installation of electronic gas monitors in sealed areas is considered unacceptable due to the potential exposure of power supplies to high methane concentrations, and also impractical as instruments could not be serviced, calibrated or repaired. Tube bundle sampling systems, therefore, represent the accepted method for monitoring inaccessible areas of a mine.

The problem of intrinsic safety with multi-core data transmission cables could be overcome by the use of fibre optics. According to Hind (1999), the application of this technology in mining has been restricted due to the cost of connectors and the difficulty of terminating optical fibres in dusty environments. He states that progress has been made in overcoming these problems and predicts that fibre optic data transmission will be used underground in the future. Hind (1999) reviews current applications of mine monitoring and control systems but makes no reference to any applications involving sealed areas. Over 10km of optical fibre was installed in an underground trial of a temperature sensing system for spontaneous combustion (Willett et al, 1995) successfully demonstrating the potential of the technology.

The former US Bureau of Mines has investigated the application of fibre optic technology for remotely measuring methane and carbon monoxide in mines (Dubaniewicz and Chilton, 1992). The methane monitoring system described was based on differential absorption of infra red light. Concentrations from 0.2% to 100% methane could be detected using a fibre optic cable up to 2km in length. The system requires no electrical power within the mine so it could be installed in areas identified for abandonment. However, no maintenance of the installation behind the seal would be possible.
"Tube bundle" sampling systems (Chamberlain et al, 1974) have been installed in most UK coal mines and have proved invaluable for monitoring spontaneous combustion or

fire after temporarily sealing off the affected part of the mine. Tube bundle systems consist of a collection of sheathed tubes. Open ends of individual tubes are exposed in areas to be sampled. A surface pump applies suction to the system. Automatic valves and an industrial controller ensure that representative samples are presented in rotation to an infra-red analyser, or other suitable gas analyser on the surface, and the results recorded. A schematic diagram of a typical mine-wide layout is shown in Figure 2.1.2. Advantages and disadvantages are compared in Table 2.1.2. The major weakness of tube bundle systems is the possibility of sample dilution due to leaks. When the sampling end is accessible, standard gas mixtures can be injected to assess leakage effects but such a check is not applicable to inaccessible sample locations.

Table 2.1.2 Advantages and disadvantages of tube bundle systems.

Advantages	Disadvantages
Not reliant on underground power supplies.	Delay between sampling and analysis.
Intrinsically safe in all conditions.	Leaking joints or damage can result in sampling dilution and loss of accuracy.
Low maintenance.	Blockages and leaks can be difficult to trace.
Easily installed.	
Surface analyser easily upgraded.	

2.1.3 Monitoring temporarily sealed areas

Methods for monitoring of inaccessible areas are of particular importance to mines susceptible to spontaneous combustion risks.

Should an uncontrollable heating, or fire, develop, the mining district is temporarily sealed to enable inertisation treatment, usually nitrogen injection, to be carried out. Prior to, and during this process the tube bundle system provides invaluable information on the composition of the atmosphere in the sealed area. Thermal gradients will cause some gas mixing, therefore, in the absence of a significant ventilation current, some compositional variability is expected. Caution must be exercised in the interpretation of results because gas sampled by the tube bundle system may not be representative of the general body due to poor mixing of gases in non-turbulent flow conditions.

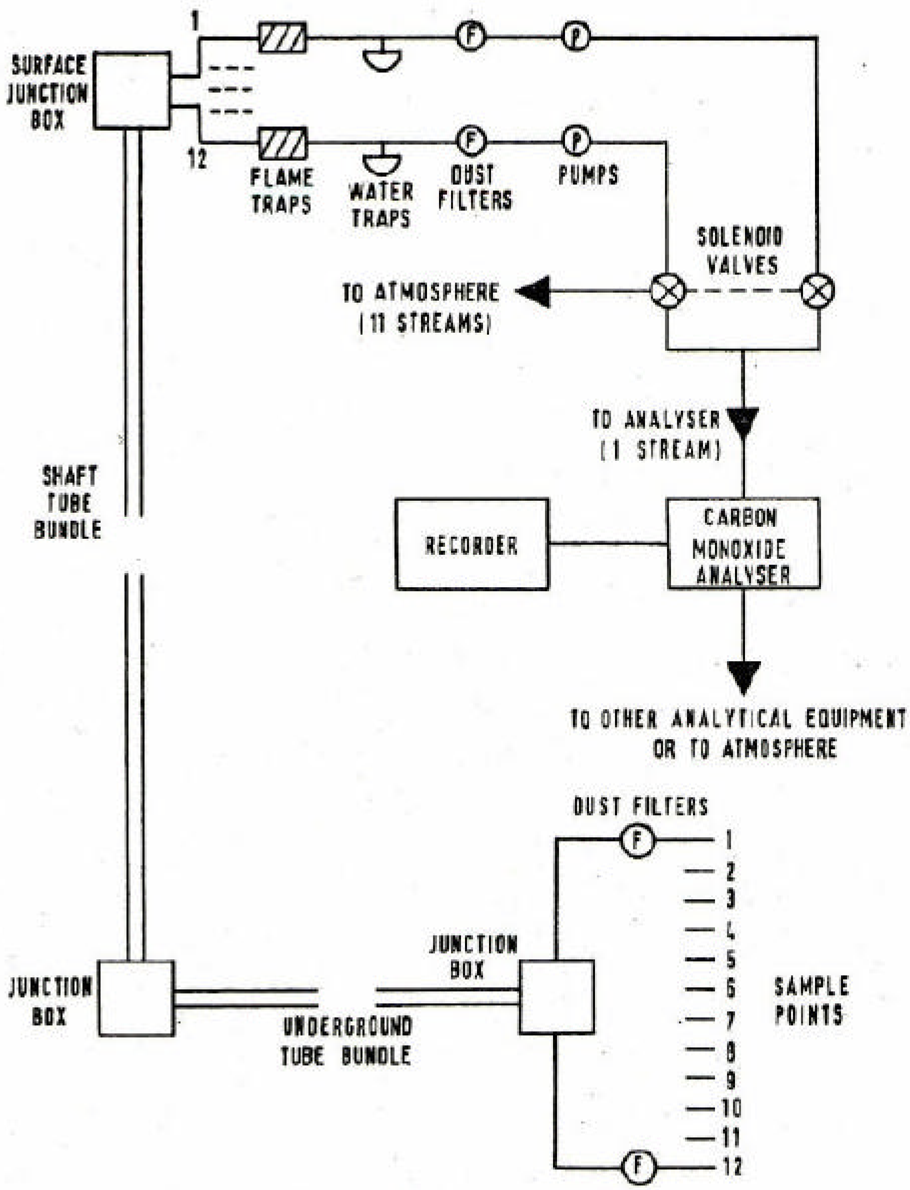


Figure 2.1.2 Schematic of a tube bundle monitoring system (after Chamberlain et al, 1974)

It is important to note that sample variation is less problematic in European mines where section layouts generally consist of a single intake and a single return roadway.

Tracer gas (sulphur hexafluoride) has been used to confirm the presence of flow and assist the interpretation of gas compositions in an inaccessible area. An open fire had occurred in a longwall section and part of the mine had been sealed off and was being treated by nitrogen inertisation (British Coal, 1990). Nitrogen and tracer gas were injected at the intake stopping and extracted at the return stopping to establish a flow of gas past the sampling point. The nitrogen extraction rate was slower than the injection rate to prevent air ingress. Gas samples were obtained for analysis from a tube bundle sampling point located relatively close to the fire. The time elapsed between tracer gas release and detection yielded the lag between the event being monitored and the measurement being obtained.

Current interest in monitoring inaccessible areas in US mines is mostly aimed at the treatment of fires and the exploitation of methane.

The behaviour of gases behind seals is well understood. The effectiveness of seals is judged by monitoring trends. Methane, oxygen and barometric pressure are plotted against time on semi log graph paper. Methane concentration decreasing and oxygen content increasing while barometric pressure is rising shows that air is leaking into the "sealed" area. Under similar barometric conditions, methane concentration would rise and oxygen concentration decrease behind an effective seal. The better a seal, the greater the time elapse between a fall in barometric pressure and changes in gas concentration. A possibly hazardous situation can develop on the "fresh air" side of a high quality seal where methane may unexpectedly start to flow out after a protracted barometric pressure fall.

The only practical approach to obtain information on the atmospheres within a sealed fire area, according to Mitchell (1990) is by analysis of samples taken from shafts and boreholes. Boreholes are sited to enter specific roadways in the sealed area. Boreholes are sometimes cased and grouted to within a metre or so of the roof of the mine roadway to ensure strata gases are not inadvertently sampled, which could confuse interpretation. Mitchell (1990) has developed practical rules for sampling from sealed areas some of which, although aimed at fire treatment, have a wider application. The most relevant of these rules can be summarised thus:

? Never sample a borehole into which air is being drawn from the surface, or through a seal if underground. For satisfactory, undiluted samples, the pressure in a borehole should be equal to or greater than the ambient. The best time to sample surface boreholes is at night when the outside temperature is generally less than that underground.
? Purge the sample tube by pumping for a period at least three times longer than that required for the exchange of air in the sampling tube.
? Obtain sufficient measurements to identify trends and then act accordingly.

2.1.4 Monitoring inaccessible goaf areas

In the UK, tube bundles are sometimes installed in the return roadway of a retreat longwall panel to facilitate subsequent sampling of the gas concentrations in the goaf, particularly at the face start line. Pressure differentials across the goaf cause gas flow around the abandoned roadways, ensuring some movement of gas past the tube mouth into which gas samples are drawn. Gases may not be thoroughly mixed, but trends can generally be obtained which are reasonably indicative of the conditions at the return side of the longwall goaf. These data can provide information on gas emissions at the face start line, the mobility of the gas "fringe" (gas concentrations at and above the legal maximum allowed) and the effectiveness of cross-measures methane drainage, where it is employed.

In the past when advancing methods of longwall extraction were practised at most coal mines in Europe, short lengths of steel pipe were commonly installed in the packs formed on the goaf side of return roadways where spontaneous combustion risks were identified. Gas samples drawn from the pipes were usually analysed for carbon monoxide, hydrogen and oxygen.

2.1.5 Monitoring of abandoned areas

Areas of a mine to which access is no longer required are abandoned and sealed off from the operating mine with stoppings. Thus, the available ventilation air can be concentrated at the active working faces. When a longwall district is mined-out, the access roadways are permanently sealed and the pressure differential across the district is removed. This is achieved by either breaching an overcast, or dismantling doors to short-circuit the ventilation system. Methane drainage may be continued, with the stopping being sealed around the collection pipes. In many instances, monitoring of the sealed area is limited to the face of the stopping. The quality and quantity of gas flowing in the methane drainage, if present, is also generally monitored.

Any gas emission problems associated with abandoned areas are invariably manifested at the stoppings. The methods of monitoring such stoppings used routinely in gassy mines throughout Europe involve:

- measuring gas concentrations in airways upstream and downstream of stoppings;
- taking samples of the gas from pipes passing through the stopping and,
- methanometer traverses across the stopping face, and around its edges.

The response to unacceptably high gas concentrations entering mine roadways can involve remedial treatment of the stopping to improve the sealing, roadway ventilation enhancements or the connection of the methane drainage system to a pipe through the stopping.

There are no critical methane concentrations behind seals which are considered unacceptably high in European mining legislation, provided the gas does not impinge on airways causing concentrations to rise above permissible limits.

2.1.6 Monitoring atmospheres in abandoned mines

Techniques have been developed for monitoring gaseous environments in abandoned European mines due to concerns regarding surface gas emission hazards which can affect properties and their occupants. Some of these techniques may be applicable to sealed areas of South African coal mines where the princ ipal hazards are underground.

The composition of gas in old coal mine workings depends on fresh air ingress, gas emission and oxidation processes and the relative rates of these processes. The various gases will not form homogenous mixtures unless sufficient time has elapsed to allow complete diffusion mixing or the gases are moving under turbulent flow conditions.

Turbulent flow alone is not a sufficient condition to ensure mixing of methane with the denser mine gases due to the buoyancy of methane. Where methane enters a mine roadway at roof level it can form a buoyant layer of gas capable of migrating considerable distances. Methane layering processes will influence the variability of gas compositions monitored in abandoned mine workings. In the low flow conditions likely to persist in unventilated workings, it is assumed that thick layers will accumulate and spread rapidly along ascending roadways towards the surface or shallower workings.

The buoyancy or layering properties of methane also has other implications for gas regimes in abandoned coal mines:

? layered methane may not be detected by monitoring if a borehole standpipe protrudes through the roof of the mine roadway;
? greater mobility of methane-rich gases than other gas mixtures in abandoned workings;
? a tendency for methane-rich gases not to mix with other gases except where atmospheric pressure fluctuations induce high air flow velocities, and hence turbulent mixing, in the vicinity of surface vents.

A technique involving the construction of ternary diagrams has been devised to assist with the interpretation of large volumes of variable gas compositional data obtained from monitoring abandoned shafts, passive gas vents (installed to prevent build-up of pressure as water levels rise) and purpose drilled boreholes. The ternary plots can be used to assess the interaction of mine gases with atmospheric air. For instance, the presence of air in a monitoring borehole drilled into old workings may indicate the presence of an unidentified surface connection through which an emission to the surface could occur in the absence of any control measures. In this situation, it is important to confirm that air ingress is not occurring through the gas sampling system. To facilitate plotting, the gas compositions are classified as:

? firedamp (methane);
? blackdamp (carbon dioxide and nitrogen in excess of the proportions normally found in atmospheric air);
? fresh air (oxygen as measured, with nitrogen and carbon dioxide allocated in the same proportions as those found in atmospheric air).

Figure 2.1.6, plotted using the above technique, shows the gas regimes detected in an investigation borehole drilled into abandoned coal workings at a depth of about 15m below ground level. The measurements shown were taken over a period of six months under various barometric conditions. The occurrence of a high fresh air content in the borehole is interpreted as indicating a surface connection, probably from shallow outcrop workings or abandoned shafts. The UK application is aimed at predicting surface mine gas emission risks. The methane hazard is low and the blackdamp hazard is high in the instance shown in Figure 2.1.6. In South African conditions, a similar result might indicate the presence of abandoned surface exploration boreholes entering the sealed area, and a potential for emissions of asphyxiating gas mixtures at underground stoppings.

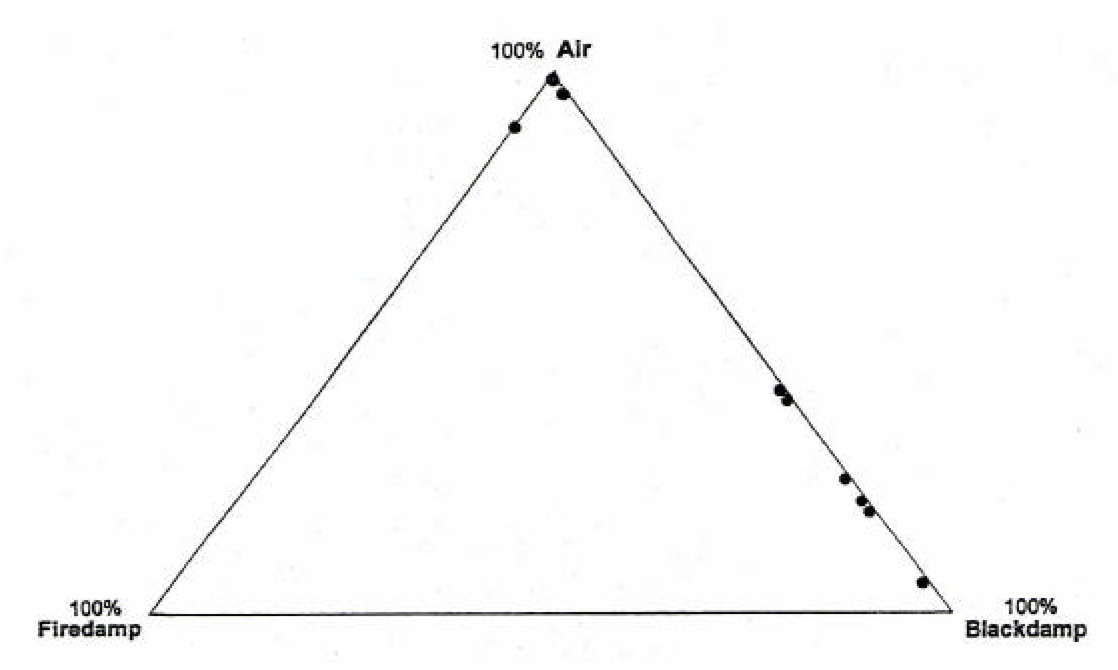


Figure 2.1.6 Ternary diagram showing gas compositions in abandoned coal mine workings

An alternative method for processing and plotting the gas compositional data involves adjusting the measured gas concentrations to exclude the fresh air component. This provides a representation of the gas regime prior to dilution with air and indicates the possible worst-case composition of gas, which could be emitted during a major atmospheric pressure fall. When using this method, the gas analyses are adjusted to an air-free basis and the carbon dioxide, nitrogen and methane concentrations plotted on the ternary diagram. The nitrogen component, in most cases, represents de-oxygenated air**.**

2.1.7 Current developments in Europe and the USA

Interest is developing in the exploitation of gas from abandoned mines in both Europe and the USA. Current projects are increasing knowledge of methane availability and sources within extensive sealed areas of longwall mines (Hupp et al, 1999). Gas monitoring is limited to flows and compositions in shafts and boreholes but it is likely that new techniques will be needed to facilitate improved management of the resource which may also offer benefits for safety monitoring.

Considerable research has been undertaken on the distribution of methane and other gases in longwall goafs to aid the design of methane and spontaneous combustion control measures. Scale models and computerised fluid dynamics (CFD) models have been used in these studies. The most difficult aspect of the research has been obtaining measurement data from inaccessible areas to verify models. Experimental pipework has been installed behind longwall coalfaces with single intake and return roadways to enable gases to be sampled with limited success. However, this type of work is of little significance to the monitoring requirements of abandoned bord-and-pillar sections in South African mines.

The safety of sealed areas from explosion risks depends largely on the quality of the seals. The monitoring information gathered is usually aimed at assessing the adequacy of seals which, in some locations, may be prone to deterioration as a result of ground instability or nearby mining activity. A fundamental problem in South African mines is the large number of seals required to isolate an abandoned area, barrier pillars having been rarely employed.

Simple, practical techniques have been developed to assist the interpretation of gas compositional information obtained from sealed areas and wholly abandoned mines which could have applications in South African mines.

2.2 Monitoring of atmospheres in inaccessible areas of coal mines - practices in Australia

2.2.1 Introduction

The states of New South Wales (NSW) and Queensland are the two main coal producing regions in Australia and both states employ underground and surface methods of extraction. In both states surface extraction methods are favoured in comparison to underground with 57% and 78% of saleable output being derived from surface operations in NSW and Queensland, respectively. In NSW, the predominant underground method is longwall, which accounted in the 1999/2000 financial year for about 36,6 Mt out of an underground total saleable output of 45 Mt. The remaining 8,4 Mt or 18.6% was produced from bord and pillar workings. Over the 9 year period between 1990 and 1999 there has been a complete reversal in the contributions from the two underground mining methods of bord and pillar and longwall. In 1990 the saleable output from the longwall method was in the region of 2 Mt while that for bord and pillar was in excess of 40Mt. The result of the change in mining methods is that the longwall method does not leave behind large volumes of open workings in which flammable and noxious gases can accumulate. Although the caved goaf area behind a longwall can accumulate gases, the space available is considerably less than the ‘open’ spaces left by old bord and pillar panels.

The longwall method of underground extraction is more prominent in Queensland from the point of view of percentage contribution to underground saleable output. From a total underground saleable output of 26,7 Mt in the 1999/2000 financial year, 25,4 Mt (95,1%) was derived from longwall operations whereas only 1,3 Mt (4,9%) was produced by the bord and pillar method.

During the 1999/2000 financial year, the two states had a combined saleable coal production of 229,7 Mt, of which 158 Mt (68,8%) was derived from surface operations and 71,7 Mt (31,2%) was produced from underground workings. Longwall operations resulted in a saleable output of 62 Mt (86,5% of underground output) while bord and pillar operations produced 9,7 Mt (13,5% of underground output).

From the above statistics it can be deduced that underground coal mines in both NSW and Queensland do not currently leave vast areas of underground void, as results from bord and pillar operations, because of the extensive use of the longwall method. The required number of seals will generally be much less on completion of a longwall panel in comparison to a completed bord and pillar panel. However, competent seals are required to prevent the migration of flammable and noxious gases from the goaf area of the longwalls into the adjacent mine airways. In some cases the seals will have to be 'explosion-proof'.

2.2.2 Current practice in Queensland

The Queensland Department of Mines and Energy issues approved standards (Queensland DME, (a) – (d), 1996 – 1998), which provide guidance and advice on such topics as; *ventilation control devices, the use of gas monitoring devices and the monitoring of sealed areas.*

Seals are defined (Queensland DME, b, 1996) as 'ventilation control devices designed to prevent the movement of atmosphere either into or out of an enclosed area of the mine'. Monitoring of sealed areas (Queensland DME, d, 1998) "should be carried out in order to adequately predict and define the potential for an explosive atmosphere to occur within a sealed area. Sufficient samples should be taken to delineate both the size of any explosive zone and the time that the zone will be within the explosive range. In addition, monitoring is to be carried out to identify any occurrence of spontaneous combustion within the sealed area, as a potential source of possible explosive gas mixtures".

It is recognized (Queensland DME, d, 1998) that monitoring locations, in general, will be limited to the periphery of the sealed area and that gas concentrations in deep sealed areas will have to be estimated from these measurements. It is noted that sample locations within sealed areas should extend as far as practicable into the sealed area to minimise the effects of breathing seals and dilution with air caused by diurnal pressure changes. Where potentially hazardous atmospheres may occur in a sealed area, it is noted that remote continuous monitoring systems allow sampling to be done more frequently and from a safe position compared to the taking of manual samples. In this context specific reference is made to tube bundle systems as a method of remote continuous monitoring.

Tube bundle systems are used in all underground coal mines in Queensland (Hester, 2001) but these are used to monitor areas of mines for the onset of spontaneous combustion rather than to detect an explosive or noxious atmosphere. Usually these systems are used to monitor the atmosphere behind seals of longwall panels. The view is that the samples taken from tube bundle systems can be analysed by gas chromatography, which can measure hydrogen, ethylene and ethane as well as the more normal gases such as carbon monoxide, carbon dioxide, methane and oxygen. It is considered that the early detection of hydrogen, ethylene and ethane, along with the other gases, gives an early indication of a heating. However, explosive atmospheres behind seals are catered for by the installed monitoring systems. Cognizance is taken of the fact that the sample positions are only a short distance into the sealed areas (longwalls or bord and pillar/pillar extraction panels) and may not be fully representative of the whole atmosphere behind the seal. In the Approved Standard For The Monitoring Of Sealed Areas (Queensland DME, d, 1998) t is stated that “Gases monitored in a sealed area can only represent a small part of a large volume. It has therefore been necessary to place a Factor of Safety around the traditional Coward Triangle methane/air explosive zone and define it as an EXPLOSION RISK FACTOR”. The boundaries of the explosion risk buffer zone are defined as being from 2½ % to 22 % methane (that is 50 % of the L.E.L to 150 % of the U.E.L) and oxygen ? 8 %. Figure 2.2.2 shows the Coward Triangle with the modified buffer zone around it. If the atmosphere close behind the seals was fully representative of the whole sealed area the modification would not be necessary.

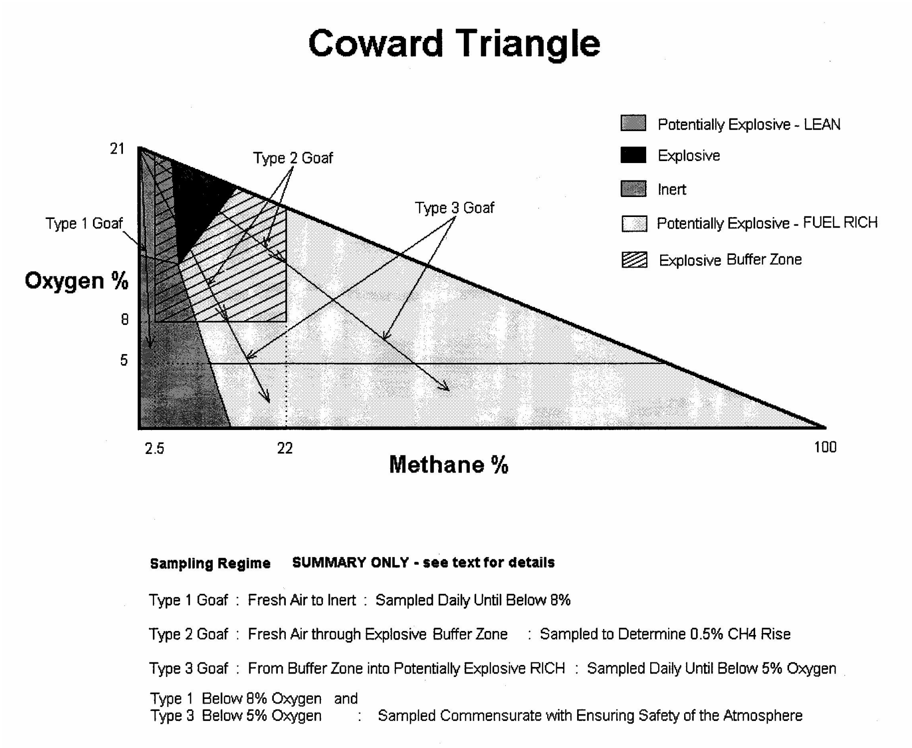


Figure 2.2.2 Modified Coward Triangle
(taken fromQueensland DME(d), 1998)

It is apparent that apart from monitoring for explosive atmospheres in sealed areas, the Queensland mines are particularly aware of the dangers of spontaneous combustion. This may be because of the prevalence of longwall mining and problems with coal left in the goaf areas which become subject to the pressure of the caving roof or it could be a consequence of the Moura Colliery explosion. During the operating life of the longwall sufficient air may pass through the goaf to remove products of combustion but on initially sealing the area, the reduced airflow may initiate spontaneous heating conditions. Similar situations are possible on completion of pillar extraction operations following bord and pillar development.

2.2.3 Current practice in New South Wales

The only reference to seals and monitoring behind seals is made in clause 99 (3) of part 4 of the Coal Mines (Underground) Regulation 1999 (N.S.W. Coal Mines (Underground) Regulation, August 1999). Clause 99 (3) states “A stopping constructed for the purpose of sealing off a part of a mine must be substantial in structure, airtight and designed to resist damage in the event of an explosion. Provision to allow sampling of the atmosphere in the sealed off area must be made”.

However, a manager of a mine must have a ventilation control system (N.S.W. Coal Mines (Underground) Regulation 1999, Part 4, Ventilation) which, amongst many other requirements, must provide for ’the manner of sealing of parts of the mine and the precautions to be taken in sealing parts of the mine.’

It is apparent that mines must have procedures for monitoring the atmosphere behind sealed areas of a mine but no specific information has been found to indicate what these requirements might be. It can only be assumed that, in a similar manner to the requirements of standard procedures in Queensland, NSW underground coal mines will also only be required to monitor ‘as far as practicable’ into the sealed area.

3 Monitoring Atmospheres in Sealed Bord and Pillar Panels in South African Coal Mines

3.1 Introduction

In 1999, run of mine coal production in South Africa was 282Mt, of which approximately 140Mt was produced from underground operations. The major proportion of underground production comes from bord and pillar operations, some 111Mt in 1999, with the remaining production coming from longwall, shortwall and pillar extraction operations. It can be estimated that there may have been in the region of 200 bord and pillar panels formed in 1999, all of which, unless the pillars were going to be removed immediately, should be sealed to isolate the ‘old’ workings from the remainder of the mine. Thus each year there are large volumes of space created in which flammable and noxious gases can accumulate.

If disused bord and pillar panels are not sealed off from the rest of the mine workings, legislation (regulation 10.8.1.1) requires a manager to ensure that ‘a sufficient quantity of air is continuously supplied to all accessible underground workings’ so that the general body of the air complies with legal requirements. That is to say, the general body atmosphere must not contain harmful or dangerous quantities of noxious or flammable gases or dust. To maintain ventilation requirements to the required level in a disused bord and pillar panel utilises resources which may be better used in the working areas of the mine where there is a greater need of the ventilating air. Since the generation of ventilating air costs money, there is a financial incentive in maximising ventilating air utilisation.

To change the status of a disused bord and pillar panel from that of being ‘accessible’ to ‘inaccessible’, regulation 10.8.1.2 defines ‘accessible underground workings’ but excludes from such workings those that have been ‘sealed off’ in a manner defined by a code of practice required by regulation 10.8.2. Therefore, a disused bord and pillar panel which has been sealed off in an approved manner does not need to be ventilated and the ventilating air which was previously used in that panel becomes available for use elsewhere in the mine.

The sealing off of a disused bord and pillar panel should be undertaken as soon as practicably possible on completion of the coal extraction operations, not only as a means of conserving ventilating air, but also to reduce the risk of a dangerous occurrence arising. In Simrac report COL 031, it is pointed out that the deteriorating conditions in a disused bord and pillar panel can be conducive to spontaneous combustion, particularly if the ventilating air is reduced in quantity rather than maintaining it at the prescribed level. Thus, best practice is to seal disused workings and the sooner this is accomplished, the lower the financial and safety risk to the mine.

3.2 Sealed off Bord and Pillar Panels

All coal mines must have a code of practice that describes the method of sealing off disused bord and pillar panels and which also includes seal construction and provisions for monitoring the atmosphere behind the seals. Normal practice for monitoring the atmosphere behind the seals is to incorporate one or two sampling pipes of about 6 mm diameter into the seal, which extend into the sealed panel at least to the first intersection. The number of seals required to seal off a panel will depend on mine standard procedures, but monitoring the atmosphere in the sealed off panel is normally only done at one of the seals. One of the two pipes will be at roof level and the second, if used, at mid-seam height. It is also practice to install a water drainage pipe of about 100mm diameter at floor level. All pipes through the seals will contain a control valve on the outbye side of the seal. Air samples will be taken at time intervals prescribed in the code of practice and which will depend on the atmospheric conditions within the sealed panel.

Monitoring the atmospheric conditions in sealed bord and pillar panels is done to determine the explosive nature of the atmosphere. A high risk to the mine, or section of the mine, prevails during the period that the panel atmosphere passes through the explosive range. Thereafter, the higher the concentration of flammable gases and the lower the concentration of oxygen, the lower the risk becomes and monitoring of the atmosphere may only need to be done at 3-month or 6-monthly intervals. Depending on the methane content and permeability of the coal seam and surrounding strata the atmosphere in sealed panels can vary widely between mines and also between areas of the same mine. Some panels may never reach the explosive range, whereas others may quickly pass through and remain at high levels of methane concentration, or flammable gas mixtures consisting of methane, hydrogen and carbon monoxide.

Seals do not have to be explosion-proof but if monitoring results show that the atmosphere in a sealed panel remains in the explosive range, then a mine should convert the existing non-explosion-proof seals to explosion-proof ones. Non-explosion-proof primary seals should be able to withstand a pressure of 140kPa and explosion-proof seals should withstand an over-pressure of 400kPa.

3.3 Monitoring, reliability and representative samples

Sampling pipes that pass through the seals into the sealed off panel usually reach as far as the first intersection in the panel. This means that, depending on the pillar size and the position of the seal in relation to the length of the pillar, the sampling pipe will reach between 6m and 30m into the panel. Considering that a panel may be from 500m to over 1000m in length, the sampling position from which an air sample is taken covers only a small area of the overall panel volume. Therefore, the question must be asked as to how representative such a sample can be of the total atmosphere in the whole sealed off panel.

The present method of sampling sealed off panels has been in existence for many years and it has always been accepted that the air sample taken just inbye of a panel seal is representative of the total atmosphere in the panel.

The sealing procedure is prescribed by a code of practice and will include the simultaneous closure of the final intake and return seals. When the final closures have been made the flow of air through the panel will cease and the atmosphere will quickly become static unless there are leaks in or around any of the seals, or through the barrier pillar or indeed between the panel and the surface. The only atmospheric movement that can be expected would be localised molecular movement of gases (diffusion mixing), movement due to differential densities and any movement due to thermal gradients, should such exist.

3.4 Monitoring results from a colliery.

During 1999, one colliery in Mpumalanga implemented a program of monitoring in sealed off panels for the purpose of comparing the results of atmospheric samples taken close to the seal to the results of samples taken at various positions within the panel. At some sampling positions, samples were taken at different heights to assess if layering of gases was taking place. Samples were taken from within the panel using the tube bundle method.

Figure 3.4.1 shows the position of the 14 sampling points spread throughout the sealed panel and Table 3.4.1 shows the distance of the sampling points from the monitoring seal. In addition to these 14 sampling points, samples were also taken at a distance of 0,5m and 30m into the sealed panel. The latter two sample distances being the standard positions used by the mine. This particular panel was short, being only 300m in length.

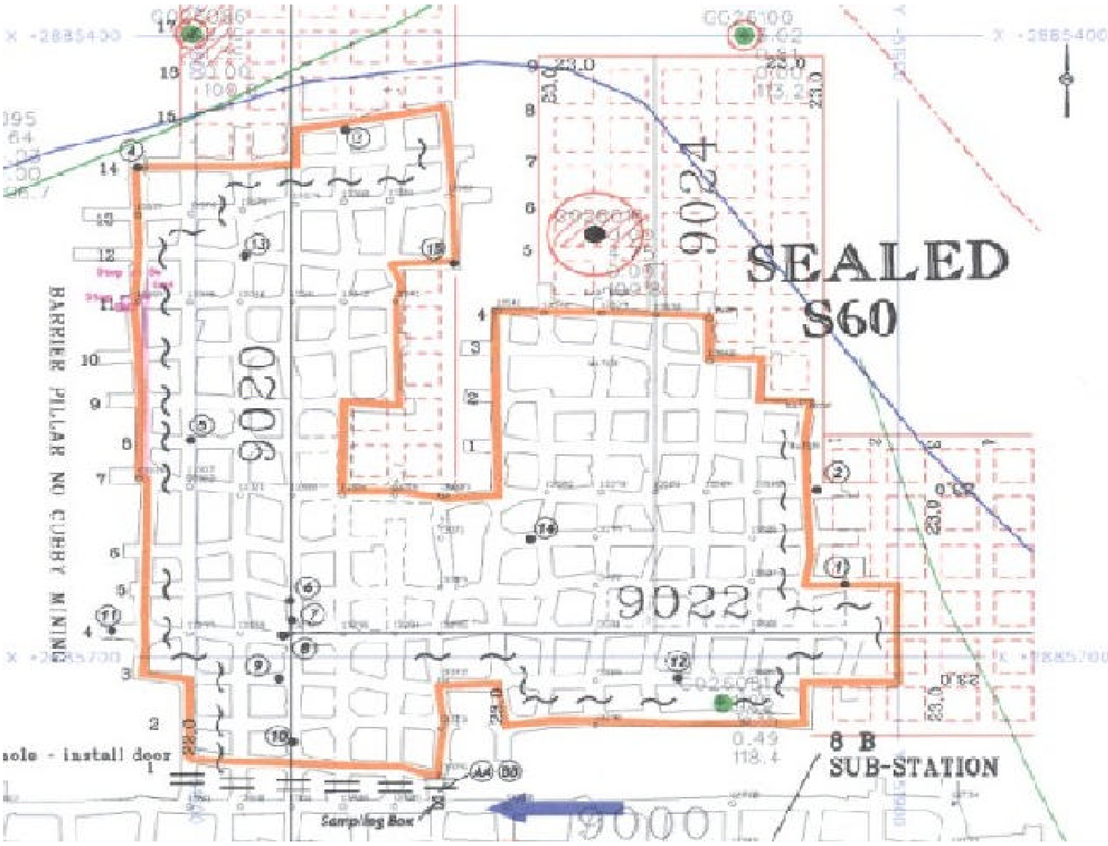


Figure 3.4.1 Tube bundle sampling positions in the sealed panel

Table 3.4.1 Length of sampling tube into sealed panel from the monitoring seal

Sample Number	Tube Length (m.)
1	375
2	350
3	330
4	410
5	250
6_R	100
7_M	100
8_F	100
9	50
10	25
11	170
12	200
13	300
14	200

(6_R – roof sample, 7_M – mid-height, 8_F – floor sample, all at the same position)

The panel was sealed on 25 May 1999 and sampling results have been obtained up to October 2000.

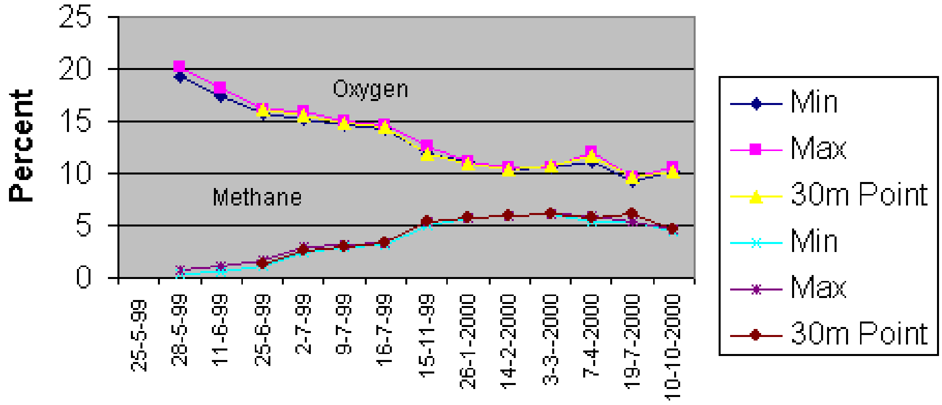
Samples were taken from the tube bundle system using a Crowcom gas detection instrument, with check samples also being sent for analysis by the mobile gas analysis laboratory (MOGAL) instrumentation.

For the purpose of this Simrac project the change in the atmosphere behind the seals is not the subject of interest. The primary interest is in the variation in the results obtained from the sample points spread over the sealed panel in comparison to the results given by the two sample points just inbye of the monitoring seal.

The detailed results are shown in Table 3.4.2, where it is noticeable that there is very little variation between the results of the gas analysis from the 14 individual sample points compared to the results obtained from just inbye of the monitoring seal. For the duration that results were obtained from positions 6, 7 and 8, which are respectively roof, mid-seam and floor sample positions at the same point, there was no difference in the methane readings on the various dates that samples were taken. This indicates that at this particular position, over a time period of approximately 7 weeks during which the methane content in the atmosphere increased from 0,4% to 3,2%, there was no layering of the methane. Unfortunately, 7 weeks after the panel had been sealed, the sample tubes to points 6 (roof sample) and 8 (floor sample) became inoperative and further sampling from these two points could not be accomplished.

Figure 3.4.2 shows the trend in the percentage oxygen and percentage methane over a 15 month period. For this figure the results of all 14 sample points have been averaged and the minimum and maximum values of methane and oxygen percent have been plotted. The data used in the construction of this figure is detailed in Table 3.4.3. The results of the tube bundle monitoring system are compared to the actual methane and oxygen percent obtained from the sample point at 30m into the panel (this point being the mine standard sampling point in sealed panels) and at the seal (0.5m). The similarity in the methane and oxygen results is apparent, irrespective of which sample point is considered.

Figure 3.4.2 Trends in oxygen and methane content



Firstly, there is very little difference between the maximum and minimum readings for both methane and oxygen content of the atmosphere. The greatest difference in oxygen percent between the 14 sampling points on any one sampling occasion was 1%, where the minimum was 19,2% and the maximum was 20,2% when the points were sampled on 28/5/1999. For methane, the greatest difference between the minimum and maximum readings on any sampling occasion was 0,6% with a minimum of 2,4% and a maximum of 3,0% when the 14 points were sampled on 2/7/1999. Therefore, although the sampling points are spread a considerable distance from each other, as well as from the monitoring seal, the monitoring results are remarkably similar.

Secondly, there is little difference between the sample results obtained at 30m into the sealed panel and those obtained from all of the other 14 sampling points. This is indicated by the closeness of the trend lines for both oxygen and methane in Figure 3.4.2. As shown by Table 3.4.3 sample results obtained at a point 0,5m into the sealed panel follow the same trend as those for the 30m point but, for reasons of clarity, have not been included in Figure 3.4.2.

Table 3.4.2   Tube bundle gas monitoring results for a Mpumalanga colliery

(Samples taken using a Crowcon gas detection instrument)

Date	28.05.99			11.06.99			25.06.99			02.07.99			09.07.99			16.07.99			15.11.99		
Point	O_2	CH_4	CO	O_2	CH_4	CO	O_2	CH_4	CO	O_2	CH_4	CO	O_2	CH_4	CO	O_2	CH_4	CO	O_2	CH_4	CO_2
1	*	0.7	11	*	0.8	9	15.7	1.6	0	15.2	2.6	4	14.7	3.1	0	14.6	3.2				
2	19.5	0.7	4	18.1	0.7	4	15.9	1.4	13	16.0	2.5	-	14.8	3.0	0	14.5	3.1				
3	*	0.7	11	**	**	**	16.1	1.2	14	15.5	2.8	4	14.8	3.0	0	14.3	3.2				
4	19.2	0.7	4	17.4	0.8	0	15.9	1.3	14	15.4	2.7	4	14.8	3.1	0	14.3	3.2		12.6	5.0	1.20
5	*	0.6	0	*	1.0	9	16.1	1.2	14	15.6	2.8	-	14.8	3.0	0	14.2	3.2		12.0	5.35	1.20
6	20.2	0.4	3	17.4	0.9	0	16.0	1.2	14	15.5	2.7	-	14.8	3.0	0	14.3	3.2				
7	20.2	0.4	3	17.6	1.0	1	16.0	1.2	13	15.6	2.7	-	14.9	3.0	0	14.3	3.2		11.9	5.35	1.25
8	20.2	0.4	2	*	1.0	9	16.1	1.2	14	15.5	2.6	-	15.0	3.0	0	14.3	3.2				
9	*	0.6	0	*	0.9	9	16.1	1.2	14	15.6	2.9	-	15.0	3.0	0	14.3	3.2		12.0	5.40	1.25
10	*	0.6	0	*	1.0	9	16.1	1.3	14	15.4	3.0	-	14.9	3.0	0	14.2	3.3				
11	*	0.3	0	*	0.9	9	15.9	1.2	14	15.3	3.0	-	14.8	3.2	0	14.2	3.4				
12	*	0.6	8	17.8	1.1	0	16.1	1.2	14	15.3	2.8	-	15.0	3.0	0	14.3	3.2		11.8	5.35	1.25
13	19.6	0.6	4	*	0.6	10	16.1	1.2	14	15.3	2.9	-	15.0	3.1	0	14.3	3.2				
14	19.7	0.6	4	17.8	1.0	0	16.0	1.2	14	15.6	2.4	-	15.0	3.0	0	14.5	3.1				
AA	-	-	-	*	0.9	9	16.1	1.3	2	15.5	2.6	-	14.9	3.0	0	14.4	3.3		11.9	5.35	1.25
BB	-	-	-	*	1.0	9	16.1	1.3	2	15.6	2.6		14.8	3.1	0	14.3	3.3		11.8	5.40	1.25

Date	26.01.00			14.02.00			3.03.00			7.04.00			19.07.00			10.10.00					
Point	O_2	CH_4	CO_2	O_2	CH_4	CO_2	O_2	CH_4	CO_2	O_2	CH_4	CO_2	O_2	CH_4	CO_2	O_2	CH_4	CO_2	O_2	CH_4	CO_2
1																					
2																					
3																					
4				10.4	5.95	1.70	10.6	6.15	1.75	11.2	6.00	1.90	9.60	5.40	2.35	10.4	4.60	2.55			
5				10.5	5.85	1.60				11.2	6.00	1.60				10.3	4.60	2.50			
6																					
7				10.5	5.85	1.65	10.6	6.10	1.70	11.5	5.75	1.80	9.60	5.30	2.30	10.2	4.55	2.45			
8																					
9				10.4	5.90	1.70	10.6	6.15	1.70	12.0	5.45	1.70	9.30	5.35	2.30	10.1	4.60	2.50			
10																					
11																					
12				10.6	5.85	1.70	10.6	6.10	1.70	11.7	5.60	1.75	9.50	5.30	2.30	10.6	4.45	2.50			
13																					
14																					
AA	11.0	5.80	1.55	10.4	5.95	1.70	10.7	6.10	1.65	11.6	5.75	1.80	9.70	6.05	2.25	10.2	4.60	2.50			
BB	11.0	5.85	1.55				10.6	6.10	1.70	11.5	5.75	1.80	9.40	5.30	2.30						

AA = 30m sampling point, BB = 0,5m sampling point

Table 3.4.3 Comparison of tube bundle and standard monitoring results

		Tube Bundle Monitoring Results											
Date	Number of Samples	O_2			CH_4			CO			CO_2		
		Mean/sd	Min	Max	Mean/sd	Min	Max	Mean	Min	Max	Mean/sd	Min	Max
25-5-1999	Date panel sealed												
28-5-1999	14 (7 x O_2)	19.8/0.4	19.2	20.2	0.56/0.13	0.3	0.7		0	11			
11-6-1999	13 (6 x O_2)	17.7/0.27	17.4	18.1	0.90/0.14	0.6	1.1		0	10			
25-6-1999	14	16.0/0.12	15.7	16.1	1.26/0.12	1.2	1.6		0	14			
2-7-1999	14	15.49/0.2	15.2	16	2.74/0.18	2.4	3		4	4			
9-7-1999	14	14.88/0.11	14.7	15	3.04/0.06	3	3.2	0	0	0			
16-7-1999	14	14.33/0.12	14.2	14.6	3.21/0.07	3.1	3.4						
15-11- 1999	5	12.1/0.31	11.8	12.6		5	5.4				1.23/0.03	1.2	1.25
26-1-2000	1	11.1	11.1	11.1	5.8	5.8	5.8				1.6	1.6	1.6
14-2-2000	5	10.48/0.08	10.4	10.6	5.88/0.04	5.85	5.95				1.67/0.04	1.65	1.7
3-3--2000	4	10.60/0	10.6	10.6	6.12/0.03	6.1	6.15				1.71/0.03	1.7	1.75
7-4-2000	5	11.52/0.30	11.2	12	5.76/0.24	5.45	6				1.75/0.11	1.7	1.9
19-7-2000	4	9.50/0.14	9.3	9.6	5.34/0.05	5.3	5.4				2.31/0.02	2.3	2.35
10-10- 2000	5	10.32/0.19	10.1	10.6	4.56/0.06	4.45	4.6				2.50/0.03	2.45	2.55

		Standard Monitoring Positions For Mine					
Date	Number of Samples	30m Point			0.5m Point		
		O_2	CH_4	CO_2	O_2	CH_4	CO_2
28-5-1999	14 (7 x O_2)						
11-6-1999	13 (6 x O_2)						
25-6-1999	14	16.1	1.3		16.1	1.3	
2-7-1999	14	15.5	2.6		15.6	2.6	
9-7-1999	14	14.9	3		14.8	3.1	
16-7-1999	14	14.4	3.3		14.3	3.3	
15-11- 1999	5	11.9	5.35	1.25	11.8	5.4	
26-1-2000	1	11	5.8	1.55	11	5.85	
14-2-2000	5	10.4	5.95	1.7			
3-3--2000	4	10.7	6.1	1.65	10.6	6.1	1.7
7-4-2000	5	11.6	5.75	1.8	11.5	5.75	1.8
19-7-2000	4	9.7	6.05	2.25	9.4	5.3	2.3
10-10- 2000	5	10.2	4.6	2.5			

3.5 Conclusions relating to monitoring the atmosphere within a sealed bord and pillar panel using a tube bundle system.

From the above results of the application of a tube bundle system to monitor the atmosphere in a sealed off bord and pillar panel, it is apparent that the atmosphere is amazingly consistent throughout the panel. There is no practical difference between the results of gas samples taken at 0,5m inbye of the seal nor at 30m inbye of the seal in comparison to the gas samples taken over a wide area within the sealed panel. On the basis of these results it can be stated that gas samples taken just inbye of a seal are representative of the whole panel in this instance.

The tube bundle system that was used to draw samples of the atmosphere from within the sealed off panel in the above mine initiated project, is a well-proven and tried system of remote monitoring (Hunneyball, 2000). It is apparent that some of the sample points ceased to function but this can occur with any remote monitoring system. The tube bundle system is reasonably flexible with regard to distance to be sampled, does not need to be accessed to undertake any maintenance or calibration and is cheap to install and run.

4. Sampling systems

4.1 Introduction

It is obvious from the review of practice in Europe, the USA, Australia and South Africa that sealed, inaccessible parts of a mine are extremely difficult to monitor effectively. The situation may be summarized as follows:

- once a panel has been sealed there is no possibility of access unless it is re-opened. It may be re-opened and ventilated, in which case there is a significant risk of explosive or noxious gases entering the working area of the mine or it can be partially opened and rescue teams equipped with breathing apparatus can enter. In either case, the decision is not taken lightly and stringent measures must be adopted to ensure safety is not compromised
- it is not advisable and may be in breach of regulations to leave any live electrical apparatus in a sealed area
- the sealed area may, in the longer term, be subjected to periodic or permanent flooding and may also be subject to falls of ground.

These environmental constraints severely limit the type of instrumentation and monitoring systems that can be deployed in sealed panels e.g. mains powered systems may be considered high risk, while intrinsically safe battery systems would require maintenance and expose proto teams to unnecessary risk merely to change batteries at fixed intervals. As is often the case, alternative risks need to be carefully weighed in choosing the monitoring system for sealed panels.

4.2. Currently available technologies

As has been described previously in section 3.2, the standard procedure adopted at South African coal mines for monitoring sealed areas has been to draw samples through small diameter pipes set a distance of between 0,5 and about 30 m into the sealed area i.e. the usual distance is the first intersection beyond the seals. This is the same practice as in many other countries and has served the mining industry well. However, while there is no general evidence that misleading results can be obtained, there is a strong possibility that, in a large sealed off area, near-seal monitoring will not always give the complete picture. Three conditions, in particular, can give rise to heterogeneous atmospheres i.e. panels with a considerable dip, panels in which a dyke or other geological anomaly was encountered and panels with a history of methane being emitted from the roof. Under these conditions the thorough mixing, reported in section 3.4.3 above, is unlikely to occur and methane can accumulate in elevated areas or methane layering can occur. Under these circumstances alternative monitoring methods should be considered.

At this time the only accepted alternative to near-seal testing is the tube bundle system. This sampling method, as described in section 2.1.2, has been widely used for nearly 30 years and is well accepted in Europe and Australia as a reliable method of detecting spontaneous combustion in sealed areas. Obviously the same system can be used to detect explosive atmospheres. Recent trials of tube bundle monitoring systems in South Africa have shown it to be reasonably reliable and inexpensive. Provided sufficient sampling points are specified and tube routes are chosen carefully, the chances of system damage due to roof falls can be minimized and false readings due to tube damage can easily be identified and these results discarded.

As part of this study, discussions have been undertaken with three gas monitoring equipment manufacturers:- Draeger, GfG and Trolex. All three companies have a range of semi-portable, fixed position gas monitoring equipment but all these devices require a power supply and have a need for maintenance and calibration during operation. The reliability of such devices is also questionable once oxygen levels reach levels of less than 10%. None of the manufacturers were able to report developments that may lead to a new monitoring system capable of meeting the stringent requirements of a sealed area. Repeatedly reference was made to the tube bundle as the only “passive” system that can operate without a power supply or maintenance.

In section 2.1.3 reference was made to the work of Mitchell (1990), who advocated the use of boreholes to obtain samples from fire areas. Since coal seams in South Africa are generally shallow and underlie a predominantly flat, rural surface, it would be feasible to drill boreholes into appropriate intersections in a sealed area and to case the hole to the roof of the workings. Samples could then be drawn to surface from a variety of heights immediately below the borehole. While this would provide an ideal method of sampling the atmosphere in a sealed panel, the incidence of lightning strikes in South Africa and the history of explosions caused by lightning induced stray currents is such that this method poses an unacceptable risk. In fact, there is a requirement to seal all boreholes intersecting the workings and to withdraw the casings before sealing takes place.

4.3. Alternative technologies

During the course of this study two developments, funded by the USBM in the early 1990's, appeared to offer an alternative to the tube bundle system. The first was a flammable gas detector made from a thin film semiconductor that could operate for perhaps 20 years using an intrinsically safe battery. Apart from the fact that development was cancelled at the time of the USBM's closure, no further information could be obtained.

The second development was the use of infra red beams to measure flammable gas. While it is reasonably easy to obtain path average results, the USBM was attempting to develop algorithms to obtain point specific readings by overlapping two beams. Again this work has ceased and the most recent review of the remote sensing of flammable gas is contained in the SIMRAC report COL601 (Kononov, 1999). One of the conclusions reached in this review was that open path remote methane detectors could possibly have an application in the monitoring of flammable gases in a sealed bord and pillar panel. One of the reasons for this conclusion was the supposition that the atmosphere in a sealed off panel would be relatively homogeneous. This has been shown to be the case in the study reported in section 3.4 and it means that the "integrated methane concentration per metre will directly correspond to the point concentration measurement". Kononov concludes that it should be feasible to pass an infra red beam through a window incorporated into a seal. This would have some implications should explosion proof stoppings be used but with normal seals a system giving average flammable gas concentrations over a path of tens of metres in length should not be too difficult to design.

Finally some of the difficulties of open path infra red systems and the problem of intrinsic safety with multi-core cables could be addressed simultaneously by the use of fibre optics. Although such a system is not currently available, fibre optics could be used to transmit light to a sampling point and back to the point where measurement takes place outside the sealed area. This would eliminate the danger of using electricity in the sealed off area, allow alternative calibration methods to be used and obtain a reading at a pre-defined location. However, it must be stressed that, while the concept of using fibre optics has been suggested by Dubaniewicz and Chilton (1992), this type of monitoring system for mine atmospheres does not currently exist and would need considerable development. In particular, there would be the need to design the sampling cell, where the incoming IR would pass through the ambient atmosphere.

5 Conclusions and recommendations

The primary objectives of this research were

? to review the practical problems in monitoring the non-homogeneous air content of sealed-off panels
? to identify the technologies available for this purpose
? to identify and recommend strategies to measure non-homogeneous atmospheres in sealed areas.

Some of this work has been impossible to accomplish since, for a number of reasons, there is little interest in this topic world-wide and the only work undertaken in South Africa has indicated that the atmosphere in the particular sealed panel investigated was homogeneous over a wide area.

This report has, however, reviewed current practices in Europe and North America, Australia and South Africa and some general conclusions may be drawn.

In Europe and North America, where longwall operations dominate production, substantial seals are used and there is little interest in monitoring deep in sealed areas. Gas testing is either at the stoppings or from relatively short pipes passing through them. In Australia, where conditions are sometimes similar to South Africa, i.e. bord and pillar operations, it is recognized that, in general, monitoring will be limited to the periphery of sealed areas and "as far as practicable" into the sealed area. Hence, the current practice in South Africa is in agreement with that adopted elsewhere i.e. in low risk situations near-seal sampling is considered adequate. However, in interpreting the results of near-seal sampling under difficult circumstances, e.g. when a panel adjacent to current workings passes through the explosive range, then it may well be advisable to adopt the Queensland practice of applying a Factor of Safety around the explosibility triangle, as reported in section 2.2.2.

If a sealed panel is considered to pose a risk e.g. a risk of spontaneous combustion or explosion proof seals have not been installed at the time the sealed atmosphere goes through the explosive range or because the panel has features likely to produce a non-homogeneous atmosphere, then the only proven method is the tube bundle monitoring system. Despite its disadvantages, as listed in Table 2.1.2, this system is widely used and works well. Should a risk analysis indicate the need for monitoring particular locations within a sealed panel, the only available, proven technology is the tube bundle system.

During the course of this study, two technologies have been identified which could, if developed, offer an alternative to the tube bundle system. These were the open path infra red system proposed by Kononov (1999) and the use of fibre optics to transmit infra red through sealed areas, including the use of IR sensor cells at remote locations. It is recommended that the feasibility of both systems should be investigated but, in keeping with the general conclusions of this report, this should be a low priority for SIMRAC and the South African coal industry.

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