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INTERPRETING THE STATUS OF AN UNDERGROUND COAL MINE HEATING FOR VALID RISK MANAGEMENT AND CONTROL

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ABSTRACT: The status of an underground coal mine heating event is predominantly assessed based on gas sampling results from the affected area. The gas samples can be obtained in a number of different ways, but for accurate determination of the gases present analysis is normally performed using gas chromatography. Several gas indicators have been identified from past experiences that are used in combination to determine a Trigger Action Response Plan for individual mines. The upper levels of the Trigger Action Response Plan contain more urgent actions in response to the assessed level of advanced heating, with the ultimate level being withdrawal from the mine. Once this point is reached the only action that can be taken to control the event has to be done remotely and also, once activated it is difficult to re-enter the mine. Recent experience of a heating event provides new data that demonstrates the importance of understanding and interpreting the status of hot spot development to risk management and control applied by an Incident Management Team. This paper discusses the use of gas trending, including the development of: a new gas indicator ratio that is very sensitive to the heating status and control measures applied; and a hot spot tracking diagram that provides a good visual representation of the heating status and the response to actions taken.

NTRODUCTION

The identification of a spontaneous combustion event in an underground coal mine relies on vigilant use of a valid Trigger Action Response Plan (TARP) that has been designed to match the likely spontaneous combustion behaviour of the coal being mined. The TARP contains trigger levels based on a combination of physical (visual) signs and gas or gas ratio indicators that are chosen to enable appropriate early responses to be implemented to manage and control the event. At a more advanced stage of an event it may be necessary to prepare for sealing of the area to exclude air ingress, or in a more extreme case to completely inert the sealed area by injecting for example nitrogen. Once an event has been identified there is also the need for appropriate decision making to be implemented by an Incident Management Team (IMT) based on sound risk management supported with valid data interpretation of the status of the "heating event". This decision making process is very important as the uppermost level of the TARP is withdrawal from the mine, which has consequences for both safety of mine personnel and the management options available once this point is reached.

This paper presents a case study of a spontaneous combustion event that occurred in 2015, which was successfully managed and controlled by applying sound engineering principles. Key stages of the event are discussed in the paper rather than a blow by blow description of all the actions taken. As a result of the event some new lessons were learned that may assist in improving the management of future events.

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BACKGROUND TO THE SPONTANEOUS COMBUSTION EVENT

On Thursday 25th June 2015 a "heating event" was confirmed in 18 CT of the West Headings in the Great Northern Seam (GNS) at Mannering Colliery (Figure 1). This discovery resulted after a lengthy and difficult search initially triggered by a low level carbon monoxide alarm spike from the tube bundle monitor point at the GNS entry to the upcast shaft of the mine. The indicators found at the site included heat haze, sweating and a "benzene" smell, with elevated levels of carbon monoxide recorded by hand held gas detectors. Prior to this event, there were no known recordings of spontaneous combustion occurring at Mannering Colliery throughout its more than 50-year mine life. In addition, there were very few known recorded occurrences of spontaneous combustion in the Great Northern Seam workings throughout its extensive mining history, although spontaneous combustion events have been known to occur in stockpiled coal on the surface.

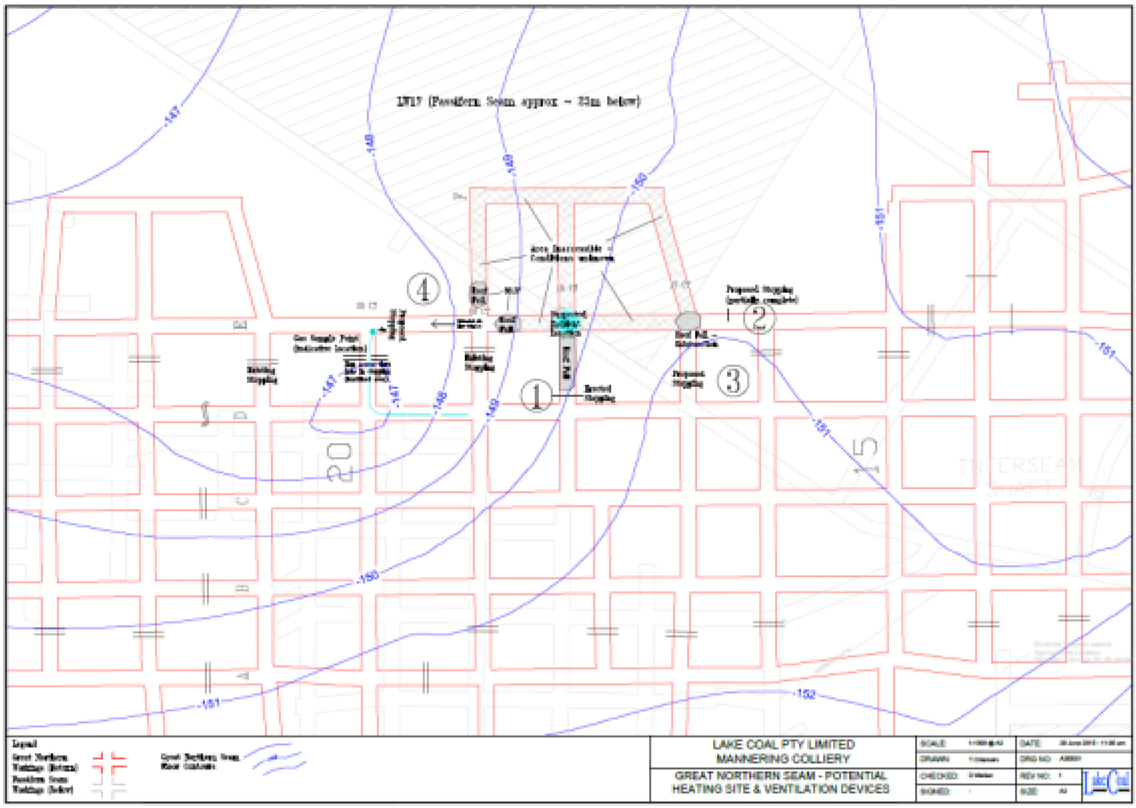

Figure 1: Location plan of heating site

The depth of cover to the Great Northern Seam is generally in the range of 150-210 m and there is typically around 30 m of interburden between the Great Northern Seam and the underlying Fassifern Seam. In-situ gas contents range from 1.6-2.75 m3/t for the Great Northern Seam and 2.4-3.5 m3/t for the Fassifern Seam. The seam gas composition is predominantly methane (>95%). R70 self-heating rate test results indicate an intrinsic spontaneous combustion propensity rating of medium to high for the Great Northern Seam, dependent on the ash content. However, the incubation period for this coal is strongly dependent on a number of site specific parameters and other coal properties.

The mine ventilation arrangements in place for more than the past two years, since placing the mine on care and maintenance, consists of a reduced flow of approximately 130 m3/s at a collar pressure of around 600 Pa. Typically, much of the underlying Fassifern Seam workings ventilation air returns up through inter-seam staple shafts and flood ventilates the old Great Northern Seam workings prior to returning to the upcast shaft. The mine has five inter-seam staple shafts that are still in use to some extent. Very few areas of the mine, either in the Great Northern Seam or the Fassifern Seam are effectively sealed. This is typical of the district, which has been mined for in excess of 100 years.

The mine uses a Maihak 10 point tube bundle monitoring system. The bottom of each of the staple shafts is monitored to capture all Fassifern Seam workings return air just prior to entering the Great Northern Seam workings. In addition, five other fixed locations are monitored within the Great Northern Seam workings, including the top of the upcast shaft, which captures the total mine return air. Mine atmosphere monitoring also includes the Mining Supervisor underground inspections and hand held monitoring. Bag samples are typically taken monthly from the top of the upcast shaft.

GAS MONITORING RESPONSE TO THE "HEATING EVENT"

Initial data and interpretation of the "heating event" status

On Friday 26th June 2015 an IMT was formed consisting of the Mine Manager, the Ventilation Officer and the General Manager of Mines Rescue and Regulation and Compliance. A number of actions were implemented including the mobilisation of the Coal Mines Technical Services (CMTS) gas chromatograph to be onsite as soon as possible as well as planned underground activities to manage and control the incident. All formal notifications had been issued the day before as required by the WH and S (Mines) Act 2013 Part 3, WH&S (Mines) Regulation 2014 Cl 179(d): "any initial indication that any underground part of a coal mine is subject to windblast, outbursts or spontaneous combustion".

The IMT were keen to establish the status of the "heating event" as this would have implications for the management actions required to control the event. The IMT contacted an external consultant who had previous experience and knowledge of the self-heating behaviour of the Great Northern Seam coal to place the initial gas readings taken the day before and the subsequent gas monitoring results into perspective. Subsequently, an additional consultant with gas monitoring experience was engaged so that the two consultants could work as a team and report back to the IMT on interpretation of the "heating event" gas monitoring results in response to control actions as they were implemented. At 6:30pm tube bundle sample point #10 was set up on its own purge pump at location 4 shown in Figure 1 and bag sampling commenced every hour, processed via the newly setup gas chromatograph and reported using SmartMate software.

The initial downstream gas readings of the "heating event" at location 4 (Figure 1) indicated a Graham's ratio of 2.54, with ethylene present. The general information in the SmartMate software indicated that for European coals this would correspond to a serious heating. It is also noted that all mines should establish their own levels and that older coals can produce a higher Graham's ratio. None of the literature values take into consideration the status of hot spot development.

In 2004, bulk self-heating tests were conducted on coal from Mandalong Colliery in both a gassy as-mined state and non-gassy, dried coal state (Jabouri 2004 and Beamish and Jabouri 2005). The coal tested is analogous to that present at Mannering Colliery (same seam and only 8 km away). The relationship between hot spot coal temperature and Graham's ratio from these tests (Figure 2) indicates that for the Graham's ratio of 2.54 the hot spot temperature is in the range of 110-130 °C, depending on how dry the coal is. In the area of the "heating event" site the coal had been standing for a considerable number of years. Therefore the hot spot temperature was more likely to be closer to the lower end of the temperature range indicated by the Graham's ratio. In addition, this was only a spot reading and subsequently 53 regular readings from 6:30pm 26/6/2015 to 5:56pm 28/6/2015 yielded a Graham's ratio of 2.21±0.10.

A review of the data obtained by Jabouri (2004) from bulk self-heating tests of Mandalong coal showed that at the hot spot temperature indicated by the Graham's ratio, the ethylene/ethane ratio becomes a good confirmation indicator of the hot spot development status (Figure 3). When this ratio is 0 it is an indication that the hot spot has not advanced to a significant stewing stage. Once the value increases above 0.3, a well-defined hot spot has formed and the hot spot begins to migrate towards the free surface. The faster this ratio approaches 1 the more rapid the temperature increase becomes with ignition being imminent. This trend in the ethylene/ethane ratio was also confirmed by additional bulk self-heating test results for Mandalong coal obtained from testing conducted in 2010 (Pantano, 2010). The initial bladder sample produced an ethylene/ethane ratio of 0.12. When compared to the results of the bulk self-heating tests of Mandalong coal this indicated a hot spot temperature range of approximately 100-120 °C (Figure 2). The slightly lower temperature range indicated by the ethylene/ethane ratio compared to the Graham's ratio may be an artefact of minor ethane seam gas being added to the airstream and thus lowering the ethylene/ethane ratio. Fifty three subsequent readings yielded an ethylene/ethane ratio of 0.12±0.01.

Using the ethylene/ethane ratio removes the risk of missing hot spot temperature acceleration due to the dependence on gas indicators obtained from a single gas such as carbon monoxide make for example. An error in the measurement of carbon monoxide due to drift in calibration could also result in a false higher or lower Graham's ratio.

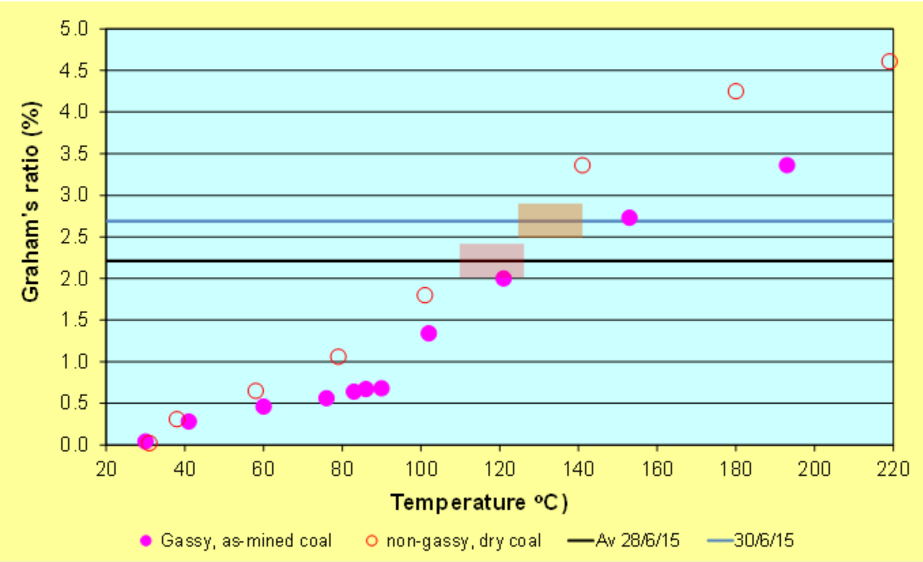

Figure 2: Relationship between hot spot temperature and Graham's ratio for Mandalong coal (original data from Beamish and Jabouri 2005)

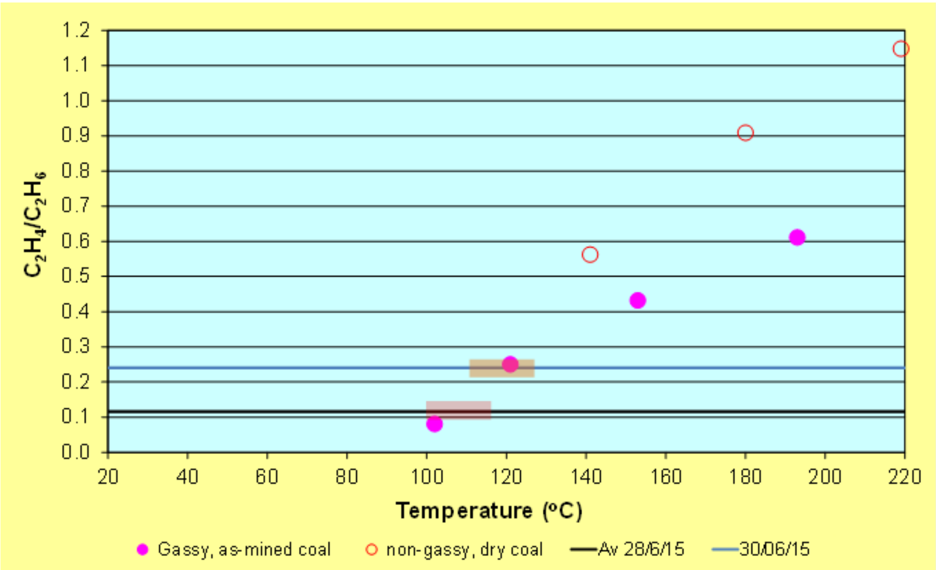

Figure 3: Relationship between hot spot temperature and ethylene/ethane ratio for Mandalong coal (original data from Beamish and Jabouri, 2005)

Once the hot spot status had been identified it was possible to provide a more realistic risk assessment to amend the TARP to make use of logical trigger levels. These were assessed by considering the rate of increase in both the Graham's ratio and ethylene/ethane ratio with temperature. Looking at the sensitivities of these two indicators, it was decided to implement a Graham's ratio of 3 and an ethylene/ethane ratio of 0.24 for the Level 3 TARP, as these would indicate a substantial elevation in the hot spot temperature and coincide with the hot spot advancing towards a free surface.

Hot Spot Tracking diagram and application to the "heating event" management and control

Having decided on the best gas indicators to monitor the progress of the heating taking place there was a need to present this information in such a manner so that any changes taking place could be readily identified and matched against actions taken to manage and control the "heating event". An additional factor was added to this tracking sequence, namely the barometric pressure in case changing natural conditions affected the ventilation and air supply to the heating.

Initially separate plots were used for each indicator with a timeline on the X-axis. However, as the event progressed it became apparent that a composite plot was needed for tracking the hot spot development and the response to ventilation changes. Initially, the Graham's ratio was plotted on the left Y-Axis (with a range of 0 to 3, matching the Level 3 TARP trigger) and the barometer was plotted on the right Y-Axis. The values of the ethylene/ethane ratio were approximately 0.12 and the Level 3 TARP trigger had been set at 0.24. It was decided that to enable the Graham's ratio and the ethylene/ethane ratio to be on the same plot a multiplier of 10 should be applied. This composite plot can be termed a Hot Spot Tracking (HST) diagram (Figure 4).

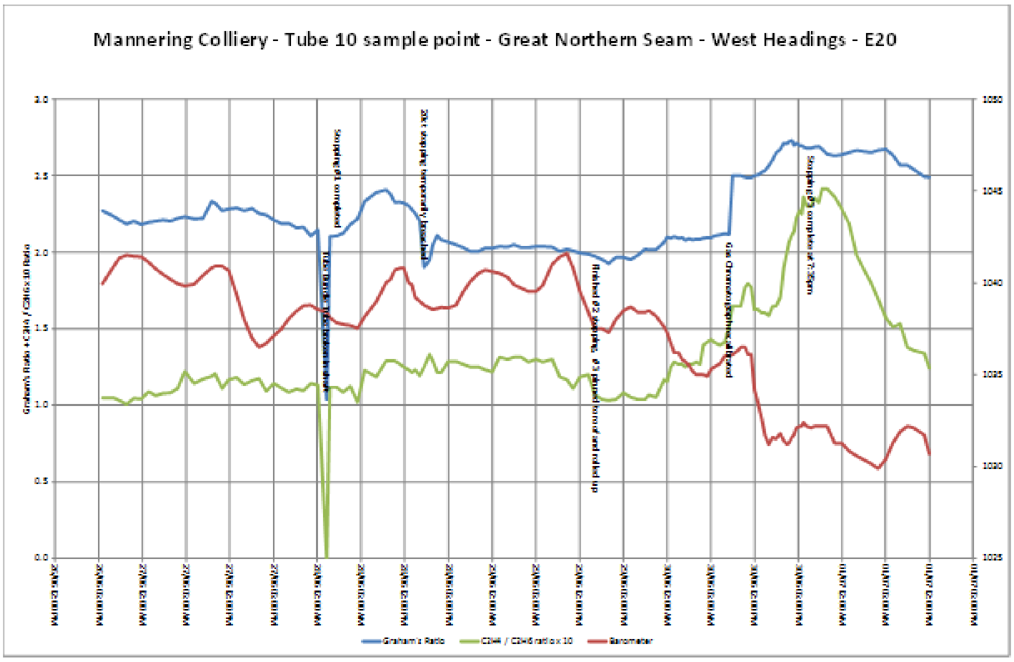

Figure 4: Hot spot tracking response from 26/6/2015 to 1/7/2015

Between the commencement of monitoring on the 26/6/2015 and early morning of 30/6/2015 both the Graham's ratio and the ethylene/ethane ratio remained relatively stable even with a falling barometer (Figure 4). This enabled preparatory work to continue unhindered with the eventual aim of sealing off the area. However, by Tuesday afternoon (30/6/2015) after a recalibration of the Gas Chromatograph CO detector it became apparent that the baseline level of the Graham's ratio had increased significantly and the ethylene/ethane ratio was increasing substantially (Figure 4). By late Tuesday evening these values were rapidly approaching the Level 3 TARP triggers.

An assessment of possible explosive mix scenarios had been performed throughout the day based on the makes of the various gases and oxygen consumption rate. Given the status of seal-up preparations at that time the only option available to control the air reaching the hot spot was to lower the previously installed rolled up flexible stopping at location 3 (Figure 1) and restrict the ventilation entering the heating site in preparation for a final sealing at location 4 (Figure 1) on the downstream side of the heating. The response to this ventilation control was expected to be a decrease in the gas indicator ratios and a decrease in the oxygen concentration.

The response from the implementation of the ventilation intervention of completing stopping #3 was almost immediate with a rapid drop in the ethylene/ethane ratio recorded within approximately three hours. A drop in the Graham's ratio was delayed by almost 12 hours. The on-going drop in both the Graham's ratio and the ethylene/ethane ratio provided confidence in being able to take additional time to organise the final seal-up of the area, particularly as no explosive mix was developing and the oxygen content began to drop noticeably. This was also supplemented with nitrogen injection into the area. Note the CO/CO2 ratio was also added to the HST diagram (Figure 5) at this stage to provide further confirmation of the success of the ventilation intervention. A scaling factor of 60 was applied to bring the value into the same Y-axis range.

A similar response in the gas indicators from restricting the ventilation to the incident area was also recorded for a spontaneous combustion event at Spring Creek Mine (New Zealand) in 2008 (Beamish and Hughes, 2009). The assessed hot spot temperature of that event was lower than this one, but the immediate response of the ethylene/ethane decrease was identical. The Graham's ratio response was also delayed.

All gas indicator readings continued to decrease after Stopping #3 was completed and approximately two and a half days later the final seal at Stopping #4 was completed with additional nitrogen injection. The Graham's ratio initially increased, but then gradually decreased over time following the seal-up (Figure 5). However, the ethylene/ethane ratio continued to progressively decline indicating that the hot spot was diminishing. Continued monitoring of the sealed area atmosphere recorded the oxygen content decreasing to below 3% and the gas indicator ratios continued to decline, indicating the event was successfully controlled.

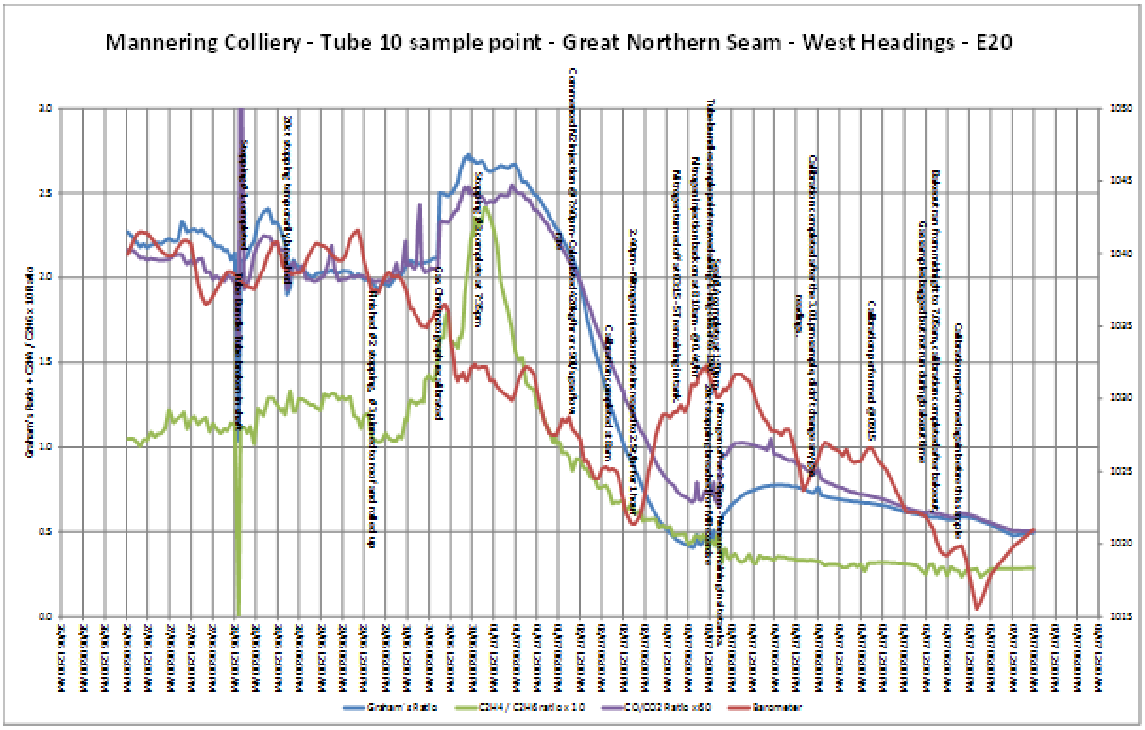

Figure 5: Hot spot tracking response from commencement of event to seal-up

CONCLUSIONS

When managing an underground coal spontaneous combustion event it is imperative that the self-heating characteristics of the coal are known so that informed decisions can be made by the IMT based on the understanding of the status of the heating. A recent "heating event" at Mannering Colliery illustrates the practical advantages of implementing this sound engineering practice. Initial detection of the "heating" indicated the presence of a hot spot that was able to be interpreted from valid laboratory data as being in a semi-stable stewing stage between 110-130 °C. This enabled preparatory work to continue towards sealing the heating in a controlled manner. A new gas indicator ratio, ethylene/ethane was also able to be introduced as confirmation of the hot spot status, which proved to be more sensitive to control measures than the normally used Graham's ratio.

Presentation of gas monitoring data to assess cause and effect was identified as crucial to interpretation of the "heating event" progress to assist with valid risk assessment for management and control. This was achieved by developing a composite plot that contained data for barometric pressure, Graham's ratio and ethylene/ethane ratio. A scaling factor was applied to the ethylene/ethane ratio to enable it to be plotted on the same Y-axis as the Graham's ratio. This new plot was termed a HST diagram as it provided a clear indication of hot spot status and progress as well as the response to control measures adopted. It was also shown that other useful gas indicators such as CO/CO_2 can be added to this diagram with appropriate scaling factors.

Staged control of the "heating event" was achieved by sequential ventilation restriction and sealing of the area. The rapid drop in gas indicators such as ethylene/ethane ratio shows how sensitive hot spot development is to ventilation control.

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