

SAFETY IN MINES RESEARCH ADVISORY COMMITTEE

# SIMRAC

## Final Project Report

Title: REDUCE THE METHANE HAZARDS IN COLLIERIES  
VOLUME I – EXECUTIVE SUMMARY AND REPORT

Author/s: F J van Zyl; P Linzer

Research  
Agency: CSIR, Division of Materials Science and Technology

Project No: COL 030

Date: October 1996

## EXECUTIVE SUMMARY

In an effort to improve safety in the underground environment of a mechanical miner section, with relation to the methane hazard, five main areas of research were identified. The areas identified are:

- improved methanometry for accurate and rapid methane detection.
- methods to optimize ventilation practices in mechanical miner sections with special attention to the curbing of methane accumulations.
- the quantification of in-seam methane content and emission rates into the workings.
- in-seam methane reduction techniques.
- the effect of external factors on methane emission rates in active sections.

The most common means of detecting methane in the underground mining environment is by means of filament and catalytic oxidation (pellistor) detectors. Methane can be detected in various other ways e.g. by electromechanical means, optical methods, thermal conductivity gas detectors, acoustic gas detectors and various laboratory based techniques. From these methods the most promising as an alternate underground low level (0 %-5 %) methane monitoring technique is the non-dispersive infrared range of optical gas analysers. From a literature survey on infrared gas analysers it was found that present infrared gas detectors do not allow for an accurate, robust and cost effective alternative to current catalytic oxidation based sensors used underground. Considerable human and financial resources would be required to develop the present infrared sensors into acceptable, cost effective and reliable sensors to be used in the underground coal mining environment.

Current catalytic oxidation sensors in use do not operate well in regions of excessive dust and humidity, as found in the immediate vicinity of the cutting drum. This is an important monitoring position from a methane hazard point of view as this is the main region of methane liberation during the mining process. In order to achieve a reliable method of methane detection from the cutting drum region, the possibility of drawing a gas sample from this region and analysing it by conventional means was investigated. A hydraulic driven rotor brush system and venturi spray system with demister were investigated as means of sample drawing. Dependancy on machine power, bulkiness, time delay from sample time to analysing, inlet clogging and limited flexibility of the systems were cited as the major drawbacks of these systems which were not pursued further.

After the difficulties experienced with the sample drawing units, a continuous multi-channel methane monitoring and recording unit was developed for research into the durability of the catalytic based sensor and sensor protection evaluation, as well as observation of general methane behaviour around an active mechanical miner. The multi-channel methane monitoring unit is an autonomous unit with six methane monitoring points and is easy to install. It can further be utilized for quantitative ventilation analysis and corresponding optimum sensor placements. Comprehensive methane data was obtained for various mechanical miners in diverse mining situations and conditions.

Data obtained with the multi-channel methane monitoring unit, combined with in situ and laboratory coal analysis data, was used as inputs to generate computational fluid dynamic (CFD) simulations for investigation into underground ventilation set-ups. The CFD simulations proved to be representative of underground conditions. They have since been applied as a design tool to investigate various ventilation set-ups and variations thereof in a cost and time effective manner.

The main observation which came to the fore during the CFD simulations and underground monitoring of actual ventilation set-ups was that methane behaviour and related methane levels could be closely linked to prevailing air flow patterns, unlike dust behaviour. This led to the conclusion that areas of poor ventilation, where a source of methane is evident, have a greater potential for increased methane levels. Areas of poor ventilation were found to be condition specific, caused either by machine movement blocking or diverting the applied ventilation, and/or auxiliary ventilation systems implemented incorrectly, effectively cancelling out the applied ventilation, creating dangerous operating conditions. From underground monitoring data, the time span for these regions of increased methane levels to manifest themselves was found to be as low as three minutes, with peaks of up to three times the initial background level recorded.

A region which is especially prone to these conditions is the region under the cutting boom. Normal ventilation conditions tend not to introduce sufficient fresh air into this area and combined with the increased methane emission from the cutting process, and air roll induced by the cutting drum rotation, give rise to increased methane levels. The situation is aggravated even more as the mechanical miner moves into a first lift, further restricting ventilation reaching the mechanical miner.

Beyond the condition specific nature of methane behaviour it was also found that general methane levels tend to be site specific ie. mine and even section specific. The possible existence of micro blowers was recorded during one of the monitoring periods, further increasing the extremely flexible and unpredictable nature of methane release into active mechanical sections.

A technique which is successfully applied in European and American collieries to reduce the in situ methane content of virgin coal seams is methane drainage. Up to now limited work has been done in South Africa on this subject, both for surface and underground systems. The reason for this is largely due to the characteristics of local coals. Although sorption potential is similar, the shallow seam depths in South Africa, with their lower diffusive properties, make the same techniques unsuitable on a large scale for South African conditions. This does not exclude the possible existence of localized areas where drainage can be applied on a limited scale.

The development of the mathematical methane prediction model will allow cost effective evaluations to be made with respect to the feasibility of the application of drainage practices. The model can be utilized to determine the optimum network layout for a specific site with regard to quantity of methane to be removed and the period required for drainage. This method of site evaluation can be applied for surface or sub-surface drainage networks.

Most methane prediction packages, mathematical or empirical, have been developed for foreign coal fields and in most cases for specific applications. With the distinct advantages of simulation over empirical prediction, a comprehensive two-dimensional mathematical, unsteady-state, dual-porosity, single-phase, numerical methane simulator was derived with South African coal characteristics as inputs. The simulator will simulate accurately the effects of gas contributions from any practical mining situation, however, the accuracy is dependant on the reliability of the input data. To address this a database was built up from continuous field and laboratory tests, as well as from relevant literature sources. The database included values such as diffusion coefficient, virgin seam pressure, Poisson's ratio etc. for various geological structures. A simulation will provide overviews and details of methane behaviour in terms of emission rates, gas content and seam gas pressure dependencies as a function of both time and locality.

For the mathematical model to be applied usefully it was translated into computer code for use on a personal computer. Due to the underlying complexity of the mathematical description and the large number of possible combinations in which it can be implemented, the writing of a computer program was an enormously complex exercise. To streamline the program and remove all redundancies proved to be a very time consuming exercise, with the result that the current program is still marred by excessive running times. The mathematical model and operating software have not been verified, partly due to the fact that this was not part of the scope of the project and partly due to the time constraints encountered during the initial development of the model and difficulties experienced during the programming phase. Discussions with overseas experts in this field have indicated that the model is sufficiently complex and general to allow for expectations of reasonably accurate predictions.

Barometric pressure fluctuations have in the past been associated with increases in underground methane levels. From a study made of 35 methane related incidents and barometric pressure fluctuations it was found that the most likely scenario for a methane ignition to occur, from a barometric pressure point of view, is during a diurnal pressure drop. To quantitatively determine the in situ effect of barometric pressure fluctuations on methane levels in a colliery, a system was developed to record barometric pressure and methane levels on a real time basis over a prolonged period. From field tests, it was found that there is a general increase in methane levels during a general downward trend in barometric pressure with the inverse also holding true. Marked increases in methane were further observed during substantial and quick pressure drops. It has to be noted that this type of barometric pressure drop is not always associated with a definite peak in methane levels, but a methane peak could always be linked to barometric pressure drops. Methane peaks associated with barometric pressure drops cannot be quantified at this stage. A site specific tendency seems to be present but, based on the available data, cannot be confirmed.

Another important question which remains unanswered at this stage is the origin of the methane responsible for the increase in methane levels. Literature suggests that methane reservoirs, i.e. sealed areas and old workings, could be responsible for increases in methane levels. This matter can be investigated by employing two or more barometric pressure and methane recording devices. This will allow not only the origin of the methane to be determined, but also how underground barometric pressure variation manifests itself, i.e. variations caused due to surface changes and the influence of fan pressure changes.

The existence of a database based on simultaneous, multiple underground location monitoring, generated by the new monitoring technology, will address the questions raised. For such a data base to be successful it will have to be generated over a few years to determine the effect of seasonal behaviour on barometric pressure fluctuations. The new monitoring technology will enable such a database to be established at relatively low cost, due to minimal manpower inputs, and will yield comprehensive data to shed light on the still ambiguous relation between barometric pressure fluctuations and underground methane levels.

In conclusion, methane can be considered as a direct and indirect threat in a mechanized heading. The direct threat coming from the actual ignition aspect of methane, and the indirect threat in the form of factors causing methane to be introduced into the active heading. These two aspects of the methane hazard have to be considered, and treated with equal respect.

From the direct threat perspective the most important aspect which came to the fore is that methane levels in an active heading are site and condition specific. It was found that in areas with

poor ventilation the possibility can increase for the occurrence of methane accumulations. Areas where inferior ventilation conditions occur are mainly due to mechanized miner operation and location, relative to the applied ventilation techniques. Another factor which induces ineffective ventilation is auxiliary ventilation systems which oppose each other. These observations indicate that the dynamic nature of the active heading has to be realized.

To reduce the indirect threat of methane a proactive approach has to be taken. This entails that methane introduction into the active heading must be minimized. The development of the mathematical methane prediction model has provided a powerful tool for colliery environment control e.g. mine ventilation planning, methane drainage network design and evaluation, effect of barometric pressure fluctuations, in-seam pressure and gas content, face emission rates etc., all with the use of a personal computer. The first software version of the mathematical model, for use on a personal computer, is complex to operate and plagued by extensive operating times, making it difficult to operate. The software has scope for improvement, which will significantly improve the use of the mathematical model as an investigative and planning tool by a larger base of environmental and planning personnel.

Significant steps have been taken to quantify and predict the behaviour of methane in the underground coal mining environment. The knowledge gained about the physical behaviour and monitoring technology of methane, has put within grasp the reaching of a safer underground coal mining environment. The technology and expertise to reach this goal have been laid down.

In order to implement this technology and expertise to its full potential, it is recommended that:

- i. With the help of multi-point methane monitoring techniques and CFD ventilation simulations, methods have to be designed to minimize areas of reduced ventilation, either by dynamic application of current ventilation systems or the development of new ventilation techniques. Site specific coal characteristics, combined with mining methods and sequences, will have to be incorporated into ventilation designs and techniques, ensuring optimum use of available energy inputs to reduce the direct methane hazard.
- ii. The existence of the relationship between barometric pressure fluctuations and methane level fluctuations has been recorded. To quantify this relationship it is now essential that the origin of the methane responsible for methane increases be established, as well as the effect fan pressure fluctuations has on the underground environment. This will allow for improved proactive responses if necessary.
- iii. It has also come to the fore that to improve the safety of the underground environment, methane and dust behaviour have to be studied in tandem, due to the fact that methane and dust behaviour are distinctive given the same environmental circumstances.

# LIST OF CONTENTS

<b>1. Introduction</b>	1
<b>2. Develop improved methods of monitoring methane, especially on continuous mining (CM) machines</b>	1
2.1 Detailed review of potential alternative means of coal face methanometry	1
2.1.1 Alternative methanometry	1
2.1.2 Optical methods to detect methane	2
2.1.3 Feasibility of optical sensors in the cutting face area	2
2.1.4 Conclusion	3
2.2 Development of a more rapid response system using existing methods of detection	3
2.2.1 Possible rapid sampling techniques	3
2.2.2 Air drawing techniques	5
2.2.3 Methanometer placement technique	5
2.2.4 System comparison	6
2.2.5 Multi-channel methane monitoring system (MMMS)	6
2.2.6 Conclusion	7
2.3 Laboratory, underground and production evaluation of improved system	8
2.3.1 Laboratory evaluation	8
2.3.2 Underground evaluation	9
2.3.3 Conclusion	11
<b>3. Develop techniques to quantify and predict methane hazards</b>	12
3.1 Mathematical modelling of methane flow and release	12
3.1.1 Simulation models and empirical models	12
3.1.2 Model development	12
3.1.3 Conclusion	13
3.2 Computer software package to operate prediction model	14
3.2.1 Programming process	14
3.2.2 Conclusion	15
3.3 Laboratory and in-seam determination of methane properties of coals as model inputs	15
3.3.1 Requirements	15
3.3.2 Required physical and geometric properties	16
3.3.3 Input data ranges	17
<b>4. Develop techniques to optimize methane management ventilation practices in mechanized mining sections and to curb accumulations</b>	19
4.1 Identify and quantify hazards and accumulations using in situ measurements and computational fluid dynamics (CFD) computer modelling	19
4.1.1 Dynamic nature of heading environment	19
4.1.2 Methodology	19
4.1.3 Analysis of results	20
4.1.4 Conclusion	21
4.2 Develop CFD models for mechanized mining sections.	22
4.2.1 Introduction	22
4.2.2 Methodology	22
4.2.3 Conclusion	24

4.3	Evaluate various methane management ventilation options using computational fluid dynamics, particularly for mechanized mining faces, and around cutting drums	24
4.3.1	Evaluation set-up	24
4.3.2	Results	25
4.3.3	Conclusion	26
<b>5.</b>	<b>Quantify methane emission changes with fluctuations in barometric pressure</b>	<b>28</b>
5.1	Development and installation of barometric and methane monitoring system	28
5.1.1	The Barometric and Methane Monitoring System (BMMS)	28
5.1.2	System evaluation	29
5.1.3	Summary	29
5.2	Evaluate monitoring results	29
5.2.1	Evaluation	29
5.2.2	Conclusion	31
<b>6.</b>	<b>Quantify the benefits of methane drainage</b>	<b>32</b>
6.1	Monitor and model SA underground and surface drainage systems	32
6.1.1	General overview of drainage systems	32
6.1.2	The South African perspective	32
6.1.3	Conclusion	33
6.2	Develop network designs and drainage guidelines	33
<b>7.</b>	<b>Quantify the hazards at Secunda mines due to the presence of other gases and gas migration</b>	<b>34</b>
7.1	Quantify the effect of other gases on the ignition of methane	34
7.1.1	Scope of work	34
7.1.2	Results and findings	34
7.2	Identify gas sources and migration patterns	35

**LIST OF TABLES**

3.1 Typical characteristics of South African coal.....18



## **APPENDICES**

### **APPENDIX A**

- A1. V.A. Kononov, Infrared Methane Monitoring, Literature study, June 1993, CSIR Division of Mining Technology.
- A2. A.P. Cook, Methane Monitoring Using a Multipurpose Data Logging Station, 26th International Conference of Safety in Mines Research Institutes, September 1995, CSIR Division of Mining Technology.

### **APPENDIX B**

- B1. P. Linzer, A 3-Dimensional Dual-Porosity Single-Phase Unsteady-State Mathematical Model of Gas Transport in Coal Structures, 26th International Conference of Safety in Mines Research Institutes, September 1995, CSIR Division of Mining Technology.
- B2. P. Linzer and A.P. Cook, Quantifying Methane Emissions from Coal, SIMRAC Symposium, July 1995, CSIR Division of Mining Technology.
- B3. P. Linzer, A Numerical Simulator for 3-D Unsteady-State Dual-Porosity Modelling of Gas Flow Within a Coal Structure, 7th US Mine Ventilation Symposium, June 1995, CSIR Division of Mining Technology.
- B4. P. Linzer, A General State Model of Methane Transport in Coal Structures, Internal Report, May 1994, CSIR Division of Mining Technology.
- B5. P. Linzer, Report Back of European Visits to Determine the Position of Miningtek's Methane Emission Model, Internal note, September 1995, CSIR Division of Mining Technology.
- B6. A.P. Cook, Evaluating the Methane Gas Conditions in Underground South African Coal Mines, 25th International Conference of Safety in Mines Research Institutes, September 1993, CSIR Division of Mining Technology.
- B7. CSIR Miningtek, Typical Values for South African Coal Properties as Methane Emission Prediction Model Inputs, January 1993 to November 1995, CSIR Division of Mining Technology.

### **APPENDIX C**

- C1. A.P. Cook, Methane Safety Research for Continuous Miners in South Africa, 7th US Mine Ventilation Symposium, June 1995, CSIR Division of Mining Technology.
- C2. A.P. Cook, Simulations of Methane Flow Around a Continuous Miner Part 1 : Comparison with Dust Flow for a Full Heading Development with Jet Fan Ventilation, Interim Report, July 1994, CSIR Division of Mining Technology.
- C3. A.P. Cook, Simulations of Methane Flow Around a Continuous Miner Part 2 : Full Split Development with Jet Fan Ventilation, Interim Report, September 1994, CSIR Division of Mining Technology.
- C4. A.P. Cook and C.F. Meyer, Simulations of Methane Flow Around a Continuous Miner Part 3 : Different Heading Development Stages with Jet Fan Ventilation, Interim Report, November 1994, CSIR Division of Mining Technology.
- C5. F.J. van Zyl, Methane Monitoring Around an Operational Continuous Miner at Mine A. Technical Report, October 1994, CSIR Division of Mining Technology.
- C6. F.J. van Zyl, Methane Monitoring Around an Operational Continuous Miner at Mine B, Technical Report, December 1994, CSIR Division of Mining Technology.
- C7. F.J. van Zyl, Methane Monitoring Around an Operational Continuous Miner at Mine C, Technical Report, September 1994, CSIR Division of Mining Technology.
- C8. C.F. Meyer and F.J. van Zyl, Methane Simulations Around a Continuous Miner Part 4: Comparison of Methane Behaviour Under Various Ventilation Conditions in a Partially Developed Heading, Interim Report, December 1995, CSIR Division of Mining Technology.

### **APPENDIX D**

- D1. V.A. Kononov and A.P. Cook, Multi Purpose Data Logging Stations for Underground Environmental Monitoring, 26th International Conference of Safety in Mines Research Institutes, September 1995, CSIR Division of Mining Technology.
- D2. F.J. van Zyl and A.P. Cook, A Preliminary Review of the Influence of Barometric Pressure on 35 Methane Related Incidents, Interim Report, June 1994, CSIR Division of Mining Technology.
- D3. A.E. Vidal da Silva, An Evaluation of the Relation Between Barometric Pressure Fluctuations and Methane Concentrations, Interim Report, December 1995, CSIR Division of Mining Technology.

#### **APPENDIX E**

- E1. A.P. Cook, Methane Drainage in South Africa an Overview, Interim Report, August 1995, CSIR Division of Mining Technology.
- E2. A.P. Cook, Methane Drainage Systems and Future Requirements for South African Coal Mines, 6th US Ventilation Symposium, January 1993, COMRO Coal Mining Division.
- E3. A.P. Cook, A Brief Overview of Coal Bed Methane, Interim Note, March 1993, COMRO Coal Mining Division.

#### **APPENDIX F**

- F1. J.N. van der Merwe, Analysis of Methane Gas Occurrences at Secunda Collieries, Report to CSIR Miningtek, October 1993, Sasol Mining (Pty) Ltd Coal Division.
- F2. P. Botha, The Origin of Methane Gas in the Secunda Area, Report to CSIR Miningtek, August 1995, Sasol Coal Division.
- F3. W.C.A. van Niekerk and P. Broere, The Characterisation of Natural Gases, Analytical Report, June 1994, Atomic Energy Corporation of South Africa.

## **1. Introduction**

The hazard associated with the presence of methane in collieries presents itself in various forms and is governed by several external factors. To manage this very real and potentially fatal hazard, various devices and systems have been designed to detect, reduce, control, predict, and model methane in the mining environment. The scope of this project was to examine the various options available to the industry to combat the methane risk in collieries, as well as to try and establish, quantitatively if possible, the effectiveness and/or accuracy of specific methods and to improve them. Areas which were investigated included the detection of methane in mechanized mining sections, mathematical modelling for the prediction of methane emission from coal, the determination of the effectiveness of ventilation systems using computational fluid dynamics (CFD) and *in situ* measurements, the influence of barometric pressure fluctuations on methane emission rates, and the benefits of methane drainage systems. The findings of each are discussed in the following sections.

## **2. Develop improved methods of monitoring methane, especially on continuous mining (CM) machines**

### **2.1 Detailed review of potential alternative means of coal face methanometry**

#### **2.1.1 Alternative methanometry**

Currently the typical methanometer used by the industry is of the catalytic sensor type. Despite improvements over the past thirty-plus years, this variety of sensor has certain shortcomings, i.e. the sensors are affected by silicones, hydrocarbons and excessive exposure to dust and water spray, which can all result in the sensor producing erroneous readings. Alternative ways of detecting methane are through optical methods, thermal conductivity methods, acoustic methods, electrochemical methods, the use of mass spectrometers and gas chromatography instruments.

Although mass spectrometers and gas chromatography techniques give very accurate results, they are not suitable for use in the underground environment. These systems are mainly laboratory based and are operated by qualified laboratory personnel. Thermal conductivity, acoustic and electrochemical based sensors are only suitable to detect high concentrations of methane, from 3 % to 100 %. These type of sensors are usually used in high range methane sensor applications where high methane concentrations are expected i.e. methane drainage systems. These sensors are also employed to override the false readings supplied by catalytic based sensors in high methane or oxygen deficient atmospheres. Catalytic based sensors have an effective accuracy range from 0 % to 10 % and are commercially manufactured for methane levels from 0 % to 5 %. The sensor type with the most potential for underground use, to determine low concentrations of methane in the working face, is an optically based methane sensor. The use of optical, rather than chemical methods, could eliminate the shortcomings of the catalytic based sensors.

## 2.1.2 Optical methods to detect methane

The non-dispersive infrared method of measuring methane concentrations is based on the gas molecules absorbing radiation in the infrared band. Infrared gas analysers have been used in laboratories and certain industries for many years, and some infrared gas detection systems are commercially available. Most of these commercial infrared sensors are fixed sensor stations.

The two main optical measuring techniques are the dual path/single wavelength and the single path/dual wavelength arrangements. While most of the testing and evaluation of these commercially available systems was aimed at non-mining related industries, very little underground testing of the systems has been done. Consequently, no comprehensive database is available on the effect(s) that rock/coal dust, humidity and atmospheric pressure have on the various IR systems.

## 2.1.3 Feasibility of optical sensors in the cutting face area

Technical aspects of current optical gas detectors:

- Optical gas detectors require optical window cleaning and calibration before every start-up.
- Changing the methane concentration from 0,2 % to 1,0 % increases the output signal by only 0,9 %.
- Temperature effects are easily reduced, but minimization of refractive index effects is very difficult. The systems also do not eliminate errors due to the presence of ethane, propane and butane.
- The influence of mine atmosphere pressure variations on gas refractive indices has not been considered.
- The refractive index of visible light (0,4 - 0,7  $\mu\text{m}$ ) has been used in the design of some systems - a better value would be the (lower) refractive index at a wavelength of 1,66  $\mu\text{m}$ .
- To achieve good resolution, an optical power meter with a cooled germanium detector has to be used, however this is inefficient and, therefore, not well suited to underground use.
- Optical infrared systems are bulky (15 - 30 kg) and still need refinement.
- Some of these systems cannot detect local peak values, presenting the real danger, as they average the methane level over a large distance.

In attempting to determine the feasibility of an optical methane monitoring system for use in a coal cutting area, three possible arrangements were identified. These arrangements were identified in terms of sensor position and the optical effect used in the corresponding instrument:

1. Emitter and receiver are positioned outside the cutting area (open path system) and attenuation of infrared radiation, reflected and scattered from the cutting area, is used.
2. Emitter and receiver are in the cutting area with an acceptable air gap between them, and attenuation of the direct infrared beam is used.
3. Two lenses are used to couple light through an air gap between transmitting and receiving fibre-optic lines in the cutting area, with the monitoring unit outside the cutting or hazardous area. Attenuation of the direct infrared beam is used.

It is evident that, in addition to temperature and gas refractive index effects, significant interference by water sprays and rock/coal dust must be taken into account. Water spray must

be considered the most important factor. Apart from directly reducing the infrared radiation, it changes dusts' optical and physical parameters, as well as the refractive indices of optical systems. It must be noted that not only does the refractive index of a gas depend on wavelength, but infrared reflection and attenuation by water vapour and coal/rock dust are also wavelength dependent, making coal face application of the optical methane monitoring method even more problematic.

As mentioned earlier, all of the above arrangements will require an optic cleaning device. The second option should provide better accuracy than option 1, since wavelength-dependent IR reflection and scattering off the mining atmosphere would be excluded from the effects which contribute to reading errors. In order to achieve good compensation for deleterious effects in the sensors, the same broad-band light source should be used for both absorption and reference measuring channels. The recommended light source for option 2 would be a halogen lamp in a flameproof enclosure. Option 3 applies a standard fibre-optic system, but requires a special trailing cable for the CM and at least two extra optical connectors. This can prove troublesome from both a production and protection point of view.

#### **2.1.4 Conclusion**

At the present level of technology, the likelihood of measuring methane concentrations at a coal face in the range 0,2 - 2 % with acceptable accuracy is doubtful. While this method of methanometry at the coal face needs further investigation and development, the cost of further research and development of infrared methane monitoring devices at the coal face (with uncertain results) will be high. Until such time as optical units are developed with acceptable levels of accuracy, weight, and cost, catalytic gas detectors will probably be widely used in the mining industry (for at least 10 years).

Initially the optical IR methane sensor was proposed for remote intrinsically safe fibre-optic gas monitoring systems, which would mean only one electro-optical measuring apparatus would be used with multiple gas cells connected to it via fibre-optic links. This approach would reduce the cost of optical monitoring systems, as the cost of separately installed units is high. This will be the most likely configuration for future optical based methane detection systems.

A detailed report on optically based sensor technology can be found in Appendix A1.

## **2.2 Development of a more rapid response system using existing methods of detection**

### **2.2.1 Possible rapid sampling techniques**

When a mechanized miner is in operation, it breaks coal from the face with picks mounted on the cutting drum. As the coal is broken free, methane is released into the mining environment at an increased rate as fresh surface area is exposed. During the process of breaking the coal (or accidental contact with other geological strata) hot spots can develop at the tips of the picks. These hot spots can have enough energy to ignite explosive methane/air mixtures, with potentially disastrous and fatal consequences. To reduce the risk of such a scenario taking place, it is

essential that methane levels in the region of the cutting drum be monitored accurately and swiftly. While, historically, the drum area is the most likely place for an ignition to occur, it is not the only place in an active heading where an ignition can originate. Falls of ground, abrupt contact of the mechanized miner with side walls, deficient flame proofing of electrical systems, roof bolt failures are all possible ignition sources. Therefore the entire heading is a danger area, and if the threat of methane ignitions is to be minimized, methane levels all around a mechanical miner must be monitored continuously.

The ideal system for monitoring methane levels around mechanized miners would be one which covers the complete mechanical miner, gives accurate and instantaneous readings, requires minimal maintenance, does not intrude on the normal functioning of the mechanical miner and is resilient to the harsh underground environment. As this is an ideal, and not a practically achievable system, the best approximation thereto has to be developed which takes into account the reality of the hostile underground environment and available technology.

Existing catalytic methane sensors do not perform well in conditions of excessive dust and humidity, and these conditions are present to the extreme in the vicinity of the cutting drum, one of the immediate danger areas in a heading. A prior solution to this problem was to move the sensor to the back of the mechanical miner, to the relative safety of the driver's cabin (cab). Taking into account the prevailing ventilation conditions in a heading and the amount of air introduced into it, it is reasonable to expect that dilution of methane levels will occur, especially towards the rear of the heading. To compensate for this dilution effect, the methane alarm levels in the industry are generally set to  $\leq 2,0\%$ , in an effort to avoid mining in possible localized zones, where methane is present in the explosive range.

This method of methane monitoring in a heading has innate inadequacies. Firstly, it is conceivable that if an abrupt increase in methane levels occur at the face, there will be a delay before it manifests itself in the driver's cabin, if at all. Such a delay can be dangerous and costly if such a transient peak is in the explosive range. Furthermore, when considering the physical size of a mechanical miner and the dynamic environment it operates in, it will be appreciated that methane monitoring at the cabin alone is not sufficient to detect possible methane accumulations elsewhere in the vicinity. This is mainly due to the cabin being well ventilated - statutes require a minimum air velocity of 0,4 m/s into the heading across the driver's cabin.

These inadequacies have been recognised by the industry and two or three methanometers have been installed on some mechanical miners. The problem now arises as to the monitoring locations of the methane sensors to ensure the mechanical miner operates in the safest possible environment with respect to methane. To determine the optimum sensor placement, it is necessary to determine the locations and the magnitudes of the maximum methane levels, which can develop around an active mechanical miner. In order to do this, a measuring technique, or system, is required which enables measurements to be taken rapidly and reliably at any position on a mechanical miner. There are two practical options for implementing this type of monitoring system, both from a research and industry application point of view. Either a sample can be drawn from the position under investigation and evaluated elsewhere, or a sensor which measures directly can be placed at this position. Both methods have their respective advantages and disadvantages.

### **2.2.2 Air drawing techniques**

The drawing of an air sample can be accomplished in various ways. Two of the more promising techniques are a hydraulically powered rotor brush system and a water driven venturi spray system with a demister unit. Both options are ideal for underground use as they are not electrically powered, eliminating the need for an intrinsically safe or flameproof design. The rotor brush system consists of a rotating brush in a housing. The brush has a dual function, it acts as an impeller, drawing in air, and, secondly, by spraying water onto its bristles, it acts as a scrubber, removing the dust entrapped in the air. This ensures that a clean and dry air sample is supplied to the methane sensor.

The venturi spray system operates on a different principle. As water passes through a venturi, its velocity increases to a maximum at the narrowest cross-section of the venturi, where the static pressure component of the water is at a minimum. The pressure difference between this and the sampling point draws air into the venturi, where the demister unit then extracts the water from the air sample, providing the methane sensor with a clean and dry air sample.

Both systems supply a clean and dry air sample to the methane sensor, which can be located in a safe and protected environment, as well as allowing air samples to be drawn from any point on a mechanical miner which a sampling tube can reach, without fear of extensive system damage or sensor failure. Although drawing an air sample provides good protection for the methanometer, inherent shortcomings of this methane monitoring technique hinder its ability to yield accurate and reliable readings:

- Both systems draw power from the mechanical miner, which results in protracted installation time. This also makes relocating the system between sites, for possible research purposes, labourious.
- The systems tend to be bulky, resulting in the positioning thereof being problematic without alterations to the mechanical miner.
- Owing to its bulkiness, the fitment of more than one system to a mechanical miner is highly unlikely. This means only one channel is available at a time for monitoring during testing. Consequently, there is a sizeable time delay between methane level readings at successive monitoring positions. This disallows a useful study of the effects, interactions and behaviour of methane levels in an active heading.
- Since an air sample has to be drawn from a distance, a time delay is introduced by transporting the sample from the monitoring point to the sensor. This is aggravated by the response time of the sensor.
- Since both systems are powered by the mechanical miner, they will only function while the mechanical miner is in operation, and during intervening periods, when the mechanical miner is inactive, no monitoring of methane levels will be done.

### **2.2.3 Methanometer placement technique**

By placing a methane sensor at the desired monitoring position, some of the disadvantages of the sample drawing method are addressed:

- The power requirement of a methane sensor is considerably lower than that of the air

sampling systems. This means the sensor can be driven from a portable, independent power source (eg. battery). Thus, the sensor system can be totally autonomous and compact, allowing for methane monitoring even when the mechanical miner is not operational. The compactness of the system will also make it portable and easy to install on a mechanical miner, minimising installation time and eliminating alterations to the mechanical miner.

- The compactness and relatively low power requirement of the sensors allow more than one sensor to be driven by a single power source. This enables multiple positions on a mechanical miner to be monitored simultaneously in order to gain a better understanding of methane behaviour around an active mechanical miner.
- The only time delay in this monitoring system will be the response time of the sensors.

There are disadvantages which can be associated with the sensor placement system. The most obvious of these is the exposure of the sensors to the extremely harsh environmental conditions at some of the positions on the mechanical miner. Excessive exposure to water spray and coal dust at these positions can prove damaging to the sensors, while the sensors and their cables are also susceptible to serious and costly physical damage as a result of impacts, contact with the coal face and falling coal.

#### **2.2.4 System comparison**

The sensor system provides for multiple simultaneous monitoring positions and it will respond more rapidly than the sample drawing system, therefore being more representative. It is also more compact and completely self-contained. By equipping the sensors located in the aggressive environments with suitable protection, acceptable reliability and greater maintenance intervals can be achieved. In terms of the specifications for the ideal system, it must be appreciated that the multiple sensor system is superior to the sample drawing system.

Discussions with people in the industry who tried sample drawing methods revealed that limited success had been achieved. For this reason, and the evident superiority of the multiple sensor system, both as a research tool and potential industrial monitoring system, efforts were directed towards the development of an intrinsically safe, autonomous, multi-channel methane sensor monitoring system (MMMS).

#### **2.2.5 Multi-channel methane monitoring system (MMMS)**

The MMMS consists of four main parts namely the data logger unit, the power supply, power/signal cables and the methane sensors. During the testing of the system it was found that sensors in areas of excessive water spray and coal dust need protection. The protection designed for these sensors subsequently formed an integral part of the system.

The first obstacle that had to be confronted to implement the MMMS was the necessity for a data recording device which could store the methane levels, measured by the apparatus for the duration of a full production shift. An off the shelf data logger was modified to meet the following design specifications:

- 8 analogue inputs of 0-2V
- Intrinsically safe



- Fully and readily programmable via a personal computer (PC)
- Real-time records
- 65K memory for data
- 12 bits A10 resolution
- Recording intervals from 1 second to 24 hours
- A 7.5V nickel-cadmium (NiCd) battery to maintain memory for up to seven days during transportation of the DL
- Compact - contained in a durable plastic enclosure (95x115x29 mm).

The MMMS was designed for real-time monitoring and logging of information from six methane sensors, capable of registering levels in the range from 0 % to 4 %. The completed system, without the sensors, consists of an IS rechargeable 12V/12AH battery, a digital/analogue interface, a plug-in slot for the data logger, six connector sockets for the methane sensor cables and an ON/OFF switch, all mounted in a sturdy 330x300x180mm plastic enclosure with an IP44 rating. The system is totally self-contained, and the battery can supply power to the sensors and the data logger for up to 12 hours continuously. The methane sensors are connected to the recording box via screened, armoured and colour coded cables fitted with water resistant plugs. The system battery and data logger can be removed from the recording box, and individual sensor cables can be disconnected. This allows damaged or failed sensors to be disconnected and replaced without having to switch off the entire system. The compact design and light weight of the system makes for rapid and simple installation on a mechanical miner, with typical installation times in the region of  $\leq 30$  minutes.

The data recorded by the data logger can be down loaded onto a PC and imported into a spreadsheet program for analysis, producing real-time graphs of the methane levels recorded by the various methane sensors on the mechanical miner.

A further system was developed to improve on the first one, and has eight recording channels available for monitoring. Another enhancement to the system is a level indicator for six of the channels, which gives immediate visual feedback of the levels the sensors are recording. This feature greatly assists the operator in determining the operational status of each sensor and the levels present at each sensor.

As expected, sensors placed in the hostile environment close to the cutting drum performed unreliably. Without protection, sensors in these positions malfunctioned within one shift after installation because of excessive exposure to water spray and coal dust. Protective hoods were developed, and this prolonged the sensors' life span from 1 day to approximately 10 to 14 days. Since the sensors should be checked for calibration after 14 days of use, the time gained with the use of the protective hoods was sufficient to ensure that comprehensive methane monitoring could be done in an active heading, with little or no interference in normal production.

### **2.2.6 Conclusion**

The fastest way of detecting methane by means of catalytic based sensors is to measure methane where it is released. At this stage it is not possible to monitor every possible position in an active heading for methane, therefore the logical solution is to monitor at positions where maximum methane levels are most likely to occur. The development of the intrinsically safe MMMS has

provided the industry with a powerful and versatile research tool which can be used to determine areas where the highest methane levels can be expected in an active heading. This information will assist the industry in the placing of methane sensors on a mechanical miner, or in a heading, to ensure the time delay between the possible occurrences of dangerous levels of methane occurring, and the detection thereof is minimized. The system has been tried and tested in the unforgiving underground environment and proved its worth as a reliable and flexible tool, with definite potential in both the research and production realms.

Apart from its intended purpose, it can also be utilized to quantitatively assess various other aspects of methane related problems. A ventilation system's effectiveness, and the impact of modifications thereto, can be studied and evaluated in terms of methane removal. The continuous sampling ability of the MMMS will also allow a quantitative evaluation of sensor protection systems to be made, as well as sensor maintenance procedures to be drawn up for sensors in specific applications. In addition the system has great potential to become a multiple environmental monitoring station with the addition of various other sensors, eg. oxygen, CO, CO<sub>2</sub>, smoke etc.

Further detail on the MMMS is available in appendix A2 and D1.

## **2.3 Laboratory, underground and production evaluation of improved system**

### **2.3.1 Laboratory evaluation**

The MMMS was tested in the laboratory to establish the system's operating characteristics. Various factors, thought to affect the accuracy and response time of the system, were identified and tested. These include:

- System battery performance
- The effect of the length of the connecting cables and coiling of these
- Disconnecting one or more of the sensors from the system
- Malfunctioning of one or more of the sensors
- Damage to the cables - electrical integrity compromised
- The effects of sensor protection measures on a sensor's accuracy and response time.

It was found the battery could support the system for 12 hours of continuous use. Signal loss due to the extension of the cables, up to lengths of 12 m, was negligible and could be reduced by calibrating the sensors when connected to the system via their designated cables. Coiling the cables does not have any effect on measured levels, due to the screening in these cables minimizing RF interference or crosstalk between them. Disconnecting sensors from the system does not influence the operation of the system or the signals from the remaining sensors.

It was found, however, that damage to a sensor, which resulted in a short circuit being formed, did influence the remaining sensors, and this problem was partly addressed by introducing a larger resistance in the circuit supplying power to the various sensors, but could not be totally alleviated. If the damaged sensor is removed from the system, the system operates normally again. The same problem was experienced with damaged cables in which a short circuit was introduced. The only

solution to this problem was to remove or replace the cable as soon as possible and to discard the data recorded for the relevant shift.

Fitting the sensors with protective hoods does not impede the accuracy or response time of the sensors. When water spray and coal dust were applied to the sensors in the laboratory, the sensors responded within specifications. During *in situ* testing, it was found that those sensors with protective hoods, not subject to direct water spray, were inclined to choke more rapidly than those in a dust and water spray scenario (typically after four to five days). This was most probably caused by the absence of water to clear away dust which had accumulated in the hood. The behaviour of the sensors with a protective hood not subjected to direct water spray was found to be erratic for the duration of a test. The most likely explanation is that dust collected in the hood, and was periodically jolted free by the motion of the mechanical miner, thus alternately blocking and unblocking the movement of air to the sensor. Regular checks, and cleaning of the hoods in such positions, will reduce this problem (three to four day intervals should suffice).

Sensor and hood combinations exposed to extreme direct water spray and coal dust, were also found to suffer a reduced life expectancy of four to five days. This is probably as a result of the hood allowing small amounts of water to penetrate through the protection, reaching the sensor where it accumulates on the activated carbon filter causing the sensor to fail after a period of time. It is also likely that water penetrates to the sensor head via the hood-to-sensor interface, as here the seal may not be adequate to deal with large amounts of water. This problem can be overcome by cautious and selective placing of the sensors in these positions, and by ensuring the hood is properly oriented relative to the direction of the water sprays. The hoods in their current stage of development can provide adequate protection to sensors in hostile environments for up to 14 days, allowing for adequate testing time, with minimum maintenance requirements.

### **2.3.2 Underground evaluation**

After the system was tested in the laboratory, it was tested in the production environment. Eight underground tests were performed of which six produced results, while logistical problems caused the other two tests to fail.

The first two tests were aimed at system evaluation, during which the behaviour of the sensors and system in underground conditions was studied. The system was mounted on a continuous miner (CM); two sensors mounted behind the cutting drum, one in the driver's cabin, one in the middle of the CM on the return air side, and one each at the intake and outlet of the scrubber. These sensor placements were chosen to cover the CM as comprehensively as possible, keeping in mind possible future permanent monitoring positions. The same configuration was kept for both tests, making the results comparable as far as sensor reliability, lifespan and recorded levels are concerned. The CM was equipped with directional sprays, an onboard scrubber and operated in a bord and pillar section with a seam height of 2,3 m. Ventilation was supplied by jet fans mounted at roof level.

The first test lasted 14 days. Three separate sessions were successfully monitored and data recorded; a session being a shift when the system was activated and methane levels around the mechanical miner recorded. A lack of manpower was the main reason for restricting the number

of sessions recorded during a test. During the first session the drum sensors malfunctioned within the first 20 minutes of monitoring, induced by extreme exposure to water spray and coal dust. On the second day during the second monitoring session, the scrubber intake sensor malfunctioned, also due to water spray and coal dust. The third session was recorded on the 14th day with the remaining three sensors reading high. This was due to the damage done to the left drum sensor cable.

The second test spanned 12 days and all five sessions returned usable results. Protective hoods were fitted to both drum and scrubber sensors, prolonging their lifespan to the full 12 days. All the sensors produced sound results over the duration of the test period. The final day's results indicated that the scrubber intake and left drum sensor hoods had been choked, which occurred sometime during the last five days of the test. Both these sensors emerged unharmed from the test after time for proper drying was allowed. Sporadic choking of the left middle sensor occurred as of the sixth day, but it was also undamaged.

The third test recorded extremely low methane levels. The maximum level recorded was 0,25 % methane, with an average of about 0,1 %. These low levels, combined with slight drift detected in some of the sensors during the post-test inspection, meant that the only conclusion which could reasonably be drawn from the data was that the underground production section had hardly any methane during the monitoring period. This was confirmed by the levels recorded by the colliery staff during the test period. All the sensors were operational at the end of the 12 day test period.

The fourth test was conducted towards year-end and difficulties were experienced in coordinating the test with the colliery. The data recorded had to be discarded because the sensors' calibration check was not performed after the nominal 14 day period, and the post-test inspection revealed considerable drift in some of them at the end of the 32 day test period. Extensive cable damage occurred and one sensor was exposed to extreme heat from a cutter motor, causing it to fail. This aggravated the situation by rendering the functionality of the remaining sensors very uncertain. The remaining sensors were, however, found to be operational during the post-test inspection.

The system was mounted on an AM85 road header during the fifth test. The closest mounting positions to the cutting head were halfway up the boom. Two sensors were placed either side of the boom at this location. A third sensor was placed in the driver's cabin, a fourth halfway along the road header on the return air side, and the last two at the intake and outlet of the scrubber, respectively. Non-directional dust suppression sprays were fitted, combined with an onboard scrubber. Ventilation was supplied by jet fans placed on the floor. The road header was active in a bord and pillar section. The seam height was 3,0 to 3,5 m. The 13 day test provided worthwhile results for all seven monitoring sessions, and all the sensors remained functional for the duration of the test, with the scrubber outlet sensor showing occasional overshoot. This was probably caused by the high air velocities present at this position. In this test the scrubber inlet sensor indicated signs of sporadic choking as of the sixth day of the test.

For the sixth test the system was mounted on a continuous miner. After various logistical difficulties, caused by the location of the shaft relative to the main administration block, had been overcome, the system was severely damaged by unknown causes before any results could be obtained.

The final two tests were performed in a CM section. Two sensors were located behind the cutting drum, one on each side. A sensor on each side at the middle of the CM, one at the rear on the return air side and one in the driver's cabin completed the arrangement. In this test, the sensors were evenly distributed around the CM as the CM did not incorporate an onboard scrubber. The CM was fitted with non-directional dust suppression sprays, and was used in a shortwall development section. A force column and trailing exhaust column supplied ventilation to the active section. The seam height varied from 1,8 to 2,2 m. The first of these tests delivered only two sets of data from a possible four. Two sets of data were lost due to the failure of devices peripheral to the system. Other difficulties encountered during the test included the system's power supply cable being severed, a sensor being destroyed, failure of the data logger's battery, and all the sensor cables being sheared off near the cabin.

The second of these 14 day tests was re-conducted and yielded better results, while all five recording periods yielded dependable results. The right front sensor failed after three days, being exposed to abnormal levels of direct water spray which caused either an accumulation of water on the carbon filter of the sensor or a breakdown of the seal at the sensor hood interface. The remaining sensors performed adequately for the duration of the test and were within specifications during the post-test inspection.

### **2.3.3 Conclusion**

From the preceding discussion, it can be seen that the system has been tested and proven under various underground production conditions found in South African collieries. Although most of the critical problems have been satisfactorily solved, it is evident that there is room for improvement to further increase reliability as well as improve the ergonomics of the system.

Although new sensors with data logging abilities are becoming commercially available at competitive prices, the MMMS retains its place as an essential research tool in the investigation of methane behaviour around active mechanical miners. This is due to the fact that different sensors can be monitored continuously on a single real-time basis. This is essential to a study which must consider various external environmental conditions, which can influence the observations, eg. ventilation conditions, mechanical miner movements, barometric pressure fluctuations, and so forth. The system will serve as a guiding tool for establishing the optimal placement and maintenance requirements of commercially available sensors for stricter monitoring of methane behaviour around mechanical miners in active production headings.

Results from the tests are contained in Appendices A2, C1, C5, C6 and C7.

### **3. Develop techniques to quantify and predict methane hazards**

#### **3.1 Mathematical modelling of methane flow and release**

##### **3.1.1 Simulation models and empirical models**

Methane behaviour analysis in terms of in-strata flow patterns and seam emissive characteristics goes beyond simple measurement. It aims to provide an overview of the time and location dependence of dangerous methane emission quantities in a given mining situation so that a more proactive approach can be taken to reducing such a hazard.

This can be achieved either by taking measurements of a particular situation and assuming them to apply to similar situations, or by developing a logical understanding of the processes involved and imitating them. The former is the empirical approach, the latter constitutes the basis of simulation.

An empirical model is derived from a sizeable body of measurements. This derivation entails identifying relevant and/or critical quantities, as well as general trends and correlations between/or among these quantities. Once identified, such trends and correlations are translated into general, usually mathematical, relationships. The resultant model abstracts and encapsulates the observations used in its derivation, normally in an approximate way, since deviant measurements are either discarded or diluted, with causal connections between various factors usually ignored. The model is then applied to similar circumstances, from which the measurements were taken, to generate relevant information about those circumstances.

Simulation is the ability to imitate the process(es) underpinning the measurements and observations. It relies on an ability to build a rigorous theoretical framework which explains the links and interrelationships among various facets of the phenomenon in a quantitative way. If this framework is an adequate model of the processes as they occur in reality, then a thorough understanding of the problem exists, which, given adequate resources, allows for imitating them in almost any conceivable situation.

With the distinct advantages of simulation over empirical prediction and measurement, it was decided that the best option would be to develop a gas emission simulator, for accurate methane emission prediction as an environmental planning tool, which would be suited to the South African coal industry conditions. However, in order to simulate the emission of gas effectively, the mechanisms which produce this effect, must be fully understood.

##### **3.1.2 Model development**

The Miningtek methane project team has developed a high level of understanding of the mechanisms of emission, but this has been a long and arduous process. When the organisation (then COMRO) undertook an investigation into the practicalities of quantifying methane emission, initial anticipation of an easy answer was overly optimistic. Several years of literature and technical research was required to bring local knowledge up to the international level, and this research is continued to maintain the level.

Two basic stages characterize the development of the mathematical methane simulator. Firstly, an understanding of the mechanisms and processes which cause methane emissions was obtained and, secondly, a suitable gas transport model was derived. The majority of time and effort was invested in the first stage, as several man years were required of the entire project team before an adequate understanding of the mechanisms was gained.

Defining and understanding these mechanisms relied heavily on previous work and literature from similar efforts in other countries. Critical parameters and the means of quantifying these were thus identified. A large database of coal properties was also prepared, and this assisted in determining the operating ranges of these parameters. Early misunderstandings of the gas transport mechanisms led to both over-optimistic attempts at modelling, and time and effort lost subcontracting the implementation of these models to a qualified mathematician.

Further study of the principles embodied in a wide variety of more or less successful gaswell and drainage simulators revealed a number of further influences needed to be incorporated into the existing description. Thus, the ideas of unsteady state dual flow modes, stress and moisture dependent permeabilities and corrections for laminar/turbulent transitions were adopted and analysed. This analysis, however, avoided three common features of other simulators. Firstly, the medium (ie. coal) was not assumed to be a continuum, rather, its fundamentally discrete nature was taken into account. Secondly, a facility was derived which allowed naturally occurring variations in certain quantities (eg. fracture widths) to be imitated by the simulator. Lastly, a rigorous treatment from first principles of permeability/strain dependency was carried through rather than approximated.

In binding the various factors together into a consistent whole, it became immediately obvious that processing the resultant equations in even the simplest case would be a mammoth task, ie. it is necessary to simulate the totality of processes occurring inside the coal at each and every particle, including the mutual influences of neighbouring particles on one another. In this way, methane emission prediction is actually a by-product of simulating interior processes, much as the marking of time by a clock is a by-product of the operation of its interior mechanism.

Consequently, the mathematical descriptions needed streamlining and/or condensation without compromising their effectiveness. This was accomplished on a trial-and-error basis by approximating one of the gas flow modes to a high degree of accuracy, thus significantly reducing the effort required to generate answers. Streamlining of permeability calculations was achieved by applying suitable mathematical transformations. The model was also enhanced by removing the assumption that one of the flow governing parameters (the diffusion coefficient) was constant in a particular situation, although further research into this parameter's relationship to others is required.

### **3.1.3 Conclusion**

The simulator has the ability to simulate any practical mining situation. The accuracy and reliability of the answers it generates will depend mostly on the degree of detail and accuracy of the input data received. The answers it generates provide overviews and details of methane behaviour in terms of emission rates, gas content and pressure dependencies on time and locality. The simulator incorporates the effects of gas contributions from mining activity, as well as from

goafing where the mining method involves this. The platform upon which the required processing occurs and the degree of geological and geometrical complexity involved will determine the effort necessary to apply the mathematical descriptions effectively.

For detail information on the model and the development thereof refer to Appendices B1, B2, B3 and B4.

## **3.2 Computer software package to operate prediction model**

### **3.2.1 Programming process**

It is often a relatively straightforward matter to translate a set of mathematical descriptions into a series of instructions, ie. a program, that a computer can execute. In this case, however, such a translation is not simple at all, due in part to the underlying complexity of the mathematical descriptions and in part to the large number of possible combinations in which these can be implemented.

To illustrate the latter point, the mathematical descriptions assume a discretised geological structure but do not indicate how one might most efficiently arrive at such a discretisation in a given instance. In the same way, the single most important factor in implementing the mathematics themselves in a program is the efficiency with which they are put into effect, and this is a function of the programmer's skill and experience.

It is absolutely crucial to the utility of the program that all redundancies in the computer code, which symbolically imitates the flow of gas in the geological structure, be eliminated, and that essential code overheads be minimized, owing to the enormous number of complex calculations which are required in a given instance. Unfortunately, many of the present day development tools (higher level programming languages) are very inefficient in this way, as a result of the huge increase in both speed and computing power of PC's in the last 10 years allowing code efficiency to fade as a priority.

With the above considerations in mind, large sections of code have to be programmed at a low level ie. assembly language/machine code. This is time consuming since apparently simple, or elementary, procedures have to be broken down into a sequence of basic individual operations, each of which can be performed directly by a computer without additional translation, and each sequence must then be examined, tested, debugged and, if possible, streamlined further.

This process is a good deal more complicated than it might appear to be at first glance, since there are usually many different ways of coding a given procedure with similar results, but normally only a very limited number of these are exceptionally economical, which in this case is the crucial factor, as indicated earlier.

In addition, much effort is expended in devising user friendly interfaces for the software. A certain amount of subjectivity is involved in this, but again the primary consideration is that of code efficiency and speed. Since most of these interfaces are of necessity graphical in nature, and a lack of a consistent standard governing graphics hardware manufacturers has allowed fundamentally different graphics implementations to flourish, this presents a further problem in that the more



common graphical platforms should all be catered for.

The program is structured in such a way that three broad phases can be identified in simulating a given situation, ie. the set-up phase, the initialisation phase and the processing phase. The set-up phase consists of basic data input, and a complete specification is required of the geometry and geology of the region to be simulated. This is entered in a graphical format as a series of line drawings to specify mining activity, with discontinuities such as dykes and slips included. All boundary types, and the conditions at each, must be specified and points, at which required properties have been measured, entered together with the applicable values. Allowable variabilities for different quantities and their type must be specified, while result intervals and formats must be indicated. This first phase is by far the most taxing from the point of view of the program user.

Once the set-up phase is complete, the user can opt to execute the initialisation phase. The essential purpose of this phase is a cursory analysis of the specifications obtained from the set-up phase. Gaps in the required input data are interpolated or extrapolated, and the geometry discretised on the basis of geology and layout. Once complete, the user still has the choice of editing the inputs from the set-up phase, but the initialisation phase must be rerun if any edits are to be done.

Having accepted both the set-up and initialisation delineations, the user may then start the processing phase. While this is active, virtually all of the computer's resources are tied up by the program. The computer will process the simulation to completion (ie. a user defined ending point), unless its power supply is interrupted, since all input devices are disabled during this phase.

### **3.2.2 Conclusion**

The model and the software to operate it have not been verified as verification did not form part of the scope of the project and because as well as the extensive time and effort was spent during the initial stages developing a comprehensive understanding of the complex processes which formed the basis of the model. Discussions with overseas experts in this field have indicated that it is sufficiently complex and general to allow expectations of reasonably accurate predictions. In its present form, the software can be further streamlined and rendered more user-friendly by including help facilities, extending the task switching abilities and accepting data from other input peripherals. Such improvements, however, must be preceded by an analysis of the model's outputs in terms of accuracy and reliability, and any revisions which may be necessary.

Appendix B5 contains further details on the programming procedure.

## **3.3 Laboratory and in-seam determination of methane properties of coals as model inputs**

### **3.3.1 Requirements**

The objective of the methane prediction model is to calculate methane emission behaviour given a number of initial conditions and values of certain coal and seam physical properties. For the methane prediction model developed by Miningtek the ideal set of initial conditions would be a

complete spatio-temporal description of the required physical properties and geometric dimensions of the entire region under investigation. Needless to say, this is virtually impossible from a practical point of view, but an indication of the likely *status quo* of the physical properties and geometry is, none the less, required for each and every element. Generally, the required quantities are known only at a few isolated points within the region, and this may be used as a basis upon which values may be assigned to other points via a suitable inter- and extrapolation scheme. This scheme is applied before the commencement of gas flow processing. Practically, either field or laboratory observations are used.

### 3.3.2 Required physical and geometric properties

The physical and geometric coal properties which are needed as model inputs are the following:

- Particle half-length
- Particle density
- Diffusion coefficient
- Langmuir constants
- Free gas temperature
- Principal intrinsic permeabilities
- Klinkenberg constants
- Moisture content
- Normal stresses
- Young's modulus
- Poisson's ratio
- Virgin (seam) gas pressure.

All the quantities referred to above, not only vary in an apparently random manner in a geological structure, but also between various geological structures. This necessitated the establishment of a database depicting typical input data ranges for South African coals. The ranges determined for the various input quantities were used as design parameters for the model. These values were determined from laboratory and field tests, as well as relevant literature.

The particle half-length corresponds to half the fissure network size (FNS) of the coal. The FNS of coal is determined by subjecting granules of various sizes to a sorption analysis. For particle sizes above the FNS, sorption rates will be approximately equal, but decreasing very gradually with increasing particle size. As soon as the particle size is at, or below, the FNS the sorption rate will increase significantly. This change results from a sudden increase in available surface area and a reduction in diffusing distance.

Particle density is related to the bulk density of the coal. Along with bulk density, the moisture content is determined by standard laboratory analysis procedures.

The diffusion coefficient (DC) and Langmuir constants are determined from the desorption data of a standard sorption analysis, and the values are obtained by applying the relevant equations to the desorption data.

The free gas temperature is determined by measuring the in-seam temperature of the gas.

The ranges for principal intrinsic permeability and Klinkenberg constants were taken from work done on the methane emission characteristics in South African coal seam strata<sup>1</sup>. The work done on the subject is comprehensive and reliable data ranges can be extracted from it. This course of action was taken because both quantities are site specific and only value ranges were necessary for the model development.

The distribution of normal stresses can most easily be found from existing rock mechanics analysis packages, while Young's modulus and Poisson's ratio are physical characteristics which can be determined by standard material strength testing procedures.

The virgin (seam) gas pressure is determined by sealing off a borehole in the coal seam and measuring the pressure in the borehole after the system has reached equilibrium. For an approximation, Kim's empirical formula, derived from data gathered by the United States Bureau of Mines (U.S.B.M.), can be used to determine in-seam gas pressure. However, this formula tends to overestimate in-seam gas pressure at shallower depths as found in South Africa.

### **3.3.3 Input data ranges**

Table 3.1 contains typical values for the required parameters discussed in the preceding paragraphs. These values were obtained from work conducted by Miningtek and from applicable literature<sup>1</sup>. The values were used to give an indication of the ranges which could be expected for South African coals. This information was necessary during the encoding of the mathematical model.

For more information refer to Appendix B6 and B7.

---

1. G.P. Stripp. Methane Emission Characteristics of South African Coal Seam Strata. PhD thesis. University of the Witwatersrand, Johannesburg, 1989.

TABLE 3.1 Typical characteristics of South African coal.

PARAMETER		UNITS	QUANTITY RANGE
Particle Half Size		mm	±1.5
Particle Density		g/cm <sup>3</sup>	1.33 - 1.98
Diffusion Coefficient		cm <sup>2</sup> /s	2.4×10 <sup>-10</sup> - 5.7×10 <sup>-9</sup>
Langmuir Constants	k <sub>1</sub>	m <sup>3</sup> /t	6.24 - 21.64
	k <sub>2</sub>	1/kPa	0.53 - 1.71
Free Gas Temperature		°K	280 - 305
Principal Intrinsic Permeability (Isotropic)		μD*	1.1 - 8.2
Klinkenberg Constants			
Perpendicular to Bedding	K <sub>⊥</sub>	μD*	850 - 8 000
	b <sub>⊥</sub>	kPa	-70 - 350
Parallel to Bedding	K <sub>∥</sub>	μD*	0 - 17 000
	b <sub>∥</sub>	kPa	-10 - 400
Moisture Content (By Mass)		%	1.1 - 5.8
Normal Stresses		MPa	0 - 20
Young's Modulus		GPa	3 - 5
Poisson's Ratio		-	± 0.2
Virgin (seam) Gas Pressure		kPa	250 - 1 600

\*μD (Microdarcies) = 9.868745×10<sup>-13</sup> m<sup>2</sup>

## **4. Develop techniques to optimize methane management ventilation practices in mechanized mining sections and to curb accumulations**

### **4.1 Identify and quantify hazards and accumulations using in situ measurements and computational fluid dynamics (CFD) computer modelling**

#### **4.1.1 Dynamic nature of heading environment**

To be able to manage an event/occurrence efficiently and economically it is necessary to know the variables involved in the scenario. The two variables which are of concern from a methane control point of view are, firstly, the amount of methane released in the heading, and, secondly, its behaviour in the heading after being released ie. interaction with the applied ventilation.

There are two options which can be employed to reduce the methane hazard. Firstly methane can be removed from the coal seam prior to mining so reducing the quantities released into the active heading. Secondly it can be diluted to below the explosive limit as it desorbs from the coal face. As methane drainage systems only drain a part of the total body of methane in a seam, the main system employed to keep methane levels below the explosive range in a section is ventilation.

Various ventilation techniques are currently used to supply fresh air to an active heading face, ie. force columns, trailing exhausts, exhaust columns, jet fans, onboard scrubber systems and directional sprays. Apart from the various air moving techniques available and the various combinations thereof, the volumetric displacement of these systems can also be varied. Another variable in the system is the point and angle of application of the air mover in a heading. Taking into account the inherent complexities of fluid dynamics and the number of permutations of the above mentioned variables, finding an optimum face ventilation solution can be difficult. As a preliminary investigation only the point of application and volumetric adjustments of air movers are considered, neglecting other effects which influence ventilation conditions. Factors such as mechanical miner movement, shuttle car movement, mining method and sequences applied, heading dimensions, length of a pass, etc. have to be taken into account, as these can also have a significant impact on air movement in a heading.

Considering the variables mentioned above plus the fact that methane emissions can vary, it has to be appreciated that finding a complete and practical solution to methane behaviour in an active heading can be difficult.

#### **4.1.2 Methodology**

As a first effort to determine possible methane hazards and accumulations in an active heading, Miningtek approached the problem from both a theoretical and practical viewpoint. With its experience in the field of computational fluid dynamic simulations, a model was developed to determine the flow vectors and methane behaviour around an active CM and shuttle car combination. Various basic development stages of a heading were modelled (refer to § 4.2). With the aid of the multi-channel methane monitoring system (MMMS), various underground tests were conducted to determine actual methane levels and trends around active mechanical miners

(refer to § 2.2). The results from the MMMS were used to verify the computational fluid dynamic simulations' results as far as possible, and also to identify possible hazardous scenarios for further computational fluid dynamic evaluations.

#### 4.1.3 Analysis of results

One of the main conclusions which can be made from the results, obtained from the computational fluid dynamic simulations and *in situ* methane measurements, is that methane levels and behaviour in an active heading are site and condition specific. From tests, done at different sites, distinct sets of data were obtained. During one of the tests the methane levels never exceeded 0,3 %, not even at the drum positions. A second test yielded levels of  $\pm 0,5$  % with limited maximums behind the cutting drum of 1,5 % to 3,2 %. Another test recorded average levels of  $\pm 0,6$  % with the maxima behind the cutting drum reaching 4,0 % with average cutting drum levels of 2,0 %. Considering the variations in the general methane levels recorded at the various sites, there is a strong possibility that levels can be linked to site specific characteristics ie. methane emission rates, in-seam gas pressure, methane content, seam integrity etc.

For all the above mentioned tests different ventilation set-ups, seam heights and mechanical miners were present making it difficult to link only site specific characteristics to the variations in recorded methane levels. These variations in mining conditions, at the various sites, also have an effect on the methane distribution in an active heading.

This fact is echoed in the computational fluid dynamic simulations done. The same ventilation set-up was modelled in various mining situations, eg. fully developed heading, split to the left and right, a partially developed heading and split etc. The steady state solutions for each of these conditions indicated different methane behaviour patterns, which can be closely linked to the prevailing ventilation conditions. From the results it can be appreciated that the position and movements of mechanical miners and shuttle cars, flowrate variations etc. will have an effect on methane behaviour in a heading as these variations will affect the airflow patterns. This was confirmed by observations done during *in situ* testing, eg. when a CM was trimming a corner. During this operation the sensor on the return air side behind the cutting drum was effectively blocked from the ventilation. This caused the methane levels to rise to 2,5 % at this position, which was substantially higher than the levels recorded by the other sensors (0,2 %). When the CM finished this operation, the sensor was exposed to normal ventilation conditions again, with a subsequent drop in the methane levels recorded (Appendix C7).

It was also found that directional sprays near the cutting drum tend to scrape methane from the face as seen from the computational fluid dynamic simulations and *in situ* testing. Despite the assistance of the directional sprays, air movement in the area under the boom seems to be insufficient, and this effect was accentuated when the mechanical miner cut a first pass, restricting additional ventilation from reaching this area. This can lead to possible methane build up under the boom, which seems to increase substantially as the boom shears down (refer to Appendices C2, C3, C4 and C7). The peak levels can increase by over a 100 % from levels recorded at the start of the shearing process. In addition to the reduced ventilation in this area, computational fluid dynamic simulations indicate that the rotation of the cutting drum tends to drag methane, released from the face, under the boom. To confirm and quantify the effect the shearing down of the boom and the rotation of the cutting drum has on methane levels in the under boom area,

further detailed tests needs to be conducted.

Computational fluid dynamic simulations indicate that methane layers form against the roof over a CM in some situations and these layers can be directly related to the ventilation conditions created in the heading. Also, once the methane mixes with fresh air in a heading it stays mixed, with the mixed state of the methane persisting throughout the heading.

The computational fluid dynamic models show that when two air movers are present in a heading the chances of forming forced vortices are increased. Forced vortices are areas of recirculation, which can lead to areas of increased methane levels. If these forced vortices are formed over, or at the rear of, a mechanical miner they tend to create areas of increased methane levels. This is due to the fact that methane tends to follow the air flow patterns closely, with the result that the air returning from the face area, already containing diluted levels of methane, is recirculated and reduces the amount of fresh air penetrating the area, with a resulting increase in methane levels. This tendency was confirmed from the underground data recorded.

From *in situ* data recorded it was found that if two air movers are used in an active heading care should be taken that they do not oppose or cancel each other out. A case in point was when a force and exhaust column were used in tandem. As the mechanical miner was cutting a first lift on the left, methane levels near the cutting head increased 8 fold within 20 minutes with no indication of dilution in this area. The average increase for this section, when cutting the second lift was 3 fold for the front sensors with definite signs of dilution. This raises the question of whether it would not have been better to switch off the forced column during the first lift, as the two systems effectively cancelled each other out in this specific scenario.

Apart from steady state solutions, and the influence of the various sites and conditions on methane levels, abnormalities do occur and this was illustrated by results obtained from underground tests. During one test a CM was parked next to the side wall, owing to a power failure. For this period the five sensors on the continuous miner were reading a background methane level of 0,2, %. After  $\pm 10$  minutes, and for no apparent reason, the sensor behind the drum next to the side wall recorded levels of  $\pm 2,0$  % for approximately 15 minutes after which it returned to the normal background level of  $\pm 0,2\%$  (Appendix C7). For the duration of the shift the sensor operated normally and the post test inspection of the sensor did not reveal any irregularities. This situation could have happened anywhere, and at any time, with even higher methane levels, again emphasising the importance of methane monitoring at various positions on a mechanical miner.

#### **4.1.4 Conclusion**

Results indicate that the directional sprays do work, but insufficient ventilation under the boom can cause possible methane buildup. Methane behaviour tends to follow air flow patterns closely, with the effect that changes in air flow patterns, for a number of reasons, can have a significant effect on the methane distribution in a heading. Care must also be taken when applying ventilation to an active heading. It has been seen that more is not necessarily better. This observation leads to the conclusion that situation related ventilation techniques should be developed. It is clear that methane levels are site, and condition, specific and this necessitates that each condition and site be evaluated separately, in order to identify potentially dangerous prevailing conditions, with

optimum ventilation setups and methane sensor placements then determined from this data. A heading can never be totally free of the methane hazard because of unforeseen methane events which do take place and to ensure maximum safety in a section, multiple strategically placed methane monitoring points must be incorporated to counter this problem effectively.

The inherent complexities and influential variables, present in the determination of methane behaviour in a heading, lead to the conclusion that each section should be individually assessed. To address a specific section's methane hazard by evaluating various ventilation methods, computational fluid dynamic simulations can be used. As the database expands, from computational fluid dynamic simulations compiled for various underground scenarios, both steady state and dynamic solutions, future assessments of ventilation conditions and variations can be done fast and accurately.

Above all else the *in situ* data and computational fluid dynamic simulations have established that the current understanding of methane-in-air behaviour, around mechanical miners in an active headings is deficient, and, hence, requires further in-depth study, with the methods employed making up a valuable part of such a study.

Detailed reports on computational fluid dynamic simulations and *in situ* tests are contained in Appendix C.

## **4.2 Develop computational fluid dynamic (CFD) models for mechanized mining sections**

### **4.2.1 Introduction**

When changes in ventilation and mining conditions occur, the effects of such changes have to be determined in order to minimize the hazard of methane and dust in the working environment. Underground surveys can be time and manpower consuming, resulting in quantifying the effects of changes being costly, and time consuming. In developing an accepted and respected CFD model for determining ventilation flow in mining situations, solutions can be obtained quickly and relatively inexpensively, allowing rapidly changing ventilation and mining conditions to be investigated, without the need for underground testing. Miningtek has used CFD as a ventilation tool since 1990, developing simulation models to their present detailed standard for CM's and road headers (RH), simulating ventilation flow patterns, dust distribution, and methane behaviour.

### **4.2.2 Methodology**

The development of a steady state methane prediction model in a mechanized mining section was divided into 3 phases, with phase 1 serving as a validation of the proposed model by simulating the least complex heading set-up and analysing the results. The results from phase 1 then served as the platform from which the more complex heading configurations were modelled.

From the work done on SIMRAC project COL027 the model for ventilation flow and dust concentrations was well established, due to the fact that dust input levels were accurately determined, thereby establishing the base for an accurate model. As the ventilation and dust data



were more reliable than that for methane, phase 1 of the model concentrated on identifying a relationship between dust and methane levels.

For phase 1 a CM and shuttle car combination were modelled on the right hand side, at the face of a full heading. The CM was modelled with its boom in the upright position. Ventilation was supplied by a jet fan ( $4 \text{ m}^3/\text{s}$ ) at ground level, on the right at the entrance to the heading. The CM was fitted with an onboard scrubber ( $10 \text{ m}^3/\text{s}$ ) and directional sprays. The last through road velocity was modelled at  $1,5 \text{ m/s}$ . Input data for the various quantities was extracted from industry wide average ventilation values. The main objective of phase 1 was to relate methane flow patterns and behaviour to that of dust and ventilation, therefore methane input levels were not considered to be significant in terms of actual methane percentages in the air. However, more important were the release points to determine the methane flow patterns after release. The input figures were, therefore, based on information from a range of coal seams and not a specific situation. The main methane emissions were considered to be immediately in front of the cutting drum at  $7 \text{ l/s/m}^2$ , and from the freshly cut coal, directly above the cutting drum, at  $1 \text{ l/s/m}^2$ . Methane was also added from the face below the cutting drum and from the broken coal at the gathering arms at  $0,2 \text{ l/s/m}^2$ . Methane concentration at the scrubber inlet was fixed at  $0,8 \%$ . Initial in situ results indicated an average constant value at this location. No emissions were considered from the side walls, roof, floor or shuttle car, as comparisons with the generated dust contours were required, and no dust release was simulated from these positions.

Results from the phase 1 simulations indicated that methane concentrations and flow patterns show very little correlation to the dust contours, with the main difference in behaviour found to be the rapid mixing of methane to constant levels within a few metres of the face, compared to the longer time and distance required for dust dilution. Dust contours also show a greater variation than the methane contours, the most significant being the high dust concentrations encountered against the roof above the CM. Results indicate that methane mixes with the ventilation air, remaining mixed at constant percentages throughout the heading where dust tends not to mix so readily, and instead is carried by the airflow. These differences in behaviour led to the conclusion that dust contour results cannot be applied to describe methane concentrations and behaviour.

Information from two sites has been used to equate the relative contours produced by the simulations to actual methane percentages in the ventilation. It was found that the actual values, recorded at the cab and scrubber intake, were both approximately one third that of the simulated values, indicating a possible correlation existing between actual and simulated conditions.

In phase 2 the model was extended to evaluate the methane flow around a CM and shuttle car combination in a fully developed split to the right. The input conditions as described for phase 1 were used for phase 2, with the CM and shuttle car combination placed on the right hand side at the face of the split. All the ventilation quantities and set-ups, methane emissions sources and rates, were kept similar, however, in phase 1 the freshly cut coal in the shuttle car was not modelled as a methane source to coincide with the dust model. Some concern was, therefore, expressed that the freshly cut coal on the shuttle car was making a more significant contribution to methane levels in the heading than was simulated. Laboratory tests were carried out on lumps of coal produced by a CM to determine their gas release rate from a pressure of  $1\ 000 \text{ kPa}$ , corresponding to a depth of  $\pm 150 \text{ m}$ . The release rate was found to be surprisingly slow, and it

was decided to perform two underground tests to verify this. Direct tests were done on coal from shuttle cars at both locations, which subsequently confirmed the laboratory results. It was then concluded that the methane emission from the broken coal on the shuttle car is not significant in terms of the total methane emission into the heading, and CFD simulations were continued without simulating broken coal emissions from the shuttle car.

After the successful completion of phases 1 & 2, phase 3 was developed. This phase consisted of three stages, each comprising a different heading layout. The jet fan position and ventilation quantities stayed the same as in the previous phases, as well as the emission sources and rates. For stage 1 a partially developed heading was modelled, however with stage 2 a partially developed split to the right was modelled, and in stage 3 a complete split to the left. The same CM and shuttle car combination at the cutting face, as employed in phase 1 & 2, was used in all the stages.

#### **4.2.3 Conclusion**

With the completion of phase 3 of the modelling, all the basic configurations of a CM section were modelled. Results obtained from *in situ* measurements indicated the levels obtained from the simulation were three times that of actual levels. More importantly there is evidence that the simulated behaviour of methane gas in a heading relates to actual conditions.

For further information refer to Appendices C2, C3 and C4.

### **4.3 Evaluate various methane management ventilation options using CFD fluid dynamics, particularly for mechanized mining faces, and around cutting drums**

#### **4.3.1 Evaluation set-up**

Initial CFD runs indicated the worst case of methane build up can be expected when a mechanical miner is cutting a partial heading or partial split. It was also found that the effect of ventilation applied at the last through road did not manifest itself very prominently during the mining of a split. Taking this into account it was decided to use a partially developed heading as a basis for the evaluation of various ventilation methods. A partial heading, developed to the right, was modelled with a CM and a shuttle car present. The CM was fitted with directional sprays and an onboard scrubber during all the simulations, and the CM was modelled cutting the floor, boom down position. The same emission rates and locations were used as in the previous phases (§4.2), and the volumetric displacements of the directional sprays and scrubber were also similar.

Five ventilation systems were investigated :

1. Floor mounted jet fan in combination with an onboard scrubber
2. Roof mounted jet fan in combination with an onboard scrubber
3. Force column in combination with an onboard scrubber
4. Independent onboard scrubber system
5. Onboard scrubber system with a trailing exhaust connected to the scrubber outlet.

### 4.3.2 Results

All the simulations show high levels of methane in the region around the CM ( $\geq 4,7\%$ ). In all cases, the region of maximum methane levels ( $\geq 4,7\%$ ) showed a distinct shape, covering the whole area from the face, roughly to the scrubber intake and then extending further along the roof, approximately to the back of the CM. It was also found that this region, for the full height of the heading, extended further than the scrubber inlet down the air intake side of the CM. This extension, of the maximum levels down the air intake side, varied and, in some cases, extended as far as  $\pm 75\%$  down the length of the scrubber.

Results indicate that the region of maximum methane concentrations is most likely caused by ventilation conditions and from the velocity vectors it is evident that limited quantities of fresh air penetrate this region, resulting in limited dilution and, hence, the high methane levels. This also holds true for the area of maximum methane levels forming to the back of the CM against the roof. In all the simulations a definite area of vertical recirculation is evident above the boom on the air intake side. This area of recirculation moves methane rich air up and across the face and then along the roof. Some of this methane rich air is also then drawn towards scrubber inlet, while some is diverted past the scrubber inlet along the roof. The remainder is drawn into the area of recirculation over the boom. Limited dilution appears to occur in this region, as most of the fresh air coming in on the air intake side gets entrained by the scrubber inlet, with limited quantities penetrating the area of recirculation. In some cases the incoming air already contains some degree of methane which is caused by the return air from the face being recirculated in a region behind the CM. The methane levels of the incoming air, going past the scrubber, seem to vary depending on the amount of recirculation occurring behind the CM.

The CFD simulations show this behaviour of the released methane, around the CM in a partially developed heading, to be the general trend for all the ventilation set-ups, with the exception of the trailing exhaust set-up. Apart from this apparent similarity between the various ventilation set-ups, distinct differences do occur.

A definite similarity can be observed between the methane contours of the jet fan mounted on the roof and the trailing exhaust systems. The independent scrubber system displayed the same trends for the above mentioned systems, although not as pronounced, while all three systems exhibit the described high methane region around the CM with methane levels behind the CM of  $0\%$  to  $0,3\%$ . For the roof mounted jet fan and trailing exhaust systems, the transition area from the high methane region ( $\pm 4,7\%$ ) to low methane region ( $0\%$ ) occurs in  $\pm 1\text{m}$ , indicating very high transition gradients. This indicates that enough fresh air reaches this point to effectively dilute the methane, but no significant penetration of fresh air is achieved past this point. The reason for these high dilution gradients between the high and low regions can be twofold, ie. firstly the majority of fresh air entering on the air intake side of the CM gets entrained by the low pressure area created by the scrubber inlet. This entrainment is assisted by the air stream returning from the face, in the area of recirculation, meeting the incoming air. Secondly, no recirculation is induced behind the CM by the trailing exhaust system and hardly any by the roof mounted jet fan system. This means the air which enters the environment around the CM does not contain any recirculated methane. The effect of this can be clearly seen from the region of high methane levels being slightly smaller for the trailing exhaust system, with no recirculation behind the CM, compared to the roof mounted jet fan set-up, with the second lowest recirculation of all the

simulations occurring behind the CM.

For the independent scrubber system the methane contours resemble the roof mounted jet fan contours, but with less steep transition gradients. This is caused by the increased recirculation induced by the scrubber behind the CM, allowing methane polluted air back into the heading. All three of the above mentioned systems effectively contain the area of high methane levels in the heading, in a region over the CM, with the remainder of the heading experiencing levels of 0 % to 0,3 %. Limited dilution takes place in this region.

On the other hand, it seems as if the force column and floor mounted jet fan systems tend to let more fresh air into the confined area around the continuous miner, but have increased areas of recirculation behind the continuous miner, tending to spread methane throughout the heading.

The methane contours of the floor mounted jet fan system roughly follow the contours of the independent scrubber system, but with a much larger transition area between the high and low methane areas. This transition area extends past the CM and over the shuttle car. Although the area of recirculation over the boom area is much the same as for the previous systems, a substantial increase in recirculation behind the CM can be observed. This increase in the recirculation behind the CM, re-introducing methane from the face back into the face, can explain the much increased transition area. As before, this system tends to contain methane over the CM but introduces levels of  $\pm 1$  % methane in the heading behind the CM.

The force column system also displays a high methane region ( $\geq 4,7$  %) over the CM, but levels of  $\pm 2$  % are reached in the heading behind the CM. The force column introduces fresh air directly behind the CM at the roof, inducing substantially higher air velocities in the region of high methane levels than is the case for the other ventilation systems simulated. This, in turn, causes more fresh air to reach the face for dilution purposes. Despite more fresh air being introduced in the area over the boom, the region of high methane levels appear to be the same as for the other systems, with largely increased levels of methane in the area behind the CM and shuttle car. The increased area of recirculation over the boom area, induced by the increased air velocities, and large amounts of return air being drawn back into the heading in the area over the shuttle car, caused by the pressure drop at forced column inlet, are likely to contribute to these conditions.

### 4.3.3 Conclusion

From the above CFD results it is evident that in this scenario areas of increased methane levels in a heading can be directly and, indirectly, linked to areas of recirculation. In general it was found that a higher degree of recirculation corresponds to increased methane levels. Although a link between recirculation and methane levels is evident from the results, the steady state nature of the solutions cannot be applied to indicate if recirculation will lead to methane accumulation. The steady state solutions also make it difficult to predict the time span required to reach the observed solution. This makes it difficult to determine time dependant effects such as how long a vortex will trap methane after methane emissions subside, and how long it takes a vortex to build up methane levels to equal those of the steady state solution. To answer these pertinent questions dynamic solutions for the models need to be obtained in conjunction with detailed site specific *in situ* methane behaviour monitoring. Dynamic solutions are more expensive than steady

state solutions, as they require more computing time, and for this reason it is necessary to establish a firm base with the steady state solutions so that accurate models can be described for dynamic solutions.

From the preliminary results it appears as if a trailing exhaust system controls the released methane in a partially developed heading most effectively, by restricting it to areas mainly in front of the scrubber intake. A roof mounted jet fan in conjunction with a scrubber, creating much the same airflow patterns as the trailing exhaust system, also seems to be effective. As the region of high methane extends to the scrubber intake for all the systems, an improvement can possibly be obtained by splitting the scrubber inlet and moving it closer to the face. Such a move can possibly reduce, or eliminate, the area of recirculation above the boom area and so limit the area of high methane levels ( $\geq 4,7\%$ ) over the CM. This reduction in size of the high methane level region will reduce the energy released during an ignition and, thus reduce the effect of the ignition.

CFD simulations can be utilised to indicate if moving the scrubber inlet will have the desired effect, and the optimum capacity of the scrubber can be determined from an effectiveness and economical point of view. Ventilation inadequacies induced by the system can also be identified. As important as the methane control abilities of the ventilation system are, CFD simulations can also be used to predict the dust control abilities of the system. From the results it is obvious that CFD simulations can be used to test and modify ventilation concepts fast, accurately and economically before they are applied underground for final evaluation.

Taking into account the complexities of the ventilation situation in a heading and the number of variables which influence it, CFD simulations will allow collieries to determine the optimum ventilation set-up for their specific mining conditions and situations. Made economically, speedily and accurately CFD simulations will enable a more accurate and informed assessment to be made of ventilation systems required, without cumbersome underground trials.

Miningtek has developed the technology to study and evaluate proposed ventilation systems for dust and methane behaviour. The model developed to date, proved to be successful when compared to in situ measurements. The model suggests that various ventilation systems exhibit different characteristics for various mining situations and conditions, indicating that ventilation conditions can be site specific. However, limited simulations have been done in relation to the number of combinations and permutations possible between mining situations, ventilation options, and various methane emission rates.

To be able to identify possible dangerous ventilation practices and hazardous abnormalities, the database of possible mining conditions needs to be expanded, which can only be achieved by further CFD simulations. Such a database could give indications of preventative and pro-active measures, which can be applied in various conditions to reduce the methane hazard.

Appendix C8 contains the detailed report on the ventilation analysis.

## **5. Quantify methane emission changes with fluctuations in barometric pressure**

### **5.1 Development and installation of barometric and methane monitoring system**

#### **5.1.1 The Barometric and Methane Monitoring System (BMMS)**

As methane gas is a very real and dangerous hazard in coal mines, all aspects relating to the gas have to be studied, eg. methane behaviour in active headings, general methane behaviour throughout the underground workings, tendencies of the gas to accumulate, emission rates from the coal face, emission characteristics of the coal, total methane content of the coal, and external factors which can influence methane levels, to mention a few. The vast number of variables which influence methane in the underground workings makes it very difficult to investigate and control, therefore, making it necessary to identify and investigate possible major factors which can have an influence on methane levels in a mine. One of the important aspects which still needs investigation is the effect of fluctuations in underground atmospheric pressure on the general body of methane in the underground environment.

To be able to study this phenomenon, a system was designed and built to monitor methane and atmospheric pressure levels simultaneously at a specific underground location. To make such a system widely applicable in the underground mining environment, the following requirements were identified during the development of the Barometric pressure and Methane Monitoring System (BMMS):

- To be able to correlate recorded data, the system has to log the data on a real time basis. Using a real time basis allows unexpected external effects, which can manifest themselves in the recorded data, to be identified and examined eg. fan stoppages, thunder storms.
- To obtain a realistic representation of the behaviour of methane and atmospheric pressure changes at the monitoring point, the system has to record data for at least one week continuously.
- The system has to be portable, making it possible for a single person to install the system underground.
- Making the system self powered ensures continuous recording of data, regardless of power failures on the colliery.
- The system must not interfere with the normal underground operation of the mine.
- The system must be easy for mining personnel to operate and maintain.

The system consists of a barometric pressure sensor, methane sensor, micro data logger, the intrinsically safe power pack and the controller, all contained in a durable plastic box with dimensions 180 x 180 x 300mm. The same data logger technology which was developed for the MMMS system is used in the system, and operates on a cyclic basis to ensure a full week of autonomous operation from the available power pack. The controller switches the system on at pre-programmed intervals, allows for the warming of the methane sensor and then records the levels of both the barometric pressure and methane into its temporary memory. The data logger then records the data which is stored in the temporary memory of the controller. The data logger and controller have different clocks, which are not synchronised, and can thus cause possible data loss, but by following the above mentioned procedure this is eliminated. The recorded data can be down loaded onto a PC and imported to a spreadsheet for analysis.

To maximize monitoring periods and ensure optimum battery life expectancy, the system does not have an ON/OFF switch, instead it has a fuse which blows when the minimum battery levels are reached, switching the system off by doing so.

### **5.1.2 System evaluation**

The system was tested underground, and dependable results were obtained, with the first test recording good results in the return airway of an active section. The next three tests experienced problems were experienced with the methane sensor. The sensor was poisoned twice, presumably by silicone vapours, and once it malfunctioned, due to exposure to water. After these problems were identified and the operating personnel informed of the possible hazards, the system operated successfully for the remaining three tests.

### **5.1.3 Summary**

The main attributes of the system are that it is portable, user-friendly and effective in recording barometric pressure and methane levels every 5 minutes over a 10 day period on a real time basis. The simplicity of the system allows it to be used as an important tool in generating substantial databases of methane and barometric pressure fluctuations, on a real time database at various locations in a mine, with little effort. This data can be manipulated on a PC and compared to other sections to determine if any correlation, or trend, can be identified. The system can also be used in conjunction with similar systems to try and establish the possible sources of methane being introduced into the workings during barometric fluctuations, and the effect of barometric fluctuations on the methane distribution and movement in the underground environment.

Refer to Appendices D1 and D3 for more detail on the system operation.

## **5.2 Evaluate monitoring results**

### **5.2.1 Evaluation**

The evaluation of the recorded data started with the generation of a graph of the barometric pressure and methane levels recorded on a mutual real time axis. This procedure allowed a first order visual inspection of the data to be made. Various interesting observations can be made from these graphs. A definite cyclic behaviour of methane can be seen for most of the monitoring periods, with two definite peaks and lows forming daily. Superimposed onto this daily cyclic behaviour of the average methane levels, continuous and significant, increases and decreases around the observed trend can be identified. As these peaks and lows only last for a short time, ranging from 5 minutes to 20 minutes between peaks and lows, they can be seen as scatter around the general methane trend observed on a daily basis. The range of this scatter around the general methane level ranges from 0,1 % to  $\pm 1,0$  %, with no specific time period linked to certain ranges of increases or decreases. On the atmospheric pressure side, diurnal pressure lows and highs can be identified from the recorded data. The long duration of the test periods allowed for general trends in the daily barometric pressures to be observed ie. decreasing, increasing or neutral trends.

It appears as if the scatter observed in the methane levels is not related to atmospheric pressure fluctuations. The scatter could possibly have been induced by ventilation conditions prevailing around the monitoring unit or by the normal workings of the colliery. Daily methane level trends observed, on the other hand, seem to be linked to barometric pressure variations. The erratic behavior of the scatter values of the recorded methane levels makes it difficult to distinguish any definite relation between barometric pressure fluctuations and variations in methane levels.

Several initial methods were attempted to analyse the recorded data with the first effort attempting to fit polynomial curves of increasingly higher order to both the methane and the atmospheric pressure curves, however limited success was obtained.

Some success was achieved with an attempt to fit a sinusoidal curve to the methane curve, but any sudden drops in methane concentrations rendered this method inappropriate for long term analysis.

Smoothing of curves was also attempted in order to try and eliminate the scatter present on the curves, but no positive results were achieved.

A more simplistic approach to eliminate the scatter was taken by determining the magnitude of the fluctuations from reading to reading for both the atmospheric pressure and the methane curves. From these values, an arbitrary lower limit was identified for each data set, below which any variation was regarded as scatter. The two sets of modified data were then plotted against the same time axis.

Only the data for the first test showed any correlation. Over a 10 day period five incidents of definite barometric pressure variation were recorded, and for each incident a corresponding methane incident was recorded. No significant correlation could be found for the remainder of the recorded data, a reason for this might be the fact that the fluctuations in the barometric pressure levels recorded, during these tests, were much lower than for the first test.

Stripp<sup>1</sup> suggests that natural barometric pressure fluctuations have a relatively insignificant effect on methane monitored, and that fan stoppages have a far more significant influence on underground barometric pressure fluctuations than natural causes. The starting of a fan, inducing a drop in underground barometric pressure, was found to increase methane levels. He also suggests it is not so much the range of the barometric pressure variations which influences the level of methane in the workings, but the time span over which they take place. He further refers to the sympathetic relation between variations in atmospheric pressure and methane emission from gas reservoirs at, or near, atmospheric pressure, and suggests that the gas ingress associated with the fan stoppage incidents originated from gas reservoirs of this type.

Van Zyl (Appendix D2) made an analysis of the relation between barometric pressure fluctuations and gas related incidents. He identified, from the available data, that the most likely situation for a methane related incident to occur was during a diurnal pressure drop, coinciding with a period of decreasing daily barometric pressure. It was also identified that the most likely time for an incident to occur during these conditions was between 09H00 and 15H00. These findings are in line with the observed trends, but do not prove or quantify the relationship



### 5.2.2 Conclusion

With the limited data available it is difficult to quantify the atmospheric pressure fluctuations which will induce variations in methane levels, and to then quantify these variations. The fact that there seems to be a link between general barometric pressure behaviour and methane levels is evident. It appears from this initial analysis that a sudden decrease in barometric pressure can cause a substantial increase in methane levels, and the inverse also seems to hold true with indications that the process is time dependant. In one of the tests a pressure variation of 0.2 kPa within 15 minutes induced a marked increase in methane, far exceeding the levels of the surrounding scatter values. It has to be noted that this phenomenon was observed during a test when the barometric pressure fluctuations were much more substantial than for the other sets of data. The site of these readings was only used once, so it is impossible, at this stage, to say if the increased fluctuations can in any way be linked to the location in the colliery.

With the aid of a broader database and more detailed statistical and mathematical analysis the effect of scatter might be identified and minimized, with the result that trends might be identified. Long term monitoring can give an indication of the effect of seasonal changes on general methane levels in a colliery.

The use of multiple monitoring systems in a colliery is recommended, as it will ensure a more complete data set for analysis. The use of multiple monitoring systems will also allow a more accurate study to be made of the origin/s of the methane responsible for level increases and spikes. The origin and nature of the scatter recorded can then also be more clearly identified and evaluated. The site specific nature of barometric pressure fluctuations, which was hinted at during the test period but could not be verified, can then also be identified.

For further information refer to Appendix D3.

## 6. Quantify the benefits of methane drainage

### 6.1 Monitor and model SA underground and surface drainage systems

#### 6.1.1 General overview of drainage systems

Methane drainage is practised worldwide by the coal mining industry, principally to improve safety by reducing seam methane emissions into workings, but also as a related or independent commercial venture. Drainage is, generally, carried out where seam gas contents and emission rates make standard ventilation techniques inadequate or impractical. The criteria, used to determine when drainage becomes necessary, range from the simple application of seam contents to the simultaneous application of several different parameters.

All currently practised methane drainage designs rely on the drilling of boreholes, implemented either from the surface or underground. Underground drainage is normally applied in the case of deeper seams, where drilling from surface is not economical, or to less extensive blocks of ground when time is limited. Surface drilling schemes are usually employed over longer periods of time, often several years, ahead of mining operations, and cover much larger areas, with borehole centres hundreds of metres apart.

#### 6.1.2 The South African perspective

In South Africa, the use of both methods has been very limited and, hence, little information is available on their respective effectiveness. The reason for the scarcity of drainage implementation in South African collieries is largely due to the properties of the coal and the average seam depths. Although sorption potentials of local coals are of comparable order to foreign coal deposits, to which methane drainage designs have been successfully applied, major differences are found in their respective diffusive properties and seam pressures. Generally, South African coals have lower diffusive properties, and correspondingly lower methane release rates. In conjunction with this are the relatively shallow seam depths, typically about 100m, and commensurately lower in-seam gas pressures, and, hence, the lower methane contents. Finally, the small amount of work done locally to determine *in situ* coal permeabilities indicates that South African coals are significantly less permeable than their foreign counterparts.

The maximum in-seam pressure measured in South Africa is in the region of 1,6 MPa at 300 m, compared with pressures as high as 8,3 MPa at depths of 729 m measured in China. Seam gas contents for South African coals, determined from adsorption and in-seam pressure tests, range up to a probable maximum of 10m<sup>3</sup>/t, but can be expected to be about 4m<sup>3</sup>/t on average. These values are not dissimilar to other coal seams at similar depths, but values as high as 30m<sup>3</sup>/t have been recorded for mines operating at deeper levels. Furthermore, the volumetric flows recorded in South African collieries from boreholes (73 to 922m<sup>3</sup>/m/y) are well below the rates recorded for deeper mines in other countries (1187 to 9513m<sup>3</sup>/m/y), where methane drainage is viable. These flow rate differences are most probably a direct consequence of South African coals exhibiting lower diffusive rates and less permeability.

### **6.1.3 Conclusion**

The limited information that is available on drainage rates, seam pressures, contents and physical properties suggests that methane drainage may not be as successful in South African coal mines as it is elsewhere if practised in the same way. This does not mean it should be discarded as an option to reduce the methane hazard, since there may well be local benefits if a suitable drainage method or adaptation of one could be realised. It may not be financially feasible to reduce borehole spacings to the extent where methane depletion rates are sufficiently rapid, but at the same time it must be mentioned that no performance figures for long-term surface drainage boreholes are available. Any drainage carried out should be closely monitored for yield rate, gas composition and usable life in order to expand the currently limited drainage database.

A decision was taken at an early stage of project COL030, to integrate methane drainage with the methane emission prediction work of output 2 of the same project. A shortage of suitably qualified personnel and the realisation that the mechanisms involved in drainage are essentially the same as those for methane emission, were the essential reasons for this decision. On completion, the emission prediction model will enable models to be put forward that can determine the optimum placement of boreholes given various input parameters of the coal field and the required outputs of the system. This will allow a more extensive and economical study to be made of the viability of methane drainage schemes, especially as it appears that such schemes might be site specific.

Refer to Appendices E1 and E3.

## **6.2 Develop network designs and drainage guidelines**

So far the limited success of methane drainage, as applied in South African collieries, and the lack of extensive and comprehensive data on the performance of methane drainage instances, renders it very difficult to formulate reliable guidelines for drainage networks. The mathematical methane behaviour simulation model, ie. output 2 of this project, has the ability to model drainage networks. This facility will allow drainage network designs to be optimised from the point of view of borehole placing, spacing, orientation, and length. Standard foreign layouts can be used as starting points.

It is likely that the ideal drainage layout for a specific location is unique to that location, and from this perspective it becomes even more difficult to prepare a set of design principles which caters for the wide variety of coal conditions found in South Africa. By modelling a potential drainage implementation, an indication of the in-seam methane behaviour is obtained, and this information readily allows the identification of design flaws or potential design improvements. Such modelling also permits the short, medium and long term drainage network behaviour to be predicted, which allows further enhancements to be made to the system.

Irrespective of the preceding considerations, however, it is clear that an adequate and quantitative appreciation of the dependence of methane emission rate on location, geometry, geology and physical properties, such as permeability, diffusion coefficient and sorptive parameters, is essential to devise reliable drainage guidelines. A single criterion, such as in-seam methane content, on its

own is insufficient to determine whether or not drainage is required in a given situation. The mathematical model encapsulates these interdependencies, and, if correctly applied, can constitute a reliable drainage information source.

For further information refer to Appendix E2.

## **7. Quantify the hazards at Secunda mines due to the presence of other gases and gas migration**

### **7.1 Quantify the effect of other gases on the ignition of methane**

#### **7.1.1 Scope of work**

Methane gas in the explosive range is a coal mining hazard which is not accompanied by readily detectable warning signs. Efforts to reduce the methane hazard in the mining industry focus on three main areas, ie detection and quantifying of methane in the underground environment (eg. via methanometers), dilution of the methane to below its explosive range (eg. by supplying sufficient ventilating air), and, lastly, the removal of all possible ignition sources (eg. by making electrical equipment intrinsically safe or flameproof and barring flammable materials from the underground environment). Despite these measures methane ignitions still occur.

This can either be due to the fact that the required precautionary measures are not implemented correctly, or that the precautionary methods are in certain instances inadequate to the task of eliminating the hazard. The latter indicates a possible deficiency in the current understanding of methane behaviour in a coal mining situation. For this reason, Sasol decided to reinvestigate basic methane associated topics, specifically relating to their Secunda mines. The first phase in this investigation was to study the gas itself, and its occurrences, and, consequently, the human factors which might promote the occurrence of methane ignitions.

The departure point for the first phase of the study was to investigate methane incidents which had occurred at the Secunda mines, in an attempt to establish whether any common factors, or distinct differences, regarding location, time and geographical features could be identified. The study was undertaken by Sasol Mining, Coal Division, in order to identify regions where incidents were most likely to occur. This information would then be useful in distinguishing sites at which the local atmosphere could be analysed in an effort to identify common elements.

#### **7.1.2 Results and findings**

There were significant differences in the specifics of methane incidents in the different geographical areas of the currently mined Secunda field. Geographical and geological features alone could not satisfactorily explain these differences, and no unambiguous relationship between principal mining direction and methane incident frequency was found. Methane incidents were relatively low in frequency and occurred sporadically over the whole coal field, with most of the incidents clustered around geological disturbances, eg. dykes and slips, except in the south east region. Time and location studies did not reveal any well developed tendencies either.

Following the results of the incident studies, it was decided that efforts would be concentrated on the development of the multi-channel methane monitoring system (MMMS), ie. output 1 of this project. The development of the MMMS would allow more complete methane monitoring to be done in an active heading, where the majority of methane ignitions occur, which could lead to a reduction of such incidents. This redefinition of the output was done with the approval of the Collieries Environmental Engineering Advisory Group, memorandum 17/94, dated 12 August 1994.

For further information refer to Appendix F1.

## **7.2 Identify gas sources and migration patterns**

The origin of natural gas is closely related to the diagenetic and thermal alteration of organic matter. Bacterial processes produce methane during early stages of diagenesis (coalification), whereas increasing thermal maturation of organic matter produces both methane and C<sub>2</sub> to C<sub>5</sub> hydrocarbons.

Likewise, the relative isotopic occurrence of both C<sup>13</sup> (Carbon 13) to C<sup>12</sup>, and D (deuterium) to H (hydrogen) in the methane molecules indicates the source from which the CH<sub>4</sub> has been derived, as well as the degree of maturation.

The main object of the study was to determine the origin of the gas and to establish whether or not this information could be applied to predict gas occurrences within the mining environment.

Samples from boreholes were taken according to standard CSIR procedures and analysed by the CSIR and Atomic Energy Corporation. The samples were analysed by gas chromatography, and the composition of one sample from each borehole confirmed by spectroscopy.

The analyses indicated the methane in the coal seams within the Secunda mines has mainly been derived from in situ biogenic processes during coalification and has been influenced by local intrusions. The methane gas will, therefore, be ubiquitous through the coal with higher concentrations near dolerite intrusions. From the results it is unlikely the methane has migrated from the underlying Witwatersrand Group.

For further information refer to Appendices F2 and F3.