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Gas monitoring - What we know so far

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GAS MONITORING WHAT WE KNOW SO FAR

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ABSTRACT: Remote gas monitoring started in the early 1960's when carbon monoxide detectors were used in Germany to monitor spontaneous combustion activity. These systems were modified and used in the United Kingdom in the late 1960's to proactively monitor the underground atmosphere; the tube bundle systems we know today. Real time methane detectors and carbon monoxide detectors were used in British Coal in the mid 1980's. Large mines in Australia can have up to 60 tube bundle monitoring points and up to 200 individual gas sensors underground. This paper discusses the development of these systems as well as potential issues relating to data handling and interpretation.

Introduction

Tube bundle systems

Infra-red carbon monoxide analysers were first used in Germany for the detection of and control of spontaneous combustion. The tube based system brought the sample back to the underground Maihak analyser was adopted in Scotland in the UK. In the late 1960's this technology was quickly adopted by the National Coal Board for the detection of spontaneous combustion with the analysers on the surface - the typical tube bundle system we still have today some 50 years later.(Chamberlain et al 1971). The reason for this adaptation was the commercial availability of bundle of tubes which were being developed for hydraulic control systems.

A handbook describing tube bundle systems was released by The National Coal Board in 1972. This handbook was revised with an emphasis to make it suitable for a wider audience and published in 1977 as *The Tube Bundle Technique for the Continuous Monitoring of Mine Air* (National Coal Board 1977).

The foreword of the handbook stated that it was notes on the use and installation of tube bundles for the continuous monitoring of mine air based on the accumulated experience of eight years' research by Scientific Control and some 80 pit installations. Figure shows a schematic for the surface layout of a tube bundle system. The handbook made many recommendations for the successful application of the system: these include:-

Use low density polyethylene and colours for tube identification, cap the tubing before using to keep dirt out, do not cut the tube with the suction on or dust will enter the system and use compression type joints.

Details of the installation of the tubes recorded on scale a plan including the route of each tube, the location of junction boxes and the sampling point. A sketch diagram was also prepared of the same information. Install one in tube in the intake and one in the return from each active district and undue lengths of tube on the surface are to be avoided.

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Slinging of tube point to point was to be avoided as water condensation and blockages may occur at low points, single tube were to be supported at 2-4 m intervals three or more tubes at 2 m intervals.

Water traps were used at the bottom of the shaft, in the analyser room and in roadway low points. Flame traps were also included as an added protection for tubes above 9.4 mm outside diameter.

Leak testing by was undertaken by introducing a known gas at the inbye end of the tube or vacuum testing for 24 hours with negligible loss being the pass criteria. The volume flow entering each sampling point was measured by flow meters recorded by deputies on their statutory reports. Spare drums of tube were held centrally for emergency response.

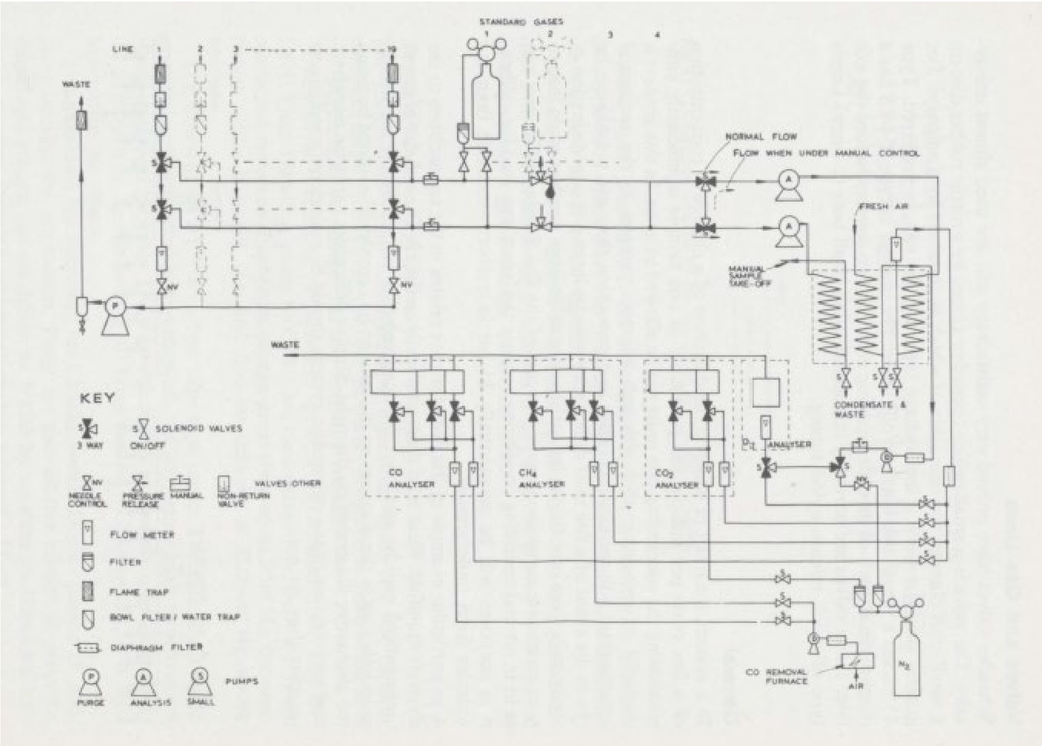

Figure 1: Schematic of an early tube bundle system (from National Coal Board 1997)

The hand book made the following recommendations for the surface installation:

The installation must be readily accessible by road, the pumps housed separately due to vibration and noise and have suitable ant-vibration mounts to protect the pump and motor bearings. The installation should include a high capacity scavenge (purge) pumps and a sample pump where the absolute inlet pressure of the sample pump must be greater than that of the scavenge/purge pump to avoid reversal of the flow when the line is sampled. The excess gas should be discharged to the outside atmosphere. The pump design should ensure there is no contamination with oil or vapour from the pump. Other subtleties in the design included the avoidance of dead volumes in the tubing, the same train of dust traps and humidity conditioner for the calibration gases as the sample gas, automatic water trap at the humidifier and the temperature in the room should be kept stable.

The instruments used were infra-red (IR) and multi range:

Carbon monoxide (CO) 0-100 parts per million (ppm) and 0-1000 ppm using subdivided cells.
Methane (CH_4)   0-5%, 0-20% and 0-100% using subdivided cells.

Carbon dioxide (CO_2) 0-5% and 0-15% using subdivided cells.
Oxygen (O_2) 0-25% paramagnetic analyser, flow sensitive.

Real time systems

Real time sensors were first introduced in the 1980's, these were mainly carbon monoxide and methane and were used in the Selby Coal Field in the UK.

Underground real-time systems were prescribed legislation in Queensland in the coal mine regulations introduced in 2001 (now dated 2017). Similar requirements for real time systems were also introduced into NSW regulations.

Underground methane detectors were also used to trip power automatically. Most detectors were electrochemical, pellistor type detectors were developed for CH_4 along with IR sensors being available for CH_4 and later for CO_2. Initial installations were at the outbye/return end of longwall panels and at key locations on conveyor roads such as at the interface between mines in the Selby Coal Field

CURRENT STATUS

Tube bundle

There are four suppliers of tube bundle systems in Australia and two of them have developed software for the control of the system. Systems are now built to comply with the specifications required by ASNZS 60079-10.1 2009 Explosive atmosphere classification of areas-Explosive gas atmospheres (IEC 60079-10.1, Ed.1.0 (2008) MOD). This is required because the sample pump supplies the gas to the analyser at positive pressure and if there was a leak a hazardous gas accumulation could occur in the analyser room. The National Coal Board (1977) discussed the possible use of negative pressure to supply the sample to the analyser, it is not known whether this was tried or not. If this process was proven all of the tubes in the analyser room would be under negative pressure and the requirements to comply with ASNZS 60079-10.1 2009 could be reviewed.

There have been several design changes made over the years to make the building of the system cheaper. For example in 1997 one of the authors purchased a system from one of the suppliers and it came with five identical pumps, four were purge pumps and one the sample pump. Each purge pump had five tubes assigned to it. The system also came with needle valves to regulate the flow in all tubes to be the same i.e. balance the flows to match the longest tube. The system also came with four analysers 0-100 ppm and 0-1000 ppm CO, 0-10% and 0-100% CO_2, 0-10% and 0-100% CH_4 and 0-25% O_2. Calibration was done with a zero gas and a gas around 90% of full scale on both ranges. The CO was also zeroed using fresh air as the ultra-high purity nitrogen for zeroing contained around 0.7 ppm of CO. Both scales were calibrated and adjustments to the potentiometer were done manually.The same supplier had to be convinced to install an automatic water trap at de-humidifier and the introduction of calibration gases at the same point as the gas samples as suggested by the National Coal Board (1977).

Current systems from the same supplier now come with one analyser with a shared optical path for the IR gases and are single range; 0-1000 ppm for CO and 0-100% for CH_4 the supplier recommends the use of 0-50% for CO_2 for improved accuracy on CH_4. The instrument is calibrated at zero and 100% with electronic adjustments being made.

All of the suppliers provide two purge pumps for a twenty point system, this makes the piping arrangement simpler. Current instructions from the supplier are to put all the tubes of the same length on the same purge pump, this is not a practical solution at a mine site as there will be variability in tube lengths and then changes as the mine develops. Regulating needle valves are not supplied unless requested.

The authors are aware of one mine that had a problem with the sample pump stalling when switching to certain tubes at the mine, the apparent resolution to this was to install check valves in line. These check valves later became an operational liability due to blockages. Note the National Coal Board (1997) recommendation of "*absolute inlet pressure of the sample pump must be greater than that of the scavenge/purge pump.*"

It is quite normal to site a seal panel, connectors and self-draining water trap, adjacent to a seal. Operationally is this the best place to locate it? The sample will come out of the seal at high humidity and higher temperature than the mine roadway. Condensation will occur and if the gradient is favourable the water will drain back to the water trap. If the gradient is not favourable the water will run in the opposite direction, if the tubes are in the return there is a likelihood that little condensation will occur until the tube enters intake (colder) roadways. This could possibly be the best place to locate the 'seal panel.'

Marshalling panel design also needs to be considered as some suppliers have low points where water can accumulate; these low points are underneath the installed water traps. One supplier insists on supplying a 10 point marshalling panel even if the bundle run is a seven core.

Tubes supplied in bundles can either be colour coded with identifying markings or all black with identifying markings. The authors have had personal feedback that the all black tubes were very well marked. Other suppliers provided coloured tubes but at least one insists on supplying bundles of tubes with different shades of yellow, blue and red which can be difficult to distinguish in underground installation conditions.

Other installation tips are to use catenary wire for the installation of tubes and attach the tube to the catenary wire every 2-3 m avoiding slack and undulations where water can accumulate. Another trick is to ensure that the analyser room is not too cold as condensation will occur in the tubing and not at the de-humidifier as planned.

All maintenance of the installations are covered by the AS2290 Part 3 2018 which now requires the testing of gas alarms and hardware alarms on a monthly basis.

The accuracy of tube bundle analysers are not specified in AS2290 Part 3 2018; the standard states that they shall be in accordance with the respective manufacturers specifications.

Real time systems

Real time gas monitoring systems are now an integral part of mine environmental gas monitoring. With return airways monitored for methane, carbon monoxide, carbon dioxide and oxygen. Elsewhere in the mine there are discreet methane monitors with an electrical power tripping function, carbon monoxide monitors along conveyor belts. Other real-time monitors are available for ventilation velocity, pressure and temperature with diesel particulate matter monitors now being introduced to the industry.

Large mine can have over 200 monitors installed which creates an appreciable workload on the electrical department to install and maintain the system. This does not include the monitors on mobile plant or the hand held monitors carried by statutory officials and key coal mine workers.

Each monitor has to be calibrated on a monthly basis in line with AS 2290 Part 3 2018 along with a response time test and a telemetry test. The standard requires the maintenance records to be kept for four months. There is a separate 6 monthly calibration requirement the records of which need to be kept for two years.

There are a number of issues that have been identified with real-time systems and tests to identify if they are occurring and remedy the situation have been include as part of the requirements of AS2290 part 3 (2018). These include the checking that all displays reflect the same value, the response time for the detector to react to the applied gas and that the telemetry system is physically capable of sending a full range value to the surface control room. The standard also provides advice on the maximum pressure that the gas sensor is exposed to (50 Pa). Specifically:

- The requirement to check that the local display and the remote display, in the control room, show the same readings when the calibration is being done.
- Establishment of the [1]T_{90} for the sensor the acceptable criteria is less than 30 seconds for CH_4 and less than 60 seconds for all other detectors.
- The telemetry test is only applicable if the gas detector raises a remote alarm or tripping function. This would mean all underground sensors are required to be tested this way. There is no specified time for a pass but this must be specified in the mines safety system.
- Dynamic range test is required to ensure that the full range of the sensor values can be communicated across the telemetry system. I.e. if the detector is exposed to 5% CH_4 the full value will be communicated to the surface control room.

The accuracy of methane detectors is prescribed as follows in Figure 2.

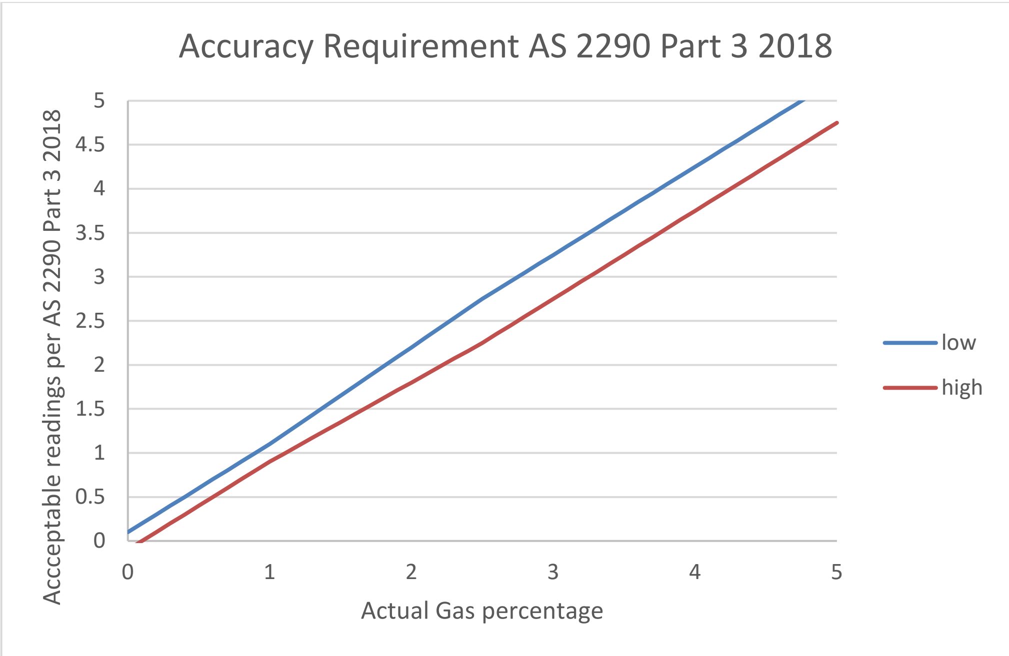

Figure 2: Accuracy requirements for methane detectors to 5% AS 2290 part 3 2018

It can be seen that a detector that is exposed to a methane percentage of 2.5% could read between 2.25% and 2.75% and still pass the requirements of AS 2290 Part 3 2018.

The standard also provides information on the effect on T_{90} times when sensors are blocked and provides an example of when a calibration cup is pressurised with a 2.5% challenge gas the detector will read 2.75%. If the detector is then calibrated to read 2.5% at this pressure. When the detector is exposed to a real gas concentration of 2.5% it will report an actual concentration of 2.2%.

[1] T_{90} is the time taken for a detector to read 90% of the value applied gas concentration.

With over 200 sensors to maintain this becomes a full time job for a dedicate team of electrical staff when production priorities call there is a danger that the routine maintenance of the gas monitoring system will be neglected.

DATA HANDLING AND INTERPRETATION

AS 2290 Part 3 2018 requires the maintenance records for calibrations to be kept for four months. There is a separate 6 monthly calibration requirement the records of which need to be kept for 2 years.

The NSW Work Health and Safety (Mines and Petroleum Sites) Regulation 2014 S58 Records of air monitoring require the keeping of the gas records for seven years. Given that hand-held instruments and mobile plant are in fact an integral part of the gas monitoring system it is possible that there could be a need to keep these results also.

In Queensland the ventilation reports are required to be kept as part of the mine record but the requirement for keeping the real time gas data is not clearly defined under the Queensland regulation 2017. However, recognised standard 09 the monitoring of sealed areas (2009) requires the records for each seal to be kept for the life of the mine, this is the tube bundle data.

The Queensland regulations 2017 s 222 Gas monitoring system also requires “*the keeping the information on which the values and trends mentioned in paragraph (d) were based at the mine in a way that enables the information to be easily accessed and inspected”*.

Gas Monitoring Data Improvements

Data storage

It has been observed that “*excess gas data*” has occurred in data storage/databases for some real-time systems. This condition caused the gas data file to become *“bloated*” with repeated data, hence the file size is much larger but contains no extra gas information.

Excessive data storage rate leads to following issues:

1. The gas monitoring system is sluggish in trends and display and the control room operator (CRO) is not able to pursue further investigation into the gas record.
2. Alarm generation and acknowledgement could be delayed or take a long time to complete.
3. The computer equipment struggles to store or display the data.
4. The history gas data file becomes excessive in size, becomes unusable and fills all the available disk space.
5. Extremely difficult to share the data file with internal and external experts.

20 megabyte (MB) is the practical limit for email, many accounts have smaller limits, so the file has to be shared by online file transfer services. A standard tube bundle file can be between 20 and 150 MB and a real-time system can generate files from several hundred MB to a few gigabytes (GB) in size.

In a recent test at Simtars, the uploading of a 6 GB file took approximately 4 hours (50 MB/s download, 20 MB/s upload). As most mine sites are in remote areas, the internet connect will probably be slower than the tested connection and therefore it would take even longer to share the gas data once that data file size exceeds few hundred MB.

The size of the gas data is a severe limitation to the rapid response required after a serious incident onsite. The size of the gas data can be excessive due to the following reasons –

1. Gas data storage rate is too high.
2. All the gas data is stored into a single repository.
3. The time range of data is too large.

Some of these issues can be resolved by sending a copy of the gas data to a secure website for sharing to various parties, as required. The advantage of this approach is the data is always available for download and only the user account access needs to be shared in the case of an emergency. In addition, if the data were stored in smaller time periods, the downloads would be a more manageable size.

Finally, the trending of the gas data must be managed in the real-time system. Due to the rapid sampling rate, a typical real-time system has records stored every 3-20 seconds per location. A single location can produce 201,600 records in a week period. The excessive data size can be even worse if the user chooses to trend data with longer time range then compare multi location data in the same graph.

Some systems display the average gas data between set intervals and this can mask out the important information. It is important to display correct gas value acquired. Transient gas changes occur for a reason and thus provide an opportunity to better understand the operation of the mine ventilation/gas monitoring system. For example, a rapid drop in the barometric pressure will cause the goafs to breathe out while a spike on a real-time sensor will show when it was calibrated.

Therefore, the gas monitoring system should apply two different approaches –

1. Represent all values in trend when reasonable dataset size is chosen.
2. Present using a correct data managed approach such as set value filtering or rate of change should be applied if a large quantity of information is selected.

Such data management will allow the user to filter certain percentage of the background data to reduce the data size. In the same time, the system will keep all the sharp rise peaks and present all the data values that exceed a pre-defined threshold.

Such an approach will enable the user to carry out a quick analysis on the overall data for a set period and apply further data analysis at a detail level without compromise.

Data process

Although tube bundle and real-time systems operate using different principles and hardware, both systems are monitoring the same gas parameters in the same environment and should be used to compensate each other. However the modern tube bundle and real-time systems still operate as single individual system. The end user must go through different methods to merge data in to a single repository before further analysis can be done. This is not a simple process and is usually avoided by the mine site.

In addition, standard single longwall block can take a few months to 1+ years to complete. The background history data can help the user understand the overall gas condition for the life of the longwall block. Unfortunately, it is common for the standard modem gas monitoring practices to keep a small amount live history data and archive all the rest. Such an approach is done to allow faster system response time. The problem is the end user left with multiple history data files that require further merging processing or a large history data repository where the user requires sufficient computer skills to navigate and obtain the useful information.

In order to overcome above and retain the same response user experience, a separate centralised database can be used to address this problem. Such a share repository should allow collected data through different hardware such as real-time, tube bundle or even a gas chromatograph. This approach offers greater flexibility in term of cross reference between gas data and will not increase workload on the operation of the monitoring system. A graphical interface application with simple interface should be use allow user analysis data without in-depth computer skillset.

Quality of gas data

The quality of the raw gas data is vitally important as this will be one of the limiting factors in the accuracy of all the gas ratios/explosability calculations. Typically, the gas ratios/explosability calculations are an important consideration as to the course of action required when the mine has a heating etc. As the old saying goes Garbage In = Garbage Out.

The quality of the gas data can be affected by:

1. Gas monitoring method used (Tube Bundle, real-time, Gas Chromatograph, hand held.)
2. The analyser/sensor uncertainty (the quality/range of the sensor)
3. Maintenance level (frequency of calibration, how well it is calibrated)
4. Skill of the operator (bag sample collection, analysis, etc.)
5. When the sample was collected (goaf sample collected when the barometer was falling)
6. Speed of sample analysis (if the sample is not analysed quickly, some gas components are lost (hydrogen,)

More attention needs to be given to the uncertainty of gas analysers/detectors and the gas ranges that these uncertainties apply to. If the gas analysers/detectors uncertainty is not transparently stated in its manual then how do you know accuracy of the gas readings?

Choosing an analyser with tighter gas uncertainties should be part of the analyser selection process, for example for a carbon monoxide (CO) analyser with 1% uncertainty full scale -

For Example – An analyser with a 100 ppm range may have an uncertainty of ±1 ppm, hence if the actual gas value is 5 ppm then the analyser reports 4 – 6 ppm while still being within specifications. The table below provides a couple of examples of the range of values within the 1% uncertainty full scale specification.

Range	1% Uncertainty Full Scale	Tolerance Range for 5 ppm Actual Value
0 – 100 ppm	±1 ppm	4 – 6 ppm
0 – 50 ppm	±0.5 ppm	4.5 - 5.5 ppm

The smaller the gas range and the lower the uncertainty, the greater the accuracy of the resulting gas measurement. For spontaneous combustion events, early detection is vital and hence smaller ranges in the 0 – 50 ppm with a low uncertainty should provide a better representation of the gaseous environment underground.

The challenge testing of gas analysers/sensors between scheduled calibrations can be useful in detecting drift and other maintenance issues.

Another opportunity exists where the final gas data at a particular location may need to be verified prior to storage.

For example - where the data departs from the trend etc. or two different gas monitoring devices return different results.

In these cases, the gas values and measure techniques need to be double checked to ensure that the discrepancy is resolved and correction action is taken to ensure the integrity of the gas monitoring in the future. If it wasn't for the same gas values returning different results, the issue with the gas monitoring system would not have been identified.

The final gas data at a particular location may need to be verified prior to uploading for various data types i.e. where the data departs from the trend etc. or two different monitors/devices generate different results.

Data exchange

During incidents, the sharing of gas monitoring and other data is a priority so people can work in parallel to analyse/resolve the current situation. Naturally, the various parties will all have their preferred analytical software i.e. Segas Professional, SMARTMATE, Citect and Spreadsheets.

As there are many different types of gas monitoring systems and they each have their own data format, in an emergency situation, the gas monitoring data will need to be periodically (typically at the end of each shift) converted from the native data type into a common format for each of the various parties to analyse.

The fast data conversion and it's uploading to the various parties is an important aspect of the emergency response. It would be a step forward, if there was a standardised gas sample format that each of the various gas monitoring systems could export their data into. A standardised gas sample format would reduce data handling errors, scaling errors, conversion errors and speed up the generation of reports for third parties.

The emergency management system software used by the mine to store the events, actions, tasks and data relating to the incident would be improved by having a regularly updated summary of the important gas information. The running summary would allow the mine worker coming onto shift to quickly see an overview of incident and its current status. The information and directions handed over at the end of shift, if misunderstood, can quickly lead to undesired events, hence an easily assessable running summary could reduce potential misunderstandings and well as keep everyone up to date on the incident.

CONCLUSIONS

This review has not included the data from hand held instruments and gas chromatographs or the correlation of GC data to tube bundle data. Gas monitoring is at the forefront of ensuring that gas hazards are under control and it is safe to be underground. There were two serious spontaneous combustion incidents in 2018, one in NSW and one in Queensland and both states saw an increasing trend in the reporting of high potential incidents relating to gas concentrations in particular methane in longwall panels. The prescribed limit for CH_4 in Queensland is in the process of being reduced to 2% from 2.5%.

It is therefore critical that underground coal mines have reliable and accurate gas monitoring systems with data that is readily accessible for trending and interpretation. The paper has discussed some of the issues faced in the installation and maintenance of the system and the data handling and interpretation therefore the authors recommend that:-

1. Suppliers should of tube bundle systems review their designs to see how they compare with the requirements of the National Coal Board publication The Tube Bundle Technique for the Continuous Monitoring of Mine Air
2. Suppliers of tube bundle systems should review their designs for practical application underground i.e. different colours in bundles and marshalling panels that do not have low points in them are two examples.
3. Mine sites should take note of the information contained in the National coal board publication The Tube Bundle Technique for the Continuous Monitoring of Mine Air when ordering tube bundle systems.
4. Mine site electricians should be trained in the correct calibration process for real time monitors and consideration be taken for a dedicated team of maintenance electricians to report directly to the mine ventilation officer.
5. Mine sites should review their data storage protocols and increase data storage intervals when gas values exceed a pre-described amount.

6. Mine sites need to establish a protocol whereby internal and external experts have access to the gas data to provide support during incidents and emergencies
7. Graphing packages should show the peak values for the selected time range and graphing protocols need to be amended to reflect this requirement.
8. A common files interchange system needs to be developed to allow the sharing of mine gas data and enable the development of situation reports in mine emergency response systems.

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