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HOW BLOCKED GAS DETECTORS CHANGE THE APPARENT CONCENTRATION OF GAS

Ian Webster

ABSTRACT: The operation of a diffusion type gas detectors used in fixed, machine mounted and handheld applications is reliant on the natural equalisation of dissimilar gas concentrations driven by partial pressures inside and outside the detector.

Typically, this equalisation is inhibited (to a greater or lesser degree) by protective filters and barriers surrounding the fragile sensing elements from the typically harsh ambient environments. The accumulation of dust and other foreign matter on the protective filters can further inhibit the diffusion of gas into a detector.

The usual calibration process for a gas detector – typically by a ‘bump’ or ‘challenge’ test – will often fail to detect when a detector is blocked, or partially blocked. This can lead to the ‘calibrated’ detector reading high or low, but with no way to determine if that is the case.

Retrospective examination of records and equipment from Pike River Mine lead to the conclusion that critical detectors were affected by filter blockages, resulting in methane detectors reading approximately one-half of the true concentration.

This presentation explores how a blocked detector can give an erroneous reading, and what steps can be taken to avoid replicating previous mistakes.

INTRODUCTION

The Pike River Mine disaster in 2008 was investigated by multiple parties: the Royal Commission of Inquiry (Royal Commission on the Pike River Coal Mine Tragedy, 2012) was notably transparent in its deliberations and public in publishing its findings. A number of matters relevant to gas detection safety systems were raised.

GAS DETECTORS AT THE PIKE RIVER MINE

The underground workings at Pike River were separated into ‘Restricted’ and ‘Non-Restricted’ zones, generally based on the likelihood of explosive gases (methane at 0.25% vol/vol) (New Zealand Department of Labour, 2011). Equipment in the Restricted zone was required to be explosion protected, while equipment in the Non-Restricted zone was generally not explosion protected.

The perimeter of the Non-Restricted zone was monitored by a series of catalytic methane sensors. See Figure 1. These detectors were configured to trip electrical power when the ambient atmosphere reached 0.25% vol/vol methane. The efficacy of this means of protection was arguably compromised by the close proximity of the detectors to the Restricted zone – in some cases a distance of only several metres (New Zealand Department of Labour, 2011). Such proximity made no allowance for the response time of the detector, nor for the inevitable telemetry or tripping delays, given the flow of general body air forced by the mine ventilation.

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Inside the Restricted zone, personnel and explosion protected equipment were guarded by three (identical) catalytic detectors configured to trip electricity supply at 1.25% methane.

Of particular interest were the two methane detectors, located respectively at the bottom and top of the main ventilation shaft. These two detectors monitored the same general body of air, albeit with a delay (associated with the transport lag of air moving up the ventilation shaft).

The detector at the bottom of the shaft was believed to have been mounted in a conventional manner, and readily accessible to maintenance workers. The detector at the top of the shaft was reportedly suspended down the shaft a distance of several metres, in an unidentified orientation. The top of the ventilation shaft was located in a generally inaccessible area, making checking and maintenance of the detector problematic. When last calibrated (prior to the first explosion), the sensor at that location was reported as ‘wet and muddy’.

Approximately eleven weeks prior to the first explosion, the detector at the base of the ventilation shaft was withdrawn from service. The control room console marked the detector as ‘Faulty – waiting for spare’. See Figure 2.

There were several problems with the gas sensors in the ventilation shaft. First, the sensor at the bottom of the ventilation shaft stopped working on 4 September 2010, nearly 11 weeks before the explosion, and was never repaired or replaced. Indeed, the control room operator’s screen on the Safegas system was permanently annotated to say the sensor was ‘faulty’ and ‘waiting for spare’.

Approximately eleven weeks prior to the first explosion, the detector at the base of the ventilation shaft was withdrawn from service. The control room console marked the detector as ‘Faulty – waiting for spare’. See Figure 2.

![Figure 1: Designated Restricted and Non-Restricted zones at Pike River Mine](image)

*Figure 1: Designated Restricted and Non-Restricted zones at Pike River Mine*

(Royal Commission on the Pike River Coal Mine Tragedy, 2012)
When compared to the last recorded data from the methane detector at the base of the shaft, the surface fan detector appears to be reading at half the value of the detector at the base, even though no dilution of the methane concentration was possible in the ventilation shaft. See Figure 3.

![Comparison Bottom and Top of shaft CH4 Sensors](image)

Figure 3: Comparative methane detector readings at bottom (in blue) and top (in red) of main ventilation shaft at Pike River Mine
(Royal Commission on the Pike River Coal Mine Tragedy, 2012)

In the absence of the identical detector previously located at the bottom of the shaft, this detector was the principal sensor measuring the concentration of methane in the general body of air.

**THE RECOVERED DETECTOR**

After the series of four explosion at the Pike River Mine, investigators somewhat fortuitously recovered the methane detector previously located at the top of the ventilation shaft. It had been ejected from the mine at some point, and was discovered in adjacent bushland.

The recovered detector had sustained superficial damage, but was otherwise intact. See Figure 4.

![Recovered methane detector from top of main ventilation shaft](image)

Figure 4: Recovered methane detector from top of main ventilation shaft
The display was found to be non-functioning. Connections terminals inside the enclosure were present, but damaged. See Figure 5. The sensing element of the methane detector was occluded by significant debris. See Figure 6.

Figure 5: Recovered methane detector from top of main ventilation shaft

Figure 6a: Sensing element occlusion on recovered methane detector

Figure 6b: Sensing element occlusion on recovered methane detector
The detector was subjected to a forensic performance examination. The detector was found to be operational, albeit reporting gas concentrations of approximately 50% of the applied concentration. This reading anomaly is consistent with the data from the mine site during operation. Significantly, the response increased after the debris was removed from the sensor housing.

_The Gasguard Sensor (Serial No. 24063004) was inspected. Access to the enclosure was precluded by mechanical damage to one corner of the lid obscuring fixing screw. DII staff ground the lid to enable access to internal electronics._

_Blast damage had ripped external wiring through cable gland. DIN rail fittings were burned and fractured. Coal dust and charred remains were located inside enclosure. Some insulation in internal wiring was damaged and missing. Printed circuit boards appeared to be in relatively good condition. Identification labels were partially obscured. Wiring harness to catalytic bead was unplugged._

_The sensor was powered from the controller, drawing ~25 mA load current with catalytic bead disconnected. This was considered normal. The liquid crystal display on the enclosure lid did not operate._

_The catalytic bead harness plug was re-inserted. Load current increased to ~72 mA – again normal. The sensor output was measured at 5.4 mA (expected to be 4 mA with zero methane)._

_The sensor output was connected to the controller input. With zero methane controller read 0.3%._

_Methane gas at 1% concentration was applied. The sensor responded relatively slowly, rising to an indicated 0.43% (not steady state)._  

_Methane gas at 3% concentration was applied. The sensor again responded relatively slowly, rising to an indicated 1.47% (not steady state)._  

_The stone guard, hydrophobic barrier were removed, together with an accumulation of coal dust and debris._

_Methane gas at 3% concentration was re-applied. The sensor again responded more quickly, rising to an indicated 2.06% (not steady state)._  

_(Webster, 2014)_

At the time of the examination, no further consideration was given to the anomalous readings, other than to note that the response time of the detector was inordinately slow.

RESPONSE TIME TESTING

The examination of the recovered detector prompted a hypothesis that occluded detectors would have slower response (t90)\(^1\) times than a ‘clean’ detector. The hypothesis was tested using an artificially occluded detector in a laboratory environment.

Figure 7 shows the measured response times. The conjecture that more severely occluded detectors have slower response times was confirmed.

Moreover, it was also observed that more severely occluded detectors also converged to lower indicated concentrations, even though the same concentration of test gas was applied in each instance.

This observation is consistent with the reported differences in detector readings from the bottom and top of the ventilation shaft at Pike River. The sensor at the top of the shaft was observed

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\(^1\) The t90 is defined as the time taken by a sensor to reach 90% of its final value.

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to be compromised by debris, and the difficult access to that location could have limited frequent inspections and maintenance.

![Graph showing detector response times with varying degrees of debris occlusion. Vertical axis is gas concentration (CH4% vol/vol); horizontal axis time (secs)](image)

**Figure 7: Detector response times with varying degrees of debris occlusion. Vertical axis is gas concentration (CH4% vol/vol); horizontal axis time (secs)**

**WHY BLOCKED DETECTORS READ INCORRECTLY**

Subsequent work has further examined the relationship between occlusion and measured accuracy.

Firstly, comparisons were made between catalytic type and Infrared (IR) types of sensing elements. It was observed that occluded IR detectors exhibit the same (slower) response times as do catalytic detectors, but do not deviate in (final) measured accuracy in the same way as do catalytic detectors.

Catalytic detectors, unlike IR technologies, consume methane during the sensing process. Such detectors require a constant flow of methane, and oxygen, to sustain the catalytic process. Furthermore, the by-products of the catalytic process need to be exhausted from the bead surroundings.

It follows, then, that there is a constant flow of gas into, and out of, a catalytic detector, unlike an IR where a static gas sample remain essentially unaffected by the measurement process. This gas flow in the catalytic detector is clearly vulnerable to impediment by accumulated debris on the protective housing and filtering system.

**WHAT CAN BE DONE TO MINIMISE THE EFFECT OF OCCLUSION**

The most obvious mitigation strategy to avoid compromise of detectors by occlusion is to keep the sensing elements (and associated filters) clean. This is of course problematic in underground coal mines where coal dust and stone dust are frequently encountered in general air bodies in both development and production areas.
Direct measurement of the effect of occlusion caused by accumulated debris is difficult in practice. A technique that measures differential pressure across filters and membranes caused by a known, constant flow rate of test gas has been demonstrated to quantify occlusion. See Figure 8.

<table>
<thead>
<tr>
<th>Filter condition</th>
<th>Flow rate of Air</th>
<th>Manometer reading [water]</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Filter assembly" /></td>
<td>4L/min</td>
<td>434mm</td>
</tr>
<tr>
<td><img src="image2" alt="Filter assembly" /></td>
<td>4L/min</td>
<td>488mm</td>
</tr>
<tr>
<td><img src="image3" alt="Filter assembly" /></td>
<td>4L/min</td>
<td>386mm</td>
</tr>
</tbody>
</table>

**Figure 8 Measurement of occlusion by pressure differential**

The applicability of that test, however, is predicated on being able to access both sides (‘inside’ and ‘outside’) of the filter structure – a requirement that is generally not feasible in commercial detectors.

The demonstrated relationship between response time and reduced sensitivity of catalytic sensing devices also offers some insights.

Routine gas detector maintenance practices typically include a bump test whereby a test gas of known concentration is presented to the detector, and the detector adjusted to read that test concentration. Assuming that the calibration process itself does not impinge on the detector reading (say, by presenting gas at an increased pressure above ambient), this approach can arguably be used to compensate for the decreased sensitivity caused by occlusion. However, increasing the (amplitude) sensitivity of the detector does not address the compromise in detector response time. That is, an occluded detector may be adjusted to show correct concentration, but in the absence of direct measurement the response time can be compromised.

To this end, AS/NZS 2290.3 (2018) *Maintenance of gas detectors in underground coal mines* (Standards Australia, 2018) was recently revised to make response time testing a periodic requirement of the maintenance regime. The justification was two-fold:

- A compromised response time is itself a compromise of the fundamental safety function realised by the gas detector.
- A compromised response time in a catalytic detector is an indication of occlusion by debris.
Further work in the area is continuing through an ACARP\(^1\) project in association with Simtars and CMTS\(^2\).

**OTHER ISSUES WITH GAS MEASUREMENT AT PIKE RIVER**

The various aspects of safety and operations at the Pike River Mine have been documented in the media and in the Royal Commission Final Report (Royal Commission on the Pike River Coal Mine Tragedy, 2012). Amongst these, one other aspect of the gas detection installation significantly compromised is reporting of true gas concentrations.

Figure 9 shows a portion of the methane concentration log from the surface detector. An extended duration of ‘flat-lining’ at a concentration of 2.96% CH\(_4\) is readily apparent. This behaviour was considered sufficiently anomalous to warrant further investigation.

![Figure 9 Portion of the methane concentration log from the surface detector](image)

The general configuration of the detector, controller, telemetry links and programmable logic controller (PLC) are shown in Figure 10. The detector and controller were both located in the Restricted Zone, and hence were explosion protected (intrinsically safe). The PLC was located outside of the Restricted Zone and, to maintain explosion protection, an intrinsically safe barrier was inserted between the controller and the PLC. The total resistance of the PLC and zener barrier was calculated and measured to approximately 550 Ohms.

Figure 11 shows the loop resistance versus loop current for controller. It is seen that the maximum loop resistance to enable full excursion of the loop current (to 20 mA) was approximately 330 Ohms. At the actual loop resistance of 550 Ohms, the maximum loop current was approximately 13.6 mA, which corresponded to a methane concentration of 2.96%.

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Figure 10 General configuration of the detector, controller, telemetry links and PLC for surface methane detector
It follows, then, that the gas controller could never indicate a concentration of greater than 2.96%, notwithstanding any actual measured concentrations at the detector. Significantly, bump testing (calibration) of the detector was typically conducted at 2.0% – 2.5% methane, meaning that the telemetry deficiency was never revealed.

CONCLUSIONS

The series of explosions at the Pike River Coal Mine were the culmination of a large number of factors that impacted the operation and safety of the underground mine. Significantly amongst these, the accurate and timely measurement of instantaneous concentrations of explosion methane gas were found to be problematic.

One of the contributing factors was the accumulation of foreign debris into the environmental filters protecting the catalytic sensing element. The significance of this accumulated debris, and the effect on gas detection responsiveness and accuracy, were either not know, or not acknowledged.

A program of research has been initiated to quantify the effect this occlusion on gas detectors in coal mines, so as to inform the coal mining industry of the potential hazards and risks.

REFERENCES


