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Operational Considerations for Tube Bundle Gas Monitoring Systems

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OPERATIONAL CONSIDERATIONS FOR TUBE BUNDLE GAS MONITORING SYSTEMS

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ABSTRACT: Tube bundle gas monitoring systems are now common practice in the Australian underground coal mining industry. Systems are in operation at all underground coal mines in Queensland, all longwall coal mines in New South Wales, and most bord and pillar coal mines in New South Wales. This paper utilises the information assessed by Simtars as part of the project "The Application of Tube Bundle Systems in the Prevention of Mine Fires and Explosions and Post-Event Response", prepared for the National Institute for Occupational Safety and Health (NIOSH), under contract number 200-2013-56949. The operational considerations and decisions required to ensure the optimum operation of the system will be outlined. Installation, maintenance, training requirements, alarm settings and interpretation of the gas results will be taken into account. Practical solutions and explanations will be provided, drawing on Australian and overseas experience, as well as information publicised by the National Coal Board in the United Kingdom and the United States Bureau of Mines (USBM).

INTRODUCTION

Simtars conducted an investigation called "The Application of Tube Bundle Systems in the Prevention of Mine Fires and Explosions and Post-Event Response", prepared for the National Institute for Occupational Safety and Health (NIOSH), under contract number 200-2013-56949. This work involved a review of the history of the development of tube bundle systems and covers any legislative requirements and practical aspects of operating tube bundle systems. This paper utilises the information that was collected as a result of that investigation as well as the operational experiences of Simtars staff. The paper discusses the operational requirements for tube bundle installations, system maintenance requirements and provides recommendations for the optimisation of site systems. Training requirements for maintenance and software operation are also presented, including the review of alarm settings with the utilisation of valid trigger action response plans.

Early developments and background

Chamberlain (1970) describes the early introduction of tube bundle systems for the monitoring of longwall goaves (gobs) on advancing longwalls in the United Kingdom (UK). He identified that the technology was developed in Germany by Dr Luft of Bergbau-Forschung Essen and the equipment was manufactured by Maihak. The initial use of the systems was in an underground application where the analyser was housed in a flame proof enclosure and the results telemetered to the surface through colliery communication systems. These systems had been used in the Saar region of Germany and in Scotland.

Detection is based on the principle that gases such as carbon monoxide (CO), carbon dioxide (CO2) and methane (CH4) all absorb certain wavelengths of infrared radiation (Chamberlain 1970). This is not the case for gases such as oxygen and nitrogen. It is the bond between the different elements which determines the ability of the gas to absorb the radiation. Oxygen (O2) is however detectable by a

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paramagnetic analyser, these again were developed in the 1960's and were being considered for tube bundle system installations in the UK in the 1970's. Nitrogen can only be detected using gas chromatography.

The development of tube bundles for hydraulic controls enabled the development of the tube bundle gas monitoring systems we know today. A bundle of tubes is taken underground through a shaft, a borehole or a drift then distributed to the required monitoring points. This enabled the ongoing monitoring of the underground environment when the power was isolated at 1.25% CH_4.

Chamberlain (1970) states that a tube bundle installation in the Durham area of the National Coal Board (NCB) was being used to take samples directly from the goaf and identifies that if the samples analysed are high in methane the carbon monoxide can be calculated on an oxygen free-methane free basis. Chamberlain also mentions the advantage of the system allowing gas chromatography to be undertaken.

OPERATIONAL CONSIDERATIONS

The National Coal Board (NCB) in the UK produced a handbook which was updated in 1974(NCB 1974), it was developed to provide the operational guidelines for colliery personnel for the installation and operation of tube bundle systems. The foreword indicated that the handbook contained only guidelines and not rules as the technique was still rapidly developing. "The emphasis was changed to make it suitable for a wider audience who should now include not only those who have to install maintain or use it, but also those with only a temporary or limited interest in it or with a specialised knowledge of part of it such as suppliers, senior management stores officers." (NCB 1974) The handbook still provides an excellent source of information relating to tube bundles and remains a very good "how to and why" guide. It was noted that the advantage of tube bundle systems was the simplicity of the underground equipment with analysing and controlling hardware on the surface, without restrictions associated with electrical equipment being underground.

The United State Bureau of Mines (USBM) prepared a circular similar to the NCB handbook on tube bundle systems. The circular was prepared by Litton (1983) and it was targeted at the design criteria for tube bundle systems. The circular also states that "pneumatic monitoring systems can be used to monitor for hazards that develop quite quickly".

Installation

When considering options for the installation of a tube bundle system, borehole access (when available) provides the potential to reduce the length of the tubes deployed and hence reduce the delay time for the gas to reach the analyser. It is recommended that 12.7 mm (0.5 inch) Outer Diameter (OD) tube is used for runs up to 6 km and thereafter 15.9 mm (5/8 inch) OD tubing is used. In cold climates it is necessary to insulate, and in some cases heat the tubes to prevent condensation and freezing as the tubes exit the borehole.

It is also prudent to install water trap arrangements at the bottom of the borehole/shaft or drift at the low point where water will accumulate. A maintenance regime needs to be in place for the planned emptying of these water traps. In extreme cases large accumulation vessels may be required, ie in very cold climates such as in Canada, China or USA.

Groups of 5 or 10 tubes are connected to an individual purge pump (the pump that keeps the gas samples flowing in the tubes at all times). Some suppliers do not offer the option of individual line regulation but advise that all tubes of similar length are connected to the same purge pump to equalise the flow. This is not practicable in all mining situations and it is therefore recommended that individual regulators are fitted to all tubes to balance the flows for optimum performance of the system. It is also recommended that if a mine has a system that does not have this functionality that the mine investigates the option with the supplier of retrofitting line regulators. The other individual lines can then be balanced to ensure the same flow rate in each of the tubes, ie set the longest tube to zero regulation and balance all the others to that setting. A typical schematic of the surface installation is shown at Figure 1.

Other operational considerations are to run the tubes in the return roadways to avoid unnecessary condensation. Most mines have the tube run in the intake because this facilitates easier access for installation and inspection. It is worthwhile considering the operational aspect of running them in the return from the point of reduced condensation and the issues of emptying water traps. The tubes should be secured tightly every 2 m to the roof or rib, and accumulations of slack or sagging tube avoided, this will help protect the tubes from damage. Tube sagging can become a collection point for moisture and is also not as effective at surviving any possible underground explosion (Brady *et al.,* 2015).

As the tubing is food grade polyethylene, they are prone to deteriorating when exposed to ultra violet (UV) light. Even bundles of tubes which are exposed to UV light have been seen in a deteriorated state with the inner coloured tubes brittle and easy to break. If tubes have to be run over land it is prudent to run them in trenches, culverts or pipes where they will not be exposed to UV radiation.

It is imperative that good quality tubing and joiners are purchased. There have been occasions when cheaper tubing, poor quality joiners and poor installation of joiners have compromised the installation by causing leaks that were difficult to eliminate.

AS2290 Part 3 defines the leakage testing required for a tube bundle system (Standards Australia 1990). This does not include the pressure testing of tubes. The standard required the introduction of a known gas mixture at the inbye end of the tubes and it also defines the pass criteria on the gaseous result. One of the tube bundle equipment suppliers is now offering a service to leak-test tubes. The approach used is to pass nitrogen down the tube from the surface, then the flow is reversed up the tube and the gas analysed on an oxygen analyser. As the flow rate is known and the length of the tube is also know, it is claimed that leaks can be detected within ±20 m. AS2290 Part 3 is currently undergoing a review and update by industry experts.

The final point to note is the adequate sample preparation for the gas before it enters the analyser. The preparation involves chilling the gas sample to 4°C in order to condense out the water vapour. Many of the systems installed in Australia contain a large amount of stainless steel tubing and it is important to note the importance of proper air temperature in the room, in order to avoid issues with condensation within the tubing.

Tube bundle monitoring software

The Tube bundle software needs to meet the requirements of a group of professionals including Ventilation Officers, Control Room Operators (CROs), Control Engineers and Electricians. A common approach for visualisation is to have the mine plan and gas results as shown at Figure 2.

User authentication

Each individual user needs to have a unique login to the tube bundle software to ensure system configuration changes are reasonable and approved (for example gas alarm thresholds). The software would allow for different levels of access:

1. **Operator:** alarm acknowledgement, trending, holding on a tube for continual monitoring.
2. **Maintenance:** the same access as the operator with the additional rights to calibrate the analyser and troubleshoot via the maintenance screen.
3. **Administrator:** the same access as the maintenance with the additional rights to change all the configuration settings and alarm setting.

Alarms

The tube bundle software will generate alarms for all the gases being monitored in at least four levels ie HHPV (Rising Alarm Level), HPV (Rising Warning Level), LPV (Falling Warning Level), and LLPV (Falling Warning Level). The four alarm levels allow for the notification that the gas value has risen or fallen away from analyser baseline value. For gases such as CO, CO2 and CH4 the LPV and LLPV alarms are used mainly for diagnostic purposes and the same would apply for increasing O2 value (for example, O2 greater than 22.5% is not possible in fresh air). The diagnostic gas thresholds can be set reasonably tight on the fresh air point to monitor the analysers drift and raise an alarm if a calibration is required.

Important alarms should have a procedure for the Control Room Operators (CRO) to follow. The same principle would apply for tube bundle specific hardware alarms, for example purge pump failure.

An acknowledged alarm does not mean that the alarm condition has dissipated, it simply means that the CRO has seen the alarm and has accepted responsibility for it. Unfortunately, a mine site control room can be a very busy place and the work undertaken can change dynamically. Hence, it is possible that a high level alarm can be buried or hidden among a number of low level alarms. A solution to this problem is to have an acknowledge timeout set for the high level alarms where the alarm will reactivate after set period of time (for example 60 minute delay), in order to alert the operator that the alarm condition is still present and in fact could be worse.

Calibration and troubleshooting

The calibration of the tube bundle analyser is a critical part of maintaining the gas monitoring at a high standard. The process to calibrate the analyser needs to be easy and relatively fast.

The maintenance screen should allow for calibration and troubleshooting of the tube bundle system. While the calibration of the analyser can be streamlined, the troubleshooting of incorrect gas results requires the manual operation of the various valves in order to identify the problem. For example, high CH4 in a relatively fresh air return could be caused by cross contamination from a previous goaf tube.

Important parameter calculation and configuration

At a minimum to meet the Queensland Mining Regulations, Graham's ratio and CO/CO2 ratio need to be automatically calculated and alarms established. In addition, calculation of CO make can also be another useful tool for the early detection of spontaneous combustion.

Graham's ratio and the CO/CO2 ratio should be configured to have an initial location and final location. The tube bundle software needs to have the functionality to setup the necessary initial requirements, or if no initial point is available the option to select a fresh air reference point within the mine, or alternatively use valid fresh air readings.

If a large storm was to move over a mine site the barometric pressure could fall quite sharply. Atmospheric pressure can influence the amount of gas being released from both the active and the sealed goaf/gob. The barometric rate of change is an alarm that monitors the change in the barometric pressure and warns the CRO that the goaves may start to rapidly breathe out.

Data storage

The tube bundle gas results need to be recorded, continually archived and backed up to a secure storage server. The gas data may be required years in the future and easy retrieval is very important. The gas data needs to be backed up to a secure storage server to prevent data loss from failed hard drives, lightning damage and server theft.

All the alarms need to be logged, including the threshold of the value that was exceeded, for the following reasons:

- the alarms can be reviewed to ensure the alarm thresholds are reasonable.
- the alarm thresholds need to be set to identify a movement away from the baseline, without generating a large number of not so important alarms due to barometric changes .
- the number of alarms needed be minimised to prevent CRO alarm fatigue where every alarm is acknowledged. In this case the alarm procedure is not followed and there is a safety risk that important alarms are ignored.

The software needs to record all the changes to the system configuration for the following reasons:

1. If there are any problems with the new setting, the previous values can be reinstated.
2. The administrator who made the changes can be identified and the reason for the change confirmed.

Tube bundle system diagnostics

The tube bundle system should monitor fresh air as a simple diagnostic check. If the tube bundle system cannot successfully monitor fresh air then concerns need to be raised as to the monitoring of the gaseous environment underground.

If the tube bundle system is located inside a closed building then there is potential for a build up of gas. Hence the tube bundle system should monitor the air inside the building to ensure that there are no gas leaks. A risk assessment and various controls would need to be undertaken to ensure that if a gas leak is detected that the power to the tube bundle system is disconnected prior to the point of reaching explosive gas mixture.

Each tube should have its vacuum and sample flow monitored and alarmed on to assist with troubleshooting of any tube issues i.e. damaged tubes or leaking unions.

Any critical equipment for the functionality of the tube bundle system, ie purge pumps need to be monitored and alarmed on when their operational status moves outside the normal parameters.

Maintenance

System support

The maintenance, calibration and integrity testing of a tube bundle system can be a challenging task, it is highly recommended that a strong robust relationship is established between the tube bundle hardware suppliers, tube bundle software suppliers and the mine site personnel. It would be an advantage if the mine site were to have an electrician or Deputy specially trained to support and maintain the tube bundle system. The monthly tube integrity testing, as required by Australia Standard 2290 Part 3, is a major part of the maintenance of the tube bundle system. The tube integrity testing is required for the following reasons:

1. To confirm that the tube monitoring location is correctly identified in the software. Unfortunately, the tubes are frequently cut, extended and amended with different colours many times, making it quite easy for a tube to become mixed up with a different tube, especially if both are sampling a similar atmosphere.

2. To verify that the tube does not have any leaks. The tubes are under ~60kPa of vacuum which means that any small leak will dilute the sample before it reaches the surface. While some leaks are very obvious, for example a goaf tube going to fresh air, if a return tube was to have a leak it

would not be so obvious. If the mine has an incident and the power underground is turned off due to high CH4, the only monitoring available for the decision making process on re-entry. would be via the tube bundle system (or sampling from bore holes). Hence it is imperative that the tubes are collecting a representative sample correctly.

3. To calculate the tube delay time between the sample collection and when the sample is analysed on the surface by the gas analyser. If a high CO alarm is raised on a tube, the CRO needs to know when the sample was taken underground in order to determine if the condition underground could have deteriorated further.

As the tube bundle system is needed to operate 24/7, a list of critical spare parts should be formulated and stored onsite. The critical spares form two categories, namely regular maintenance spare parts and general spares. The regular maintenance spare parts include the various filters, dryer parts and membranes. The general spares include the gas analyser, Programmable Logic Controller (PLC), sample and purge pumps, and various valves. It is recommended that all the spare parts are the same as the Original Equipment Manufacturer OEM supplied.

In addition, the tube bundle system server and control room workstation need to have a replacement plan in place to ensure that the system can maintain uptime after server/computer failures.

Training

Gas monitoring and interpretation software has many configuration settings, and it takes time to become competent in using the software. In addition, even when the mines Ventilation Officer (VO) has set all requirements (the gas alarm thresholds, gas ratio initial conditions, tube bundle lag times), the mining condition can change and require tubes to be relocated, resulting in the settings needing to be updated again. This is a continuous process in underground coal mining. Each time the tubes are relocated, their sampling location needs to be carefully updated. This will ensure that if there was an emergency situation, the exact location of the gas sample source is known, for example inbye or outbye of trapped mine workers. Each month during the tube integrity testing process, the tube delay times need to be verified to reflect actual delay between the sample collection and the alarm condition identified on the surface.

Most of the configuration and updating of the gas monitoring software is undertaken by the VO. One issue to consider is frequent staff movement from mine to mine, particularly the VO. If the VO were to move to another mine site, the task of maintaining the gas monitoring software will be taken on by a new VO, who may not have had the adequate OEM training and only has a rudimentary understanding of the software. Unfortunately, while some software can appear to be simple to use, the requirements of some configuration changes can be complex, for example the setting of the initial conditions for the gas ratios and the rate of change.

Staff turnover in the control room is another area where ongoing training is required on the gas monitoring software. This could improve the gas monitoring and decision making process early in an emergency situation.

Ideally the gas monitoring software should lead itself to be simulated so trial emergencies/desk top simulations can be conducted in a safe manner. Simulation software is used for the Queensland Level 1 Emergency Exercise. While only one Queensland mine a year has the Level 1 exercise, each mine conducts a Level 2 exercise and when simulated gas data is used, it contributes to the realism of the exercise.

Gas interpretation software

Once the gas data is collected by the tube bundle software, the gas information can be reviewed in the gas interpretation software. The gas data is generally displayed for review in the manner below:

1. The raw gas data or equations can be displayed on a time graph to show its trend over time. Figure 3 is showing CH4, CO, O2 and CO2 gas concentration in seal 512 in time. The data used is from Moura No. 2, before and after the explosion event on 7th August 1994.
2. In order to display the gas sample's combustible nature, a Coward Triangle is a useful display. Figure 4 shows the position of gas mixture at point 512 seal (Moura No. 2) on a Coward Triangle. The Coward Triangle shows the percentage of oxygen with the total percentage of flammable gases in the gas mixture that was analysed. There are four zones on the triangle: explosive, fuel lean, fuel rich and the non-explosive zone. The point plotted on a triangle indicates the status of the gas atmosphere analysed at the time.
3. An Ellicott diagram is suited for trending purposes. This is useful for predicting if an atmosphere is trending towards the explosive range. Figure 5 shows the Ellicott Diagram for seal 512 on 7th August 1994, with clear indication that the atmosphere analysed is trending towards the explosive zone.

The gas interpretation software also needs to be flexible enough to allow the trending of custom equations that have been tailored to meet a specific task.

DATA INTERPRETATION

Trigger Action Response Plans (TARPs) are used to define what are normal and abnormal underground conditions, and the appropriate actions that should be undertaken should certain levels be triggered. TARPs generally consist of three or four levels ranging from normal conditions (level 1) to abnormal conditions requiring evacuation of personnel (level three or four). The data produced by a mines tube bundle system often forms the basis for the triggering of the different levels in the spontaneous combustion TARP. The quality of the installation and maintenance of a tube bundle system is therefore a direct influence on the quality and validity of the data produced. Poorly maintained installations may result in false alarms being raised, leading to complacency by mine personnel. Complacency and failure to acknowledge the danger posed by alarms can have fatal consequences.

Cliff (2009) listed eight fundamental principles for TARPs:

- They must be simple and robust
- The TARPs must be adequately resourced both in terms of personnel and equipment
- The focus of TARPs should be on prevention and control through early detection
- Setting triggers requires detailed knowledge of what is normal
- TARPs need to be regularly reviewed and revised as necessary and as experience dictates
- There is no substitute for high quality mine environment monitoring systems
- TARPs should be set based on the best available advice – both on site and off site
- If a TARP mandates an action, then that action must be carried out, properly and promptly

Trigger levels for use in TARPs should not be set using literature values, the values need to be derived from the mines own historical data with a sound scientific basis underpinning them. In the case of a new mine with no historical data, consideration needs to be given to laboratory testing results for the mines coal, mining factors and data from nearby mines if available and applicable. Caution needs to be used when using data from neighbouring mines to validate acceptable trigger levels for new mines. There are cases where neighbouring mines have a great deal of variation in the seam gas content, such as a methane based seam gas at one mine and a mixture of methane and carbon dioxide seam gas at the mine next door. A CO make in excess of 100L/min may be normal for one mine, whereas a CO make of around 5L/min may be normal for another. A basis for what constitutes normal at the mine needs to be established before higher trigger levels can be formulated. Normal conditions can vary greatly between different seams, the location of the mine (ie NSW -Sydney Basin or QLD - Bowen Basin), the seam depth that the mine is targeting, different mining methods and even the inherent properties of the coal being mined (Cliff *et al.,* 2014).

The approved standard for the use of gas monitoring systems QMD 96 7398 recommended that CO make be used for carbon monoxide related gas alarms (Queensland Department of Mines and Energy 1996). Whilst this standard was superseded by the recognised standard, this recommendation is still valid depending on the application of the monitoring location. Monitoring locations that have no airflow (eg goaf seals) should use the raw value, whereas monitoring locations that do have an airflow (eg returns) should use CO make. Ventilation changes could have the effect of diluting a raw carbon monoxide value, and therefore potentially masking a heating. Changes to ventilation do not have the same effect on CO make as the volume of carbon monoxide does not change (Cliff *et al.,* 2014).

Stephan (2000) describes the use of statistical methods when setting trigger levels. Data should be collected from an appropriate location, ensuring that there is sufficient data and that it is not compromised by outliers. Outliers could be caused by calibration of sensors or integrity testing of tubes as an example. A histogram of the data should be plotted and analysed to ensure that a normal distribution is apparent. Insufficient data points could result in the data not being normally distributed. Once a normal distribution has been established, Stephan recommends the use of three standard deviations above the mean of the data set as the point to set the first trigger level. Caution must also be given to data that has additional influences such as carbon monoxide being produced by diesel vehicles. This type of influence may result in the data not having a true normal distribution. Stephan has provided an example of how a statistical approach can be utilised when setting trigger levels, thus providing one aspect of sound scientific basis for the justification of the trigger level values.

The rate of change is an important factor that needs to be further investigated for its possible incorporation into TARPs, or at the very least its use as a tool in the decision making process for setting trigger levels in TARPs. Small and large scale testing has demonstrated that there is a rate of change for common indicators such as carbon monoxide as the temperature of the coal increases, with a final exponential increase once thermal runaway is achieved (Clarkson 2005). Incorporation of the rate of change may provide a crucial missing link for mine personnel when faced with the dilemma of where to set the trigger levels for a TARP. Similar to the approach made by Stephan (2000) with the use of statistical analysis, the rate of change has the potential to provide a sound scientific basis for the justification of values for trigger levels.

TARPs often contain "and" and "or" statements. "Or" statements are values that can trigger an increase in the TARP level on their own. "And" statements require two or more values to be achieved before an increase in the TARP level. The decision of whether to use one or the other, or even a combination of both within a TARP is dependent on many factors and requires a sound understanding of spontaneous combustion. For example, hydrogen is an indicator of spontaneous combustion but elevated hydrogen levels are also known to be associated with the use of galvanised steel. The use of an "or" statement for hydrogen in a TARP could result in an unnecessary elevation of the TARP level due to the use of galvanised steel, rather than an actual heating. A solution to this problem would be the use of an "and" statement, so that elevated hydrogen occurring must be in conjunction with another elevated spontaneous combustion indicator (carbon monoxide for example), to result in an increase in the TARP level.

Consideration must also be given to how the data used in a TARP is generated. The gas chromatograph (GC) is the only available technique for the measurement of the spontaneous combustion indicator ethylene. Most modern GCs are capable of low level ethylene detection from approximately 1ppm and upwards. There are difficulties in interpreting whether ethylene is present below 1ppm due to the nature of the technology. The use of an "or" statement for the presence of ethylene as an evacuation trigger is not advisable due to this. Ethylene typically develops at higher temperatures in coal and therefore its presence due to a heating will be in conjunction with the presence of other elevated indicators. A more appropriate use of ethylene in a TARP would be with an "And" statement along with another spontaneous combustion indicator.

The oxygen concentration at a seal is an example of the appropriate use of an OR statement. Oxygen ingress at seals can lead to spontaneous combustion, therefore the need for an AND statement with another qualifier would not be required before taking action. The presence of oxygen itself is enough to trigger the need for immediate action.

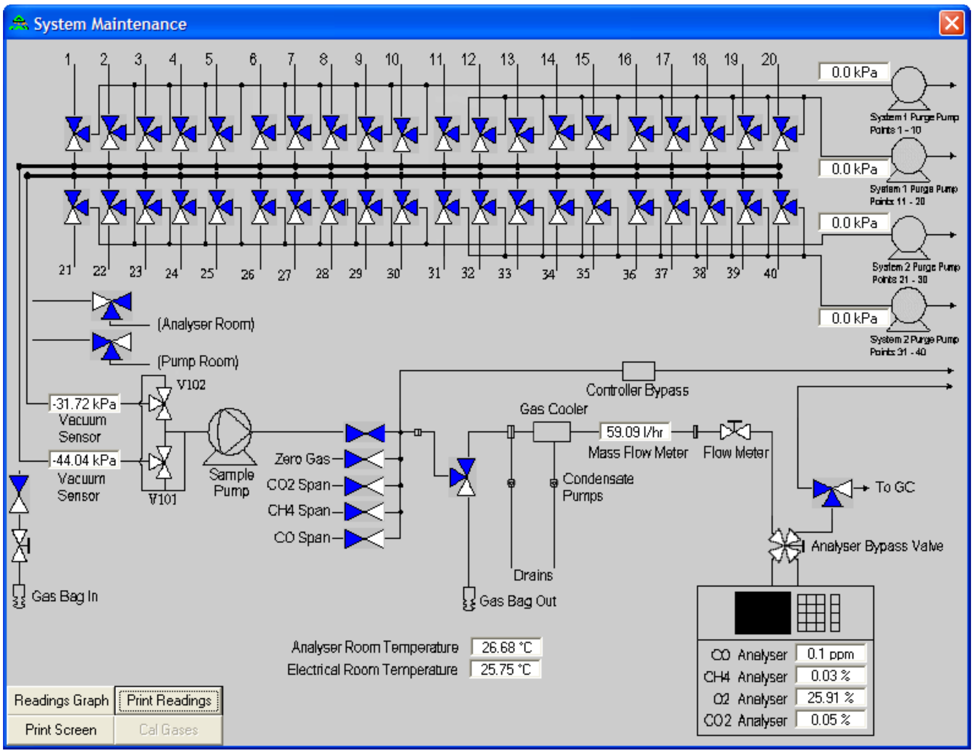

Figure 1: 40 Point Tube Bundle Schematic

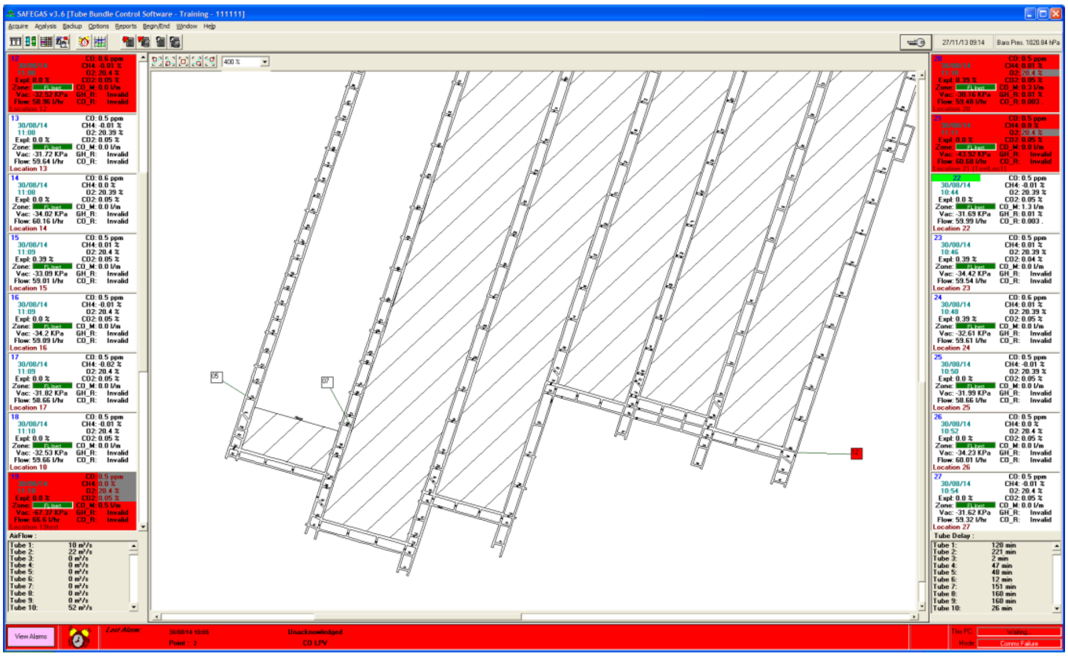

Figure 2: Visualisation of Tube Bundle gas results

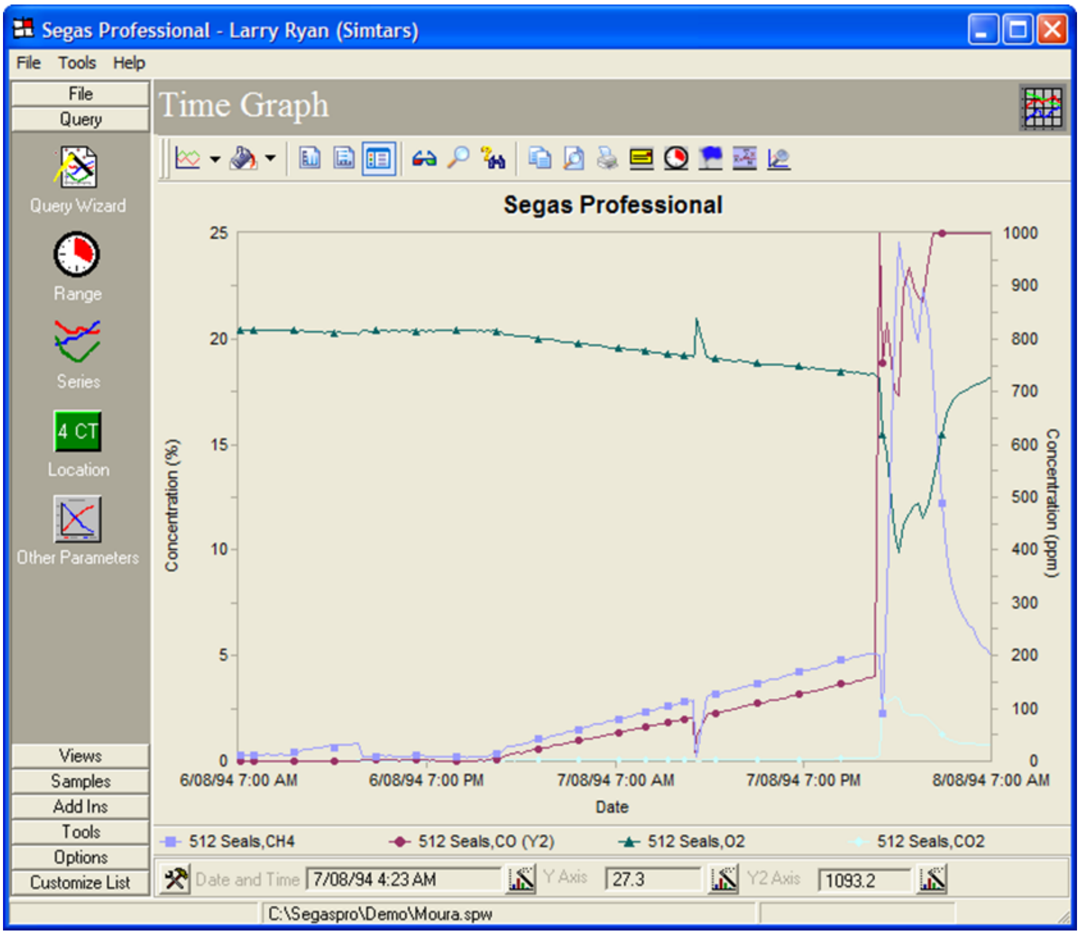

Figure 3: gas data from 512 Seal Moura No 2 1994

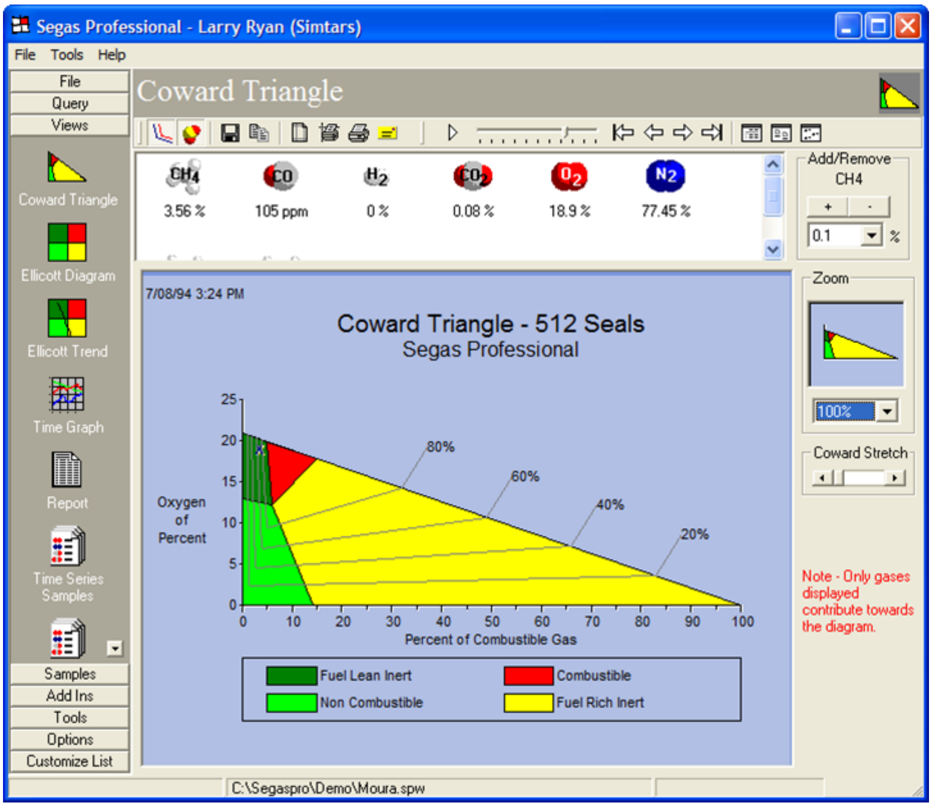

Figure 4: Segas Professional Coward Triangle

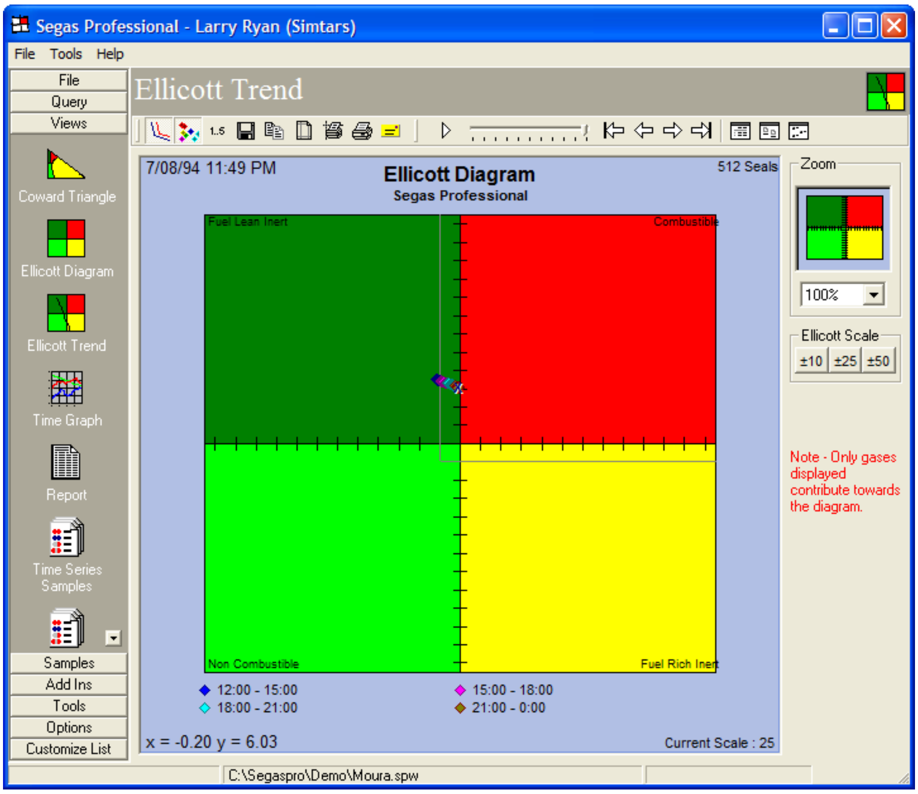

Figure 5: Segas Professional Ellicott Diagram

CONCLUSIONS

This paper discusses the main requirements that need to be considered when installing tube bundle underground monitoring systems at a coal mine. The risk of electrical equipment being underground is removed by using the tube bundle system, as its analysing and controlling hardware is established on the surface.

The main points to consider are tube bundle installation, maintenance and optimisation requirements, as well as training requirements for both the system maintenance and system software operation. The main goal of monitoring the underground atmosphere is to determine the gas mixture explosion risk, the early identification of the onset of a spontaneous combustion event and the verification of the effectiveness of inertisation techniques. The system is also used to make the decision to re-enter or not re-enter the mine after an emergency evacuation.

The climate is an important factor to consider when installing a tube bundle system. The tubes are food grade polyethylene and as such are prone to weather damage. The insulation and heating in cold climate and UV protection (for example running them in pipes) is recommended. It is recommended that 12.7 mm (0.5 inch) outer diameter (OD) tube is used for runs up to 6 km and thereafter 15.9 mm (5/8 inch) OD tubing is used.

Where practicable, individual tube flow regulators should be used on all tubes to equalise the flow in each of the tubes. Good quality tubing and joiners, as well as technical capabilities of personnel installing the system are vital for maintaining safe operation and to avoid leaks during installation and operation. The correct leak testing procedures need to be established and performed monthly on all tubes and after a relocation or new installation. During the installation stage, possible condensation points need to be considered and where possible tubes should be run in the return or conveyor belt roadways. Regular checks of tube monitoring locations is very important to ensure correct calculation of gas values and correct mine atmosphere status.

The tube bundle monitoring software is a very important part of the system. It has functionality for settings for different operational access levels and permissions to acknowledge alarms, trend the data, hold the sampling of the tube, calibrate and troubleshoot the analyser, or higher permission to change configuration and set the alarms. Individual alarms need to be stabilised for each of the tubes for all the gases being monitored (CO, CO2, CH4 and O2) as well as the relevant ratios Grahams, CO/CO2, Explosibility and CO make. The calibration of the analyser and integrity testing is an essential part of the operation and all operators need to have a high level of understanding of the processes required. All essential spare parts should be stored on site and be readily available in case of equipment failure.

Queensland or New South Wales Mining Regulations need to be considered when setting the alarms and ratio calculations within the tube bundle operating software. The alarm number and threshold needs to be justifiable and statistical analysis can be used to establish the appropriate alarm levels (Stephan 2000). TARPs are used to define what are normal and abnormal underground atmosphere conditions, and the appropriate actions that should be undertaken should certain levels be triggered.

Tube bundle gas analysis information can be displayed in time graphs, trends, explosibility triangles and diagrams (Coward Triangle and Ellicott Diagram).

RECOMMENDATIONS

1. Tube bundle should be run in mine roadways where condensation will be minimised and secured to the roof at a minimum of 2 m intervals to improve the survivability in the event there is an explosion in the mine.
2. Individual line regulation be used to balance the flows in the tubes attached to each purge pump
3. Coal mines should establish a working relationship with the supplier of their tube bundle hardware and software to ensure regular maintenance and training is undertaken.
4. Critical spares should be held on site.
5. Systems to be maintained in accordance with AS2290 Part 3
6. The gas data is backed up to a secure storage server to prevent data loss from failed hard drives, lightning damage, server theft.
7. Trigger Action Response Plans (TARPs) need to be established carefully considering many factors, such as coal seam and history, laboratory testing conditions, tube bundle system conditions and mining methods.
8. Care should be used in setting TARP levels and the appropriate use of "and" and "or" statements needs consideration and evaluation for appropriateness.
9. TARPS should be clear, unambiguous and able to be clearly understood by a coal mine worker in the early hours of the morning, when no technical staff are available.
10. Regular mine emergency exercises should be performed with coal mine tube bundle simulation software.

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