A Proposed New Method to Determine the Effectiveness of In-Heading Methane Control

F.J. van Zyl
CSIR Miningtek
Johannesburg
South Africa

ABSTRACT

Various methods have been derived to determine the effectiveness with which ventilation systems clears headings of methane in a bord-and-pillar sections. A problem with applying these methods in underground sections is that the either require the face-area air quantity to be measured, which is virtually impossible in South African collieries, or they were developed for test galleries, making it difficult to use in production sections.

Taking this into consideration the methane safety index (MSI) method was developed. The method utilizes methane data recorded around an active continuous miner (CM) and an activity log of cm operations to quantitatively asses methane control. Factors used includes methane levels, trends in peak values and regulatory safety levels. With the aid of a spreadsheet a single number is calculated describing the methane clearing ability of a ventilation system.

Advantages of MSI method is that there are three fixed and discrete categories of values, making interpretation easy. The method will also give reliable feedback were low methane levels are present and can be used to quantitatively asses how well a ventilation system coping with the methane load.

KEYWORDS

In-Situ Methane Monitoring, Continuous Miners, Methane Control Efficiency, and Methane Safety Index.

INTRODUCTION

The presence of methane gas (firedamp) in coal seams has been a thorn in the side of mining operators since the beginning of underground mining operations. The first documented occurrences of methane/air explosions stretch as far back as the mid 1500s when Georgius Agricola related the explosive power of methane and air 'to the fiery blast of a dragon's breath' (McPherson, 1993).

Even in these early times it was observed that the best way to reduce the risk of firedamp explosions in underground workings was to use air movement, i.e., ventilation. This fact still applies today (Divers and Jayaraman, 1982). Ventilation techniques have come a long way since the early ventilating furnace's and manually operated bellows' used, ending up with the electric fans used today.

Modern fans are capable of moving the large amounts of air required to dilute the increased methane quantities, liberated form modern continuous miner (CM) sections, to below the lower explosive limit (LEL) of methane in air. But explosion at the working face still occur. A possible cause of this can be that the applied ventilation system does not effectively remove methane form the cutting face.

BACKGROUND

For a system to be effective it must have a definite and desired effect. Therefore, to quantify the effectiveness of a face ventilation system it is necessary to relate the methane dilution achieved to the amount of air being supplied (input) for dilution purposes. This sounds very simple, but to apply it in a production section is difficult, due the simple fact that it impossible to determine the methane released form the cutting face. This makes it impossible to determine the methane dilution, and hence the system effectiveness.

To get an indication of the effectiveness of underground ventilation systems in bord-and-pillar production sections, surface test galleries were built to statically simulate underground conditions (Kissel, *et al.*, 1986; Rider, *et al.*, 1997). In this controlled environment the methane release could be controlled, and hence an effectiveness be calculated. Due to the dynamic conditions encountered underground, and other numerous variables that can influence airflow patterns, hence methane control, the results from such tests has to be treated with the necessary respect.

The index developed form these tests, i.e., the face ventilation effectiveness (FVE) index, were adapted for South African underground conditions with limited success achieved (Van Zyl, *et al.*, 1998).

Various other methods were also investigated, i.e., methane dilution capacity (MD) (Campbell and Dupree, 1990), face ventilation index (FVI) (Haney, *et al.*, 1995), and face ventilation measurement (FVM) (Vinson, *et al.*, 1980). These methods all require that the airflow conditions near the face be monitored. In underground sections, this quantity is difficult to monitor due to the high concentrations of water droplets from the water spray systems commonly used.

PROBLEM

From the above discussion it is apparent that there is no system or index available that can be applied in South African collieries to accurately quantify the effectiveness with which a ventilation system clears a cutting face from methane in a bord-and-pillar section.

Previous methods either simplify the problem so that the normal dynamic conditions in a heading is neglected, or requires quantities to be measured which is impossible, or difficult to measure in a production section.

As the methane hazard is a very real and constant threat, a method had to be found which would give an accurate, quantitative indication of methane control at the cutting face of a CM heading.

OBJECTIVES OF NEW METHOD

Before a solution can be found it is necessary to clearly state the objectives of such a method. In essence the new method must be able to provide a single index indicating to the effectiveness with which an applied ventilation system clears the liberated methane in an active CM heading i.e. quantify the methane hazard.

To optimize the use of such an index, there are some criteria that it has to comply with.

- Method must be universally applicable.
- Results must be simple to interpret.
- Results must be able to be used in a comparative manner.
- Results must be reliable.
- Application of the method must be easy.

By using the above set of criteria, a new method was developed to quantitatively evaluate the effectiveness with which a ventilation system controls methane in an active CM heading.

BASIS OF METHANE SAFETY INDEX (MSI)

CSIR Miningtek developed a multi-channel methane logger unit to monitor methane levels around an active CM (Cook, 1995). From the numerous data sets obtained several similar trends were observed, i.e. ;

- methane levels around the CM dramatically increases when the CM starts mining,
- the methane levels in this region consists of a distinctive series of peaks and lows (Cook, 1995, Campbell and Dupree, 1990),
- the methane levels in the cutting drum area is generally the highest (Van Zyl, 1995),
- in some cases the peaks have a tendency to increase as a CM advances into a heading.

Taking this into account the MSI method was developed. The MSI method takes the actual methane levels recorded, and the trends observed, and combines it into a single, easy to interpret number, which clearly quantify how well a ventilation system is coping with the methane "load" in a specific heading.

DATA ACQUISITION

Zone Identification

From the observations made it is clear that the critical part of methane control in a section is when the CM is cutting. Also, it is self evident that the geometry of the section and mining machine movement will significantly affect airflow patterns, and hence methane behavior. These two aspects are very dynamic and to a large extent fairly random.

The first step in applying the MSI method is to simplify the problem. To do this, three criteria points needs to be satisfied i.e. ;

1. the CM must be cutting,
2. the heading geometry must remain fairly constant, and,
3. machine movement must be at a minimum.

The answer is found in the cutting sequence. During the development of a heading a specific cutting sequence is generally used, consisting of series of organized cuts that is repeated from heading to heading to advance a section. During each cut the heading geometry is approximately the same and random machine movement is restricted. Another aspect that should also remain fairly consistent is the ventilation conditions, as a ventilation protocol must be followed, dictating ventilation system setups for a specific condition.

Taking this into consideration, a typical heading development is now divided into number of basic recurring zones. Each of these zones will have predominantly the same geometry, machine movements and ventilation conditions, making it ideal for the evaluation methane control. Hence these cutting sequence related zones are defined as fixed, and will be used as "units" to determine overall ventilation effectiveness of a section. For demonstration purposes a imaginary cutting sequence is shown in Figure 1.

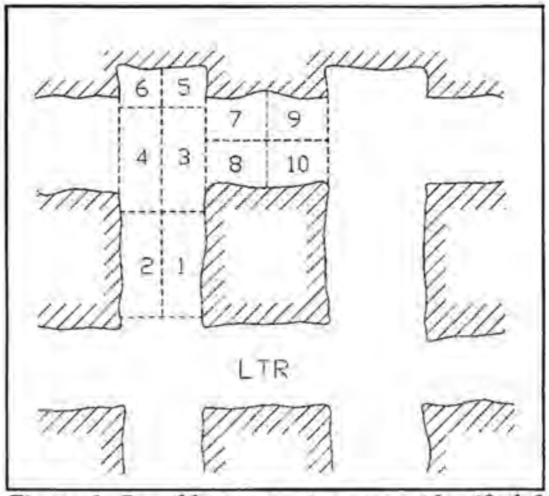

Figure 1. Possible ten cutting zones identified for methane evaluation.

Methane Monitoring Procedure

It has been found that the highest methane levels recorded during cutting operations around a CM is in the region of the cutter head (Van Zyl, 1995). With the presence of a possible ignition source in this region, in the form of picks, the drum area can be considered to be high risk area for methane ignitions. Adding to the risk is the fact this is the deepest point to which the ventilation must "reach" to control the liberated methane. So it is essential that methane levels be recorded in this region.

For certain conditions re-circulation can cause methane levels to increase at the rear of a CM, and for this reason methane levels must also be monitored in this region.

Methane levels are monitored every 10s and recorded on a data logger against a real time clock. This information is downloaded into a standard spread sheet program.

In conjunction with the methane monitoring, a time study is conducted to monitor CM location and movement. This is done to allow for the relevant methane data to be extracted from the total data set i.e. when the CM is cutting a zone.

DATA PREPARATION

Before the MSI method can be applied, the methane data has to be prepared in a format that will allow the MSI method to produce accurate, and universally comparable results. All data organization is done with aid of standard spread sheet program features, i.e., MAX VALUE, LOGIC FUNCTIONS & TREND LINE.

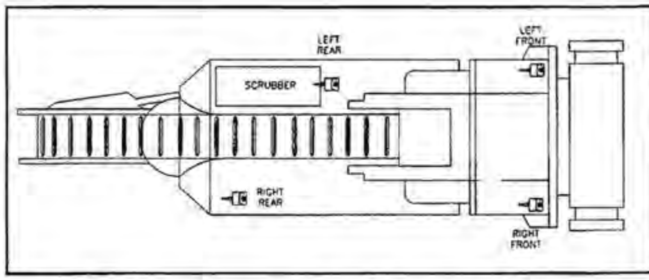

Figure 2. Typical monitoring positions on a CM.

Isolating Zone Specific Data

The first step in the data preparation is to extract the cutting only data for a specific zone using the time study. This data is pasted to spread sheet and will be analyzed independently.

Methane Data Preparation

The main of ventilation is to keep methane levels below the lower explosive limit (LEL). By investigating the maximum methane levels recorded, an indication of how well this is being done can be obtained. Hence, for each time interval, the maximum methane reading of the four sensors is identified, and used for subsequent analyzes.

To be able to compare calculated MSI values from different sections directly, the recorded methane levels are normalized with regard to the colliery or statutory maximum allowable methane level applicable for that section.

$$\text{Norm. } CH_4 \text{ Level} = \frac{\text{Re c. } CH_4 \text{ Level}}{\text{Max. Allow Level}} \qquad (1)$$

This will result in a single line graph of normalized maximum methane level vs. time, depicting the methane behavior during the cutting of the zone.

Average Advance Rate Determination

As it will be easier to interpret the data when it is related to the position of the CM in the zone, rather than the time it was recorded, the average advance rate of the CM during the cut is calculated. This done by taking the total distance cut, and dividing it by the cutting time required to achieve this. By using the average advance rate the time related data can be converted to distance advanced into the zone.

$$\text{Avg. Advance Rate} = \frac{\text{Distance Cut}}{\text{Cutting Time}} \ [\text{m/s}] \qquad (2)$$

To compare the MSI values directly between various sites, the differences in maximum advance distances per heading must be addressed. This is done by normalizing the distance advanced to the maximum allowable cutting depth per zone.

$$\text{Normalized Distance Cut} = \frac{\text{Distance Advanced}}{\text{Allowable Cut Depth}} \qquad (3)$$

A plot is then made of the normalized methane data vs. the normalized distance cut into the zone.

Peak Value Isolation

As noted before, a series of definite peaks and lows can be associated with each zone data set. As the aim of ventilation system is to keep methane levels below the LEL of methane in air, again, it is the peaks that is of concern. To reduce the effect the lows can have on the index, potentially giving an overestimation of the ventilation effectiveness, all peak values in the normalized methane data are identified and isolated. A value is deemed to be a peak value if the value immediately preceding it and following it has value lower than itself. These peaks are used for the final calculations.

MSI CALCULATION

The MSI is now calculated by using the identified peak value points on the normalized methane level vs. normalized distance cut curve.

A straight line trend is now fitted to the identified peak values. The equation describing the straight line will be of the form;

$$y = mx + c \qquad (4)$$

where:

- y = normalized methane level
- m = gradient of peak methane level increase/decrease
- x = normalized distance cut into the zone
- c = theoretical initial peak normalized methane level.

From this equation there are two properties that have to be taken into account when the efficiency of the ventilation system is to be calculated. They are the gradient (m) or rate of methane increase/decrease and the theoretical initial peak normalized methane level (c).

The gradient gives an indication of methane buildup/reduction in the zone as the CM advances and the theoretical initial normalized methane level will reflect the background levels present in the ventilation air, which potentially reduces the effectiveness of the ventilation setup.

These two quantities now have to be combined in such a way that a single number will accurately quantify the ventilation efficiency.

The first step is to determine the maximum allowable gradient from the initial normalized methane level that will result in a maximum normalized methane level of 1, being reached at the completion of the zone. This gradient is the gradient that will result in the peak levels at the end of the zone to be equal to the maximum allowable limit.

$$\text{Max. Allow. Grad.} = \frac{1 - c}{\text{Max. Norm. Advance Dist.}} \qquad (5)$$

The maximum normalized advance distance is usually equal to one. This equation is only valid for values of $c < 1$. For values of $c \geq 1$ the ventilation conditions in the mine is unacceptable as mining operation starts in air containing methane levels above the legal limit.

Once the allowable methane gradient has been determined the methane safety index (MSI) for the zone can be determined.

$$MSI_{ZONE} = \frac{m}{\text{Allow. Grad.}} \qquad (6)$$

This equation gives the MSI for a specific zone.

The MSI for each zone is determined in this manner. From this data the section MSI is defined as the maximum MSI calculated for the identified zones in the section. The section MSI will relate to the worst ventilation conditions in the section, and hence the possibility of an ignition occurring.

$$MSI_{SECT.} = MAX(MSI_{zi}) \ \text{for } zi = 1,2,3\ldots6 \qquad (7)$$

The MSI method takes both the actual methane levels and the gradient of increase or decrease into account and combines them into to one relevant number. This number quantitatively relates the methane conditions in a section, and can be used on its own to quantitatively determine if methane conditions in a section is dangerous or not.

MSI RANGES

Because the MSI method makes use of normalized quantities in its calculation, there is a fixed set of ranges, each having its own specific meaning. These are as follows;

$MSI \leq 0$

MSI values below zero indicates that the methane levels is decreasing as the CM advances into the zone. This is possible but unlikely, as it means that the initial methane levels are being reduced although methane liberation is increased. If this is the case it is always advisable to check the data and the recording instrumentation.

$0 < MSI \leq 1$

In this range the ventilation is coping with the methane load and will stay with in legal limits for the duration of the cut. The closer the MSI value is to zero, the better the ventilation conditions with regard methane control. As the value approaches one it is advisable to check the ventilation conditions as the margin for coping with unforeseen methane liberation increases or ventilation system problems reduces.

$1 \leq MSI < 3{,}5$

In this range the ventilation setup is not coping with the methane load during the cutting cycle. A MSI value of above one indicates that the peak methane levels will not be within legal limits and at some stage during the cutting of the zone.

$MSI \geq 3{,}5$

A value of 3,5 indicates that the peak methane levels during the cut is close to the LEL of methane in air (5% by volume). In this case urgent action needs to be taken to improve the ventilation conditions. In this range operations must be stopped immediately as the CM will at some time operate in an explosive atmosphere during the duration of the cutting.

CASE STUDIES

To demonstrate the new method, three zones were analyzed according to the new method. The scenarios were selected from the available data to determine if the MSI method would be able to reflect the differences in recorded methane levels for various heading setups and ventilation conditions.

Scenario 1

For this scenario the CM was cutting zone three (refer to Figure 1). For this specific scenario, the CM was closed on both sides by the seam as it advanced into the zone i.e. closed cut. The CM was fitted with a 9,0 m^3/s scrubber unit and a floor level jet fan was used to assist the ventilation (Figure 3). A total of 16 meters were cut during the monitoring period.

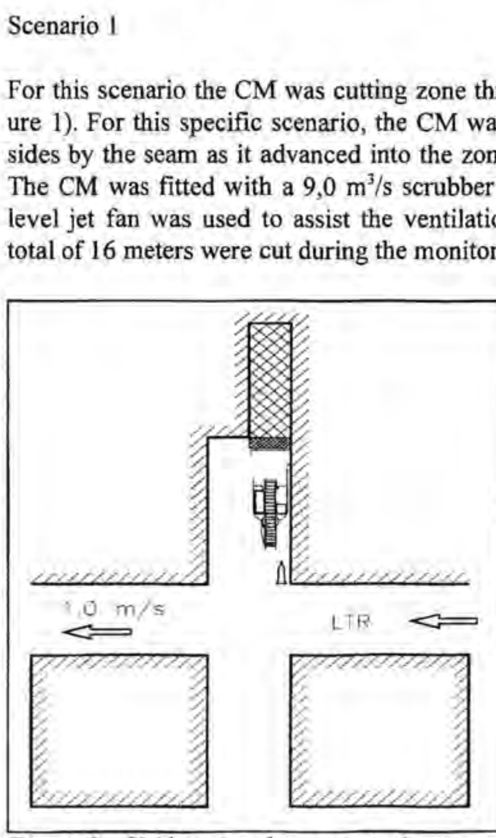

Figure 3. CM location for scenario 1.

Low initial levels were recorded, 0,15% methane, with a steady increase monitored by the front sensors, as the CM advanced in to the closed heading, reaching peaks of 0,45% methane towards the end of the cut. These levels were recorded at a depth of 32 meters from the last through road (LTR) (Figure 4).

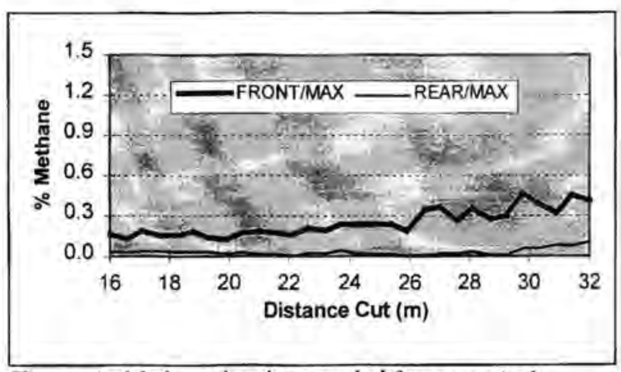

Figure 4. Methane levels recorded for scenario 1.

A MSI value of 0,40 was calculated for this scenario, indicating that the ventilation setup is capable of handling the methane liberated during cutting.

At the end of the cut, at a full depth of 32 meters, the peak values recorded are in the region 0,46% methane, and well below the legal limit of 1,4% methane applicable to this colliery. This indicates that the ventilation setup is able to cope with the methane liberation with ease. This is well reflected in the MSI value of 0,40.

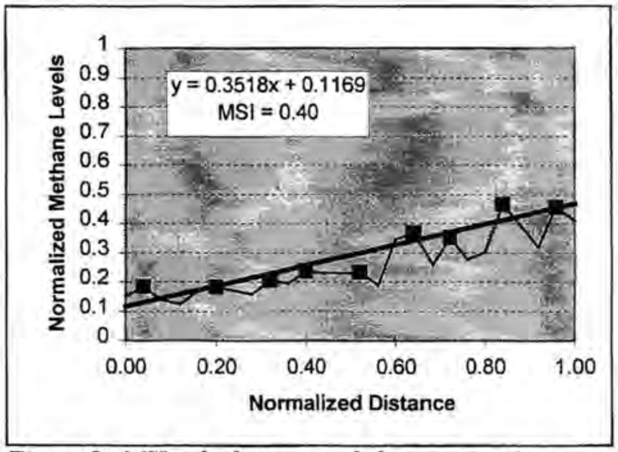

Figure 5. MSI calculation graph for scenario 1.

Scenario 2

For scenarios two and three split conditions were monitored. During the cutting operations a force column (4,0 m^3/s) and exhaust column (9,0 m^3/s) were used to ventilate the heading. The CM did not have a scrubber unit. For the monitoring period of scenario two the CM was busy cutting zone eight as a closed cut (Figure 6).

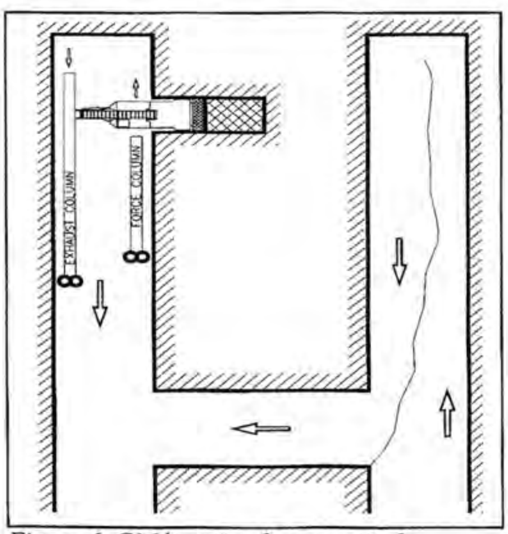

Figure 6. CM location for scenario 2.

Initial methane levels recorded were in the region of 0,30%, with a distinct rise in peaks as the CM advanced into the cut. The peak methane level recorded during the cut was just below 1,4% methane (Figure 7). This rise is due to the CM advancing into a closed cut and subsequently getting more isolated from the auxiliary ventilation. Over the first five meters the CM is predominantly in the main ventilation stream and hence the peaks levels remain relatively constant. Beyond this point the peaks show a definite increase in methane levels and reaches its maximum towards the end of the cut. The cut terminated after approximately nine meters were cut.

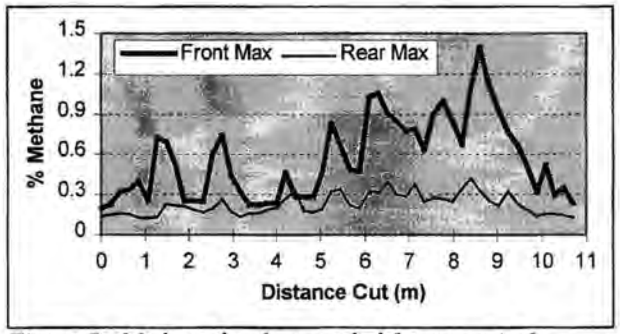

Figure 7. Methane levels recorded for scenario 2.

A MSI value of 0,94 was calculated for this scenario and is close to the cutoff point of 1. This value corresponds well with the methane levels recorded and its observed behavior as the maximum levels recorded during the cut nearly reached the maximum allowable level of 1,4%.

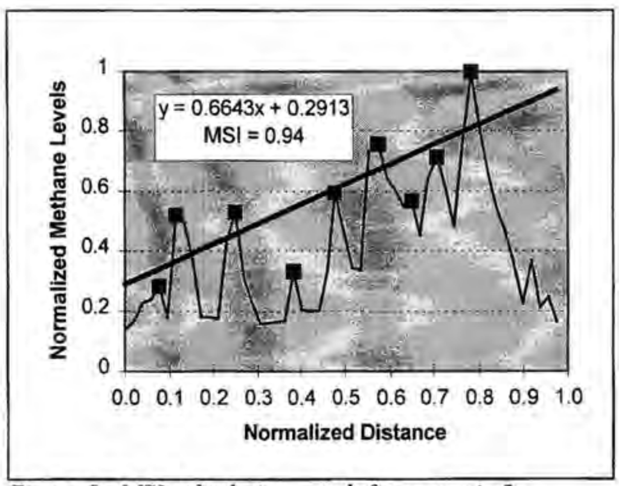

Figure 8. MSI calculation graph for scenario 2.

A value of 0,94 indicates that the ventilation is adequate to handle the current methane release from the cutting process, but that the margin to cope with unforeseen increases of methane or alterations in ventilation conditions was very small.

Scenario 3

For this scenario zone nine was cut. It was an open cut with ventilation around the CM well established. This was done by pointing the force column around the corner, and setting up a brattice in the intake road to allow ventilation to flow past the CM.

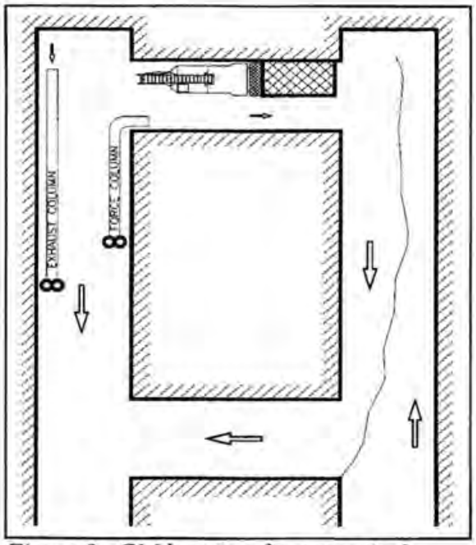

Figure 9. CM location for scenario 3.

Initial levels recorded around then CM were in the region of 0,20%. An increase in methane levels are observed but not as pronounced as the increase observed in the last six meters of scenario two. The peaks are generally in the region of 0,6% to 0,7% with an out of trend of 0,96% observed at the end of the cut.

For the scenario a MSI value of 0,23 was calculated. This indicates that the ventilation setup is capable of diluting the desorbed methane sufficiently to within acceptable limits. The relatively low MSI value also indicates that the ventilation setup can deal for unforeseen methane increases as can be seen at the end of the cut. An out of trend methane level of 0,96% was recorded towards the end of the cut. The ventilation setup was able to reduce this level by 10% in the ten seconds it took to take the next reading, indicating that the ventilation is removing the excess methane from the "burst".

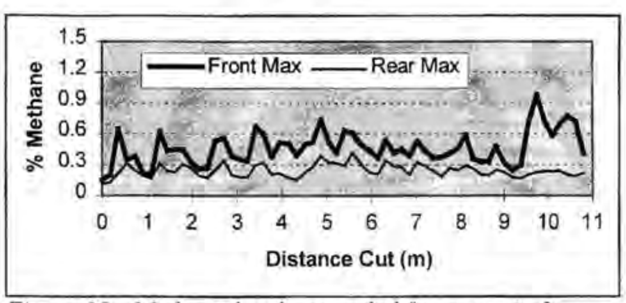

Figure 10. Methane levels recorded for scenario 3.

As the CM is constantly exposed to continuous airflow past it, it could be expected that the methane levels around the CM should stay fairly constant. This is indeed the case if we look at the recorded methane levels. In a scenario like this the main value that will influence the MSI index is the general methane peaks recorded which is in the region of 0,6% to 0,7%. Taking the slight increase over the length of the cut into consideration a MSI value of 0,4 is a reasonable reflection of the methane levels observed as the general peaks is just below half the allowable limit of 1,4%.

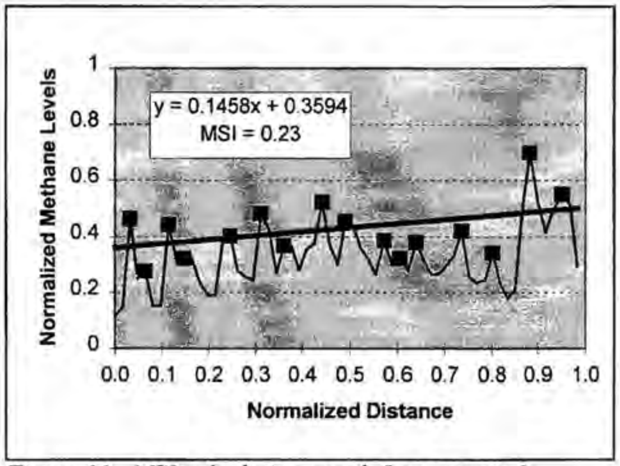

Figure 11. MSI calculation graph for scenario 3.

DISCUSSION

By applying the MSI to various mining conditions it was possible to generate a single number that fairly accurately describes the methane behavior for the zones investigated. The single number takes into account the general methane levels recorded during the cutting operation, the rate of increase of methane in the heading over the cut, and the allowable maximum levels and depths for the section. Interpretation of the results is also easy as a ventilation system is deemed adequate if the MSI is below one, and inadequate if the value is above one. The closer the MSI value is to zero the better the ventilation setup. Hence by relating the MSI to the value of one and zero, an indication of how effective or ineffective the ventilation system is can be obtained.

Both scenario one and two are closed cuts. By looking at the zones cut (Figures 3 & 6), it would appear that scenario two should have better methane control. This is due to the fact that for this the CM is closer to LTR ventilation, and it does not have to cut in that deep, (9 meters), when compared to scenario one, (16 meters). Despite this the MSI for scenario two is more than 50% higher than that for scenario one. The reason is attributable to the placing of the auxiliary ventilation equipment. For scenario two the force column is blowing across the entry to the heading. For the first four meters the heading is reasonably ventilated, and the methane peaks remains fairly constant. Past this point the methane peaks increase sharply as the force column effectively "isolates" the cutting face form the ventilation, significantly reducing the dilution of liberated methane. For scenario one on the other hand, the auxiliary ventilation is directed into the heading, assisting the methane clearing process from the beginning of the cut, reflected in the steady increase in methane peaks over the duration of the cut. Although there is an increase in peaks, the combination of the auxiliary ventilation position and maximum allowable mining depth per cut working together, ensures that this setup is capable of handling the methane load. In scenario two however the auxiliary ventilation setup isolates the face from the ventilation, introducing possible dangerous conditions, and is reflected in the MSI value.

For scenario one a MSI of 0,40 was calculated and for scenario three 0,23. For scenario three the peaks recorded are generally 45% higher than the maximum level recorded during scenario one. Despite this the MSI for scenario three is nearly 50% lower than for scenario one. This due to the fact that for the duration of the cutting of zone nine there is a more consistent ventilation flow pattern over the CM. This results in no significant increases in the peaks recorded, and hence a lower MSI value. In theory this would mean that scenario three has a more stable ventilation setup and would be more capable to deal with unforeseen circumstances, as can be seen from the dilution of the peak at the end of the cut. From this it can be seen that the MSI value is not only capable of indicating if a ventilation system is effective, but can also be used to indicate how effective it is.

The MSI method has been tested on numerous occasions and has always accurately reflected the true methane conditions in the heading. From these brief examples it is clear that the MSI show promising potential to accurately quantitatively describe the methane conditions in a heading with a single number.

CONCLUSIONS

- The MSI can be successfully utilized to quantitatively asses how effective methane is being controlled in any given production heading.
- The results are easy to interpret. This done by basing the index on an ideal value of zero and an acceptable value of one. Despite the simplicity in interpretation, the MSI value can also be used to determine "how good" the ventilation system is performing. This can be used to determine how tolerant the system will be with regard to unforeseen circumstances, i.e. ventilation changes, increased methane liberation rates etc.
- The MSI value is easy to calculate. Only the methane levels around the CM is required over time and a time study of CM actions. The MSI value can be determined with ease with the use of a standard personal computer and spreadsheet program.
- The MSI will give a true reflection of the methane conditions in a heading. The accuracy of the method depends on the accuracy of the actual methane levels recorded *in situ*.
- In headings were methane levels are low (< 0,4% methane in air), and typical pellistor type methane sensors accuracy's are in question, the MSI value will still give a true reflection of methane conditions. The reason for this is that the MSI method use the absolute methane levels recorded to determine the control efficiency, and hence for levels below 0,4% the MSI value will be very close to zero, indicating that the methane hazard is well under control.
- By normalizing the data with regard to the standards described for a particular section, or an ideal benchmark section, the results from various sections can be directly compared.

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