Tube Bundle Maintenance Really is Worth the Effort

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Abstract
Underground coal mines spend hundreds of thousands of dollars on automated tube bundle gas monitoring systems and rely on the results to assess the status of the underground environment. An Australian standard exists that outlines the required maintenance, yet very few mines fully comply with the standard.

In the case of mine emergencies, decisions made on whether it is safe to send rescue teams underground will often be based on either the results from the tube bundle system or further analysis of the gas drawn to the surface by the tube bundle system. However, often there has been no testing to ensure the integrity of the sample lines or determination of the time taken for the sample to reach the surface.

Introduction
Tube bundle systems play a frontline role in a mine's routine, automated assessment of the underground environment. They have been designed to operate 24 hours a day, every day of the year. The system operates by drawing gas samples via purging pumps located on the surface through dedicated tubes several kilometres long which run from the locations to be monitored underground to the surface. Because of these long tube runs, it can take as long as 1 hour for gas samples to reach the surface. Samples from each monitoring location are diverted from the purging pumps to a sample pump one at a time and directed to analysers that typically measure the concentrations of methane, carbon monoxide, carbon dioxide and oxygen. Since the samples are being drawn generally from dusty humid locations, they need to undergo conditioning prior to being introduced to the sensitive analytical instruments used to analyse them. For the system to remain operational these sample conditioning components must be well maintained.

Tube bundle systems are used to monitor the atmosphere in most types of locations underground. They sample from return airways to detect the onset of any spontaneous combustion, as well as from sealed and active goafs to determine explosibility, air ingress and spontaneous combustion activity.

The measured results are automatically compared to values determined by the mine for each particular location. Further investigation or immediate action is warranted if these values are exceeded, indicated by the activation of an alarm.

Tube bundle analysis is relied on heavily during sealing operations to assess the explosibility and therefore the need for withdrawal of personnel if an explosive atmosphere is measured This is a requirement under Queensland legislation. It also allows the effectiveness of inertisation to be assessed during both routine sealing and efforts to control spontaneous combustion.

An important advantage of tube bundle systems is that analysis is continued even after the evacuation of the mine which may not be the case with in-situ gas sensor systems. Because of this, during mine emergencies it is often the results from these systems, or further analysis of the gas drawn to the surface by the system, that decisions on re entry or the deployment of rescue teams underground are based, as no other information may be available.

Considering that decisions are made on the deployment and withdrawal of personnel underground based on the samples collected and measured using tube bundle systems, it is essential to ensure that the samples are, in fact, representative of the location they are supposed to represent and that the analysis is accurate. It could be disastrous to base decisions on results from systems that have not recently been tested for sample line integrity or the time taken for a sample to reach the surface is not known.

Australian standard, AS2290.3 “Electrical equipment for coal mines—Maintenance and overhaul Part 3: Maintenance of gas detecting and monitoring equipment” outlines the maintenance required for tube bundle systems. Very few mines fully comply with this standard.

Required Maintenance
Maintenance of the system is required both on the surface and underground. Mines with tube bundle systems should have operating procedures that cover all of the maintenance required including scheduling and record keeping. AS2290.3 outlines the following record retention periods.

Examination Frequency	Record Retention Period
Every shift	Daily
Daily	Weekly
Weekly	Monthly
Monthly	Six monthly
Six monthly	Yearly
Yearly	2 Yearly

Daily
Daily checks outlined in AS2290.3 include checking on the system alarm conditions, out of normal readings and, where practicable, the cleanliness of detector heads, water traps and filters. Water traps and filters are located both on the surface and underground and maintenance of these components ensures optimum flow (and hence least delay) through the tubes. If the water traps underground are not emptied or set up to automatically drain, once full, the water will pass through the sample tube where it is likely to accumulate in sags increasing the resistance in the line and even totally blocking the line. If the water traps on the surface are not emptied, once full, the water can make its way to the analyser or again cause increased resistance or total blockage in the line. Often flame arrestors are fitted at the very end of the line with the gas flowing through them prior to any filters or water traps. In this case the flame trap itself will act as a filter and particulates including dust will build up in the flame arrestor causing an increased resistance and therefore reduced flow. In these cases the flame arrestors will need to be inspected and cleaned where necessary on a regular basis.

Examination of the condition of sampling pumps and, where available, sample line vacuum readings should also undertaken daily according to the standard. In modern computer controlled systems the condition of sample pumps and tube vacuum pressures are monitored (and logged) by SCADA (supervisory control and data acquisition) software with alarming functionality available to warn of any problems. Sampling and purging pumps functioning adequately is obviously essential for the correct operation of the system as it relies on the pumps to get the gas samples to the analysers. Elementary as this might seem, without appropriate functionality within the SCADA software these checks are not always performed daily, especially when the tube bundle surface infrastructure is located remotely from surface operations

Monitoring and trending of line vacuum pressures can be a very useful diagnostic tool, highlighting problems with increasing resistance in the tubes resulting in slower flows, or a loss of vacuum pressure indicating a severed or leaking tube.

Monthly
AS2290.3 calls for a monthly verification check of the analysers’ accuracy. Certified test gases corresponding to at least 40% of full scale concentration for each measuring range used for each gas measured are to be used. Some analysers have more than one measuring range. As the calibration is independently set for each of the ranges, the accuracy of each range must be checked to ensure the accurate measurement and subsequent assessment of the atmosphere underground. This check is to comply with the accuracy requirements

defined in the standard (given below). The person conducting the testing is to be satisfied that the system is likely to continue to meet these criteria until challenged again at the next month's testing.

Once the verification check has been performed the standard requires integrity testing (leak checking) of each of the sample tubes by applying a gas of known concentration at the normal entry point of sampled gas to the system. The gas is applied for a long enough time to facilitate an accurate reading on the surface. The standard also sets acceptance criteria to determine whether or not the tube passes or fails. These acceptance criteria require that each point return results within the accuracy requirements (outlined below) for the gas applied. This is not a simple calculation, and the results from leak testing must be properly interpreted to ensure tubes meet the acceptance criteria.

An advantage of conducting testing in this way is that it will also highlight a blockage in a tube as the gas of known concentration won't make it to the surface. Integrity testing is one of the most commonly neglected areas of tube bundle maintenance, mainly due to the time taken to conduct the testing. However, considering that the automated triggering of alarms and assessment of the underground environment is based on the results for the gas passing through the analyser, which may or may not be representative depending on line integrity, the performance of this type of testing is of paramount importance.

There are a multitude of reasons why tubes could develop leaks or blockages that stop the flow of gas to the surface. Tubes are often up to seven kilometres long and can be made up of different lengths of tube joined with compression fittings all of which are possible points of leakage. The hostile nature of underground coal mining means that tubes are at risk of being damaged. The tube used is not resistant to ultra violet light and so tends to degrade over time resulting in leaks at places where it is exposed to light such as on the surface or in illuminated underground areas.

Although not required by the standard, an approximate draw time for each tube can be easily determined when performing leak checks. Knowing the time it takes for the gas to be drawn to the surface can be crucial when trying to work out what and where something may be occurring underground. It also allows assessment of whether the draw time is acceptable. Criteria can be established for what is an acceptable draw time based on the length of tube. If testing reveals a non compliant tube remedial action should be taken, which may include blowing out the tube with a dry compressed gas.

Why is the draw time important? The time taken for the gas to reach the surface must be taken into account when establishing triggers particularly for explosibility during sealing operations. If it is determined that the sample from a location set up to monitor explosibility of a goaf during sealing takes 70 minutes to reach the surface, waiting until monitoring shows the atmosphere to be explosive is too late. It already was at least 70 minutes ago! This concern can only be dealt with if the draw time is known.

When conducting leak testing and determining sample draw times it must be remembered that if the flame trap and water trap filter assembly aren't included in the test that the measured draw time could be less because of the reduced resistance in the line. Also sources of leakage may have been eliminated from the test as there are joiners on these components that could leak when they are returned to normal operation. Testing of the tubes must be conducted with them assembled as they would normally operate where possible.

Yearly
The standard states that an accredited test authority must calibrate the equipment over its full operating range(s) in accordance with that authority's terms of registration. Verification of the operation of all equipment functions with particular reference to alarm activation is also required.

The accrediting body in Australia is the National Association of Testing Authorities (NATA) who specify under their terms of registration that calibrations are to be performed every six months. As the standard does state that calibrations are to be performed in accordance with the terms of registration, calibrations are to be scheduled and performed every six months and not annually to comply with the terms of NATA accreditation. This calibration requires calibrating and checking each measuring range for the infrared analysers (typically carbon monoxide, methane and carbon dioxide) over six points plus zero. These six points are typically 15, 30, 45, 60, 75 and 90 percent of full scale. The oxygen analyser requires only three points and zero for each measuring range. The three points must cover an adequate spread of concentrations between zero and full scale. For example, 25, 50 and 75 percent of full scale would be an adequate spread of the three points. The accuracy requirement for each point tested is calculated as outlined below.

Accuracy Requirements

The acceptance criteria for accuracy outlined in AS2290.3 are calculated as follows and apply to all instruments except for those used to measure oxygen.

$$\%RE = 10 - \frac{\%FS}{20}$$

where:

%RE = allowed percent relative error in reading and
%FS = percentage of full scale concentration.

The maximum acceptable calibration error is then:

$$ME = TC \times \frac{\%RE}{100}$$

where:

ME = maximum acceptable calibration error
TC = true gas concentration.

The output produced must be within TC ±ME.

Example:

A carbon monoxide analyser has a measuring range of 0-1000 ppm and is to be checked with a certified gas mix containing 600 ppm carbon monoxide which is 60% full scale. What is the maximum allowable error?

$$\%RE = 10 - \frac{60}{20}$$

= 7

and:

$$ME = 600 \times \frac{7}{100}$$

= 42

To meet the maximum acceptable calibration error the analyser must return a reading of 600± 42 ppm, so any reading between 558 and 642 ppm is acceptable.

The acceptance criteria for oxygen measuring equipment was set for personal protection and only covers the range of 15- 21%. The difference must be no greater than ± 0.2%.

Example:

An oxygen analyser is to be checked with a certified gas mix containing 20.2% oxygen. What is the maximum allowable error?

For oxygen analysers (between 15-21%) the maximum allowable error is simply ± 0.2%. So to meet the maximum acceptable calibration error the analyser must return a reading of 20.2± 0.2%, so any reading between 20.0 and 20.4% is acceptable.

For other applications measuring less than 15% oxygen such as in sealed areas, AS2290.3 recommends that the user ensure that the equipment is calibrated to their satisfaction. Generally the same ±0.2% criterion is used.

For all equipment, the acceptance criterion for zero gas is ±1% full scale concentration.

Example:

A carbon monoxide analyser has a measuring range of 0-100 ppm and 100% nitrogen is being used to check the instrument's zero set point. What is the maximum allowable error?

1% of the full scale of 100 ppm is 1ppm, so to meet the maximum acceptable calibration error the analyser must return a reading of 0 ± 1 ppm, so any reading between -1 and 1 ppm is acceptable.

Action

Each requirement outlined in the standard also specifies the action to be taken if the system fails to meet the requirements. Essentially anything that fails to comply should be withdrawn from service in a way that leaves the system in an operational condition as far as practicable. Parts that are withdrawn are not to be reintroduced to service until they are adjusted or repaired to bring them into compliance.

What's the point of performing maintenance checks if we don't act on what we find?

Authorised Persons.

The standard specifies that persons responsible for the examination and basic maintenance of equipment shall be authorised and provided with training which will enable them to perform the work in a competent manner. A certificate or other proof that such training has been received is to be held by the authorised person.

Other Considerations

The certified test gases used for the monthly verification testing should be analysed and their concentrations confirmed prior to being used to set the instrument response. Problems have occurred in the past with concentrations present in the supplied certified gas mix differing from that on the accompanying certificate. If there is a problem with the calibration gas this will compromise the results for the points being analysed. Even when within the specified tolerances changing a span gas can cause a step change in results. To avoid these problems, prior to being used to set the instrument response the gas should be analysed either through the tube bundle analyser using the current calibration or using another technique such as gas chromatography. If a problem is identified between the reported concentrations and those measured the gas should not be used.

Commonly if an alarm is triggered, the offending result needs to be confirmed using an alternative technique (for example tube bundle results confirmed by gas chromatography analysis) before any required actions are instigated. What happens when one technique indicates a trigger level has been exceeded but another technique gives a result under it? To avoid this problem comparison should be made between measurement techniques to identify any differences that exist prior to any gas related incidents. Identifying issues like this prior to any gas problems underground will make rectification of problems easier and increase workforce confidence in results during gas incidents.

To ensure that the samples being analysed have been sampled from the sample point as recently as possible, use is made of purge pumps that continually draw a gas sample to the surface where it is vented. This means that the sample is not drawn only when selected to flow through the analyser via the sample pump. Because each purge pump applies a vacuum to multiple tubes the resistance of these tubes needs to be matched or balanced otherwise more gas will be drawn from the tube with least resistance. Conversely, if one tube has much more resistance than the others then little gas will be drawn through that tube leading to a longer draw time. Balancing the tubes drawn on by the one purge pump, overcomes this problem.

It is essential that the flow rate to the analyser is the same for all sample tubes as well as the calibration gases. Oxygen measurements are dependent on flow rate so if flow rates differ incorrect oxygen concentrations will be recorded which can influence the assessment of the atmosphere, particularly when using spontaneous combustion ratios.

The tube used in tube bundle systems is available in a variety of colours, and when initially installed the mine usually runs the entirety of the tube in one colour. When monitoring locations are advanced or changed, often extra tube added to the existing tube is a different colour. Although this doesn't affect the operation of the system it does make tracing lines a problem. If a leak is detected through integrity testing tracking a tube that changes colour and that may no longer be a unique colour makes the task more difficult than it need be. It also makes the process of changing a monitoring location more difficult, particularly if there is more than one tube of that colour running through the area the new tube is to be joined to.

Mines are good at keeping mine plans showing where the tubes are sampling from but often if it is from behind a seal the location is just shown as the seal itself. If the tube was installed by contractors responsible for the building of the seal this important information can be soon lost. Records of where the sampling point terminates should be kept, as this information could be critical during interpretation of an event. This is particularly so if multiple sample tubes exist for use with other monitoring techniques as additional tubes don't always terminate in the same location.

Very few mines keep mine plans showing how the tubes are run to get to the sampling location. Often this information is only known to the person who ran the tube and as tubes are shifted around the pit it becomes more difficult to determine where the tubes are actually run. The tube colours used should be included on these plans.

If a mine is forced to evacuate because of elevated gas concentrations, it is important that the monitoring and interpretation of the situation can continue without the need to go underground to collect samples. This essentially means that, if not already in place, the mine needs to establish enough sampling tubes from appropriate underground locations to the surface to enable an adequate assessment of what is going on underground. It is unlikely that re entry to the mine will be allowed based on one sample location. The installation and commissioning of sample tubes is not a quick task so a mine should be prepared for this prior to the escalation of any problem.

Prior to the acceptance of any results from a new sampling location that point should undergo integrity testing to the same standards as outlined above in the monthly maintenance requirements.

Most tube bundle systems allow the operator to set the time between the initial switching of the sample point to the analyser and when the measurement is recorded. This timing is critical. If it is set too low then the sample stream selected does not have sufficient time to flush out the previous sample or the analyser may not have stabilised. The concentration could be still climbing or falling depending on the sample at the time the measurement is logged. If this time is set too high although the results are not compromised the cycle time increases and the time between measurements for each sample can be increased significantly. For a thirty point system sampling each point once in a cycle, increasing this time from sixty to one hundred and twenty seconds means that each point goes from being sampled every thirty minutes to once every hour.

Modern SCADA software for tube bundle systems generally features a mine plan indicating the sample locations. When sample locations are changed this mine plan needs to be updated and locations renamed immediately to remove any chance of confusion or misinterpretation of the data. Alarm set points also need to be reviewed and, if necessary, modified to ensure they are appropriate for the new location.

Recommendations

- Perform maintenance in accordance with AS2290.3
- Perform maintenance using suitably trained and authorised personnel
- Maintain records of maintenance in accordance with AS2290.3
- Determine draw times monthly for all sample tubes and compare to acceptance criteria
- Balance/regulate tube flows connected to the same purge pump
- Regulate flow through analyser so all points have the same flow rate (including calibration gases)
- Perform integrity testing and draw time determination when commissioning new tube
- Record where sample points draw from behind seals
- Confirm concentrations of certified gases prior to use
- Identify (and rectify) any variations between measuring techniques
- Record on a mine plan how tubes are run to reach their sampling location
- Have adequate and appropriate monitoring locations in place prior to any gas related mine evacuation
- Optimise sample time for each system
- Update location names and, where applicable, mine plans in controlling software

In Conclusion

Considering the information that this system generates is used to assess the safety of the underground environment, and it is often the only means of obtaining samples in an emergency (at least initially) surely that makes it worth putting in the time and effort to ensure that the system is suitably maintained and in a state that will provide representative and accurate results.

References

Australian Standard (1990) “AS2290.3 Electrical equipment for coal mines – Maintenance and overhaul Part 3: Maintenance of gas detecting and monitoring equipment.”

NATA ISO/IEC 17025 Application Document “Supplementary Requirements for accreditation in the field of Chemical Testing” January 2007.