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# Comparison of Laboratory Bulk Coal Spontaneous Combustion Testing and Site Experience - A Case Study From Spring Creek Mine

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# COMPARISON OF LABORATORY BULK COAL SPONTANEOUS COMBUSTION TESTING AND SITE EXPERIENCE – A CASE STUDY FROM SPRING CREEK MINE

**Basil Beamish<sup>1</sup> and Robin Hughes<sup>2</sup>**

**ABSTRACT:** As part of an on-going commitment to leading practice in spontaneous combustion assessment and management, Spring Creek Mine has adopted a strategy of bulk coal testing to obtain data on hot spot development in broken coal, including the associated gas evolution pattern. This approach has been successfully integrated into the spontaneous combustion management plan for the mine and has enabled appropriate actions to be taken in response to the coal behaviour during a heating. Site experience gained at Spring Creek is presented to compare with the laboratory scale testing results. A key feature that has been identified for the Spring Creek coal in the laboratory is the stage of hot spot development associated with moisture evaporation as the hot spot prepares to migrate towards the air source. This stage of delayed thermal runaway provides a lead time for appropriate actions to be taken to control the heating.

## INTRODUCTION

Spring Creek mine is located on the west coast of New Zealand's South Island near Greymouth (Figure 1). The mine commenced development into the Upper Rewanui series of coal seams in 1999. The Upper Rewanui coal measures have been exploited by several large mining operations in the area over the past 100 years, all of which have experienced considerable difficulty in controlling spontaneous combustion. In their preparations for the commencement of extraction in 2004 mine management recognised that the propensity for spontaneous combustion would impact significantly on mine design, particularly the effect that the mining method (high pressure water monitors) would have on the ventilation circuits within the extraction panels. To facilitate the early recognition of the on-set of a spontaneous combustion situation, assistance was sought from the University of Queensland to accurately determine the issue of constituent gasses under various conditions. A 2-metre column test (Beamish *et al*, 2002) was conducted on a sample of Spring Creek coal in March 2005. The results of this test have assisted in the early recognition of spontaneous combustion potential allowing appropriate and timely intervention. One spontaneous combustion event occurred at Spring Creek mine in July 2008. This event was recognised and dealt with at a very early stage as a result of the gas signatures gained from the 2-metre column test, resulting in minimal lost production time and virtually no loss of reserves.

This paper presents the bulk self-heating test results for Spring Creek coal and places them into perspective with the experience gained from a heating event at the mine.

## UQ 2-METRE COLUMN TESTING

### Samples

Fresh ROM coal was supplied from the Spring Creek Mine in 4 x 20L sealed buckets. Prior to loading into the column, a size distribution of the coal was determined. The average particle size of the sample was 6.39 mm, based on the procedure described by Kunii and Levenspiel (1991) for estimating the surface-volume average particle size from the size distribution of the coal. Three samples were taken during the initial size distribution analysis to obtain data on the as-received moisture of the coal. The average test moisture of the batch was 11.6%, which indicated that the coal had retained its as-mined moisture. In addition, three lump samples were taken and stored in the laboratory freezer until they could be tested in an adiabatic oven to determine the  $R_{70}$  value of the coal. It should be noted that upon opening the 20 L buckets significant out-gassing occurred, which

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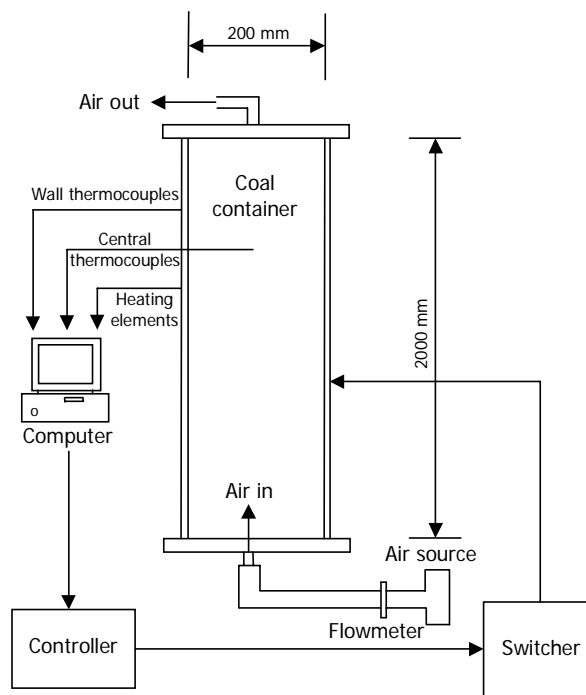
proved to be rich in methane as indicated by a Minigas handheld gas detector. Hence, the buckets were effectively self-inertised from seam gas desorption.



**Figure 1 - Location of Spring Creek Mine**

### Self-heating test procedure

Beamish *et al.* (2002) describe the basic operation of the UQ 2-metre column. The column has a 62 L capacity, which equates to 40-70 kg of coal depending upon the packing density used. The coal self-heating was monitored using eight evenly spaced thermocouples along the length of the column that were inserted into the centre of the coal at each location (Figure 2). Eight independent heaters correspond to each of these thermocouples and were set to switch off at  $0.5^{\circ}\text{C}$  below the coal temperature at each location so that heat losses were minimised radially.



**Figure 2 - Schematic of the UQ 2-metre column self-heating apparatus (modified from Arief, 1997)**

The starting conditions of the test were agreed upon with the mine so that the test was performed as close as possible to the mine environment. Once all the coal was in the column it was sealed and the heaters used to set the starting coal temperature, which for this test was  $25^{\circ}\text{C}$ . This was achieved

overnight. A sample of the gas evolved in this static condition was taken with a peristaltic pump before air was introduced to the coal at 0.25 L/min. The inlet air temperature was maintained between 23-24°C for the duration of the test. A computer recorded the temperature data from each thermocouple at ten-minute increments. The column has several safety devices including computer-controlled trips on the external heaters and a temperature trip on the air inlet line. These were set to ensure maximum safety during operation of the column. Gasbag samples were taken from the exhaust at regular intervals as self-heating progressed. All gasbags were analysed by a registered laboratory (Simtars) using an HP Quad Gas Chromatograph to determine the concentrations of oxygen (O<sub>2</sub>), nitrogen (N<sub>2</sub>), hydrogen (H<sub>2</sub>), methane (CH<sub>4</sub>), carbon monoxide (CO), carbon dioxide (CO<sub>2</sub>), ethane (C<sub>2</sub>H<sub>6</sub>) and ethylene (C<sub>2</sub>H<sub>4</sub>).

## RESULTS AND DISCUSSION

### Coal rank and self-heating rate values

The proximate analyses data (Table 1) from a nearby borehole (DH851) has been used to assess the ASTM rank and Suggate rank classification of the coal (Suggate, 2000). According to the ASTM rank classification the coal is high volatile B/A bituminous, which is in agreement with the Suggate rank of 10.4. The R<sub>70</sub> values for the three samples taken from the batch ranged from 4.71 - 4.87°C/h. These R<sub>70</sub> values show that the coal is very reactive towards oxygen and the coal is classified as having a high spontaneous combustion propensity.

Table 1 - Average analytical data for Spring Creek column sample	
DH851	Main Upper Seam
<b>Coal analysis</b>	
Inherent moisture (% , adb)	3.6
Ash (% , adb)	1.6
Volatile matter (% , adb)	41.7
Fixed carbon (% , adb)	53.1
Sulphur (% , adb)	0.39
Swelling index	3.0
Calorific value (MJ/kg, adb)	32.15
<b>Rank parameters</b>	
VM (% , dmmsf)	43.7
CV (Btu/lb, dmmsf)	14648
Suggate rank	10.4
Romax (%)	0.61
CV (Btu/lb, mmmf)	14006
ASTM rank	hvBb/hvAb

The Spring Creek coal is of similar rank to the Hunter Valley coals mined at Dartbrook, which experienced heating problems on more than one occasion (Moreby, 1997 and 2005). Hence, it displays a similar reactivity to these coals. However, it must also be remembered that the self-heating rate of the coal, and hence its propensity for spontaneous combustion is significantly affected by the presence of moisture in the coal as shown by Beamish and Hamilton (2005). Therefore to gain a better indication of propensity for spontaneous combustion the coal must be tested in an as-mined state, where the moderating effect of moisture in the coal can be taken into consideration. This is achieved with the UQ 2-metre column test.

### Hot spot development rates for Spring Creek coal

The hot spot development pattern for the Spring Creek column test is typical of the development of a heating in broken coal with a high as-mined moisture content (Figures 3 and 4). By day 12, a hot spot has been established 145 cm from the air inlet, and moves slightly downwind before the maximum coal temperature plateaus at approximately 90°C for a couple of days (Figure 4). This plateau is in response to the coal needing to discharge adsorption-bound moisture (Evseev and Voroshilov, 1986) to provide access of the air to oxidation sites allowing accelerated heating to develop. The hot spot then begins to migrate towards the air source as the coal dries out on the leading edge and by day 20

a defined hot spot tries to develop 73cm from the air inlet (Figure 3). The hot spot continues to migrate upwind as the coal dries out and eventually reaches a maximum temperature of approximately 160°C just 37cm from the air inlet after 28 days.

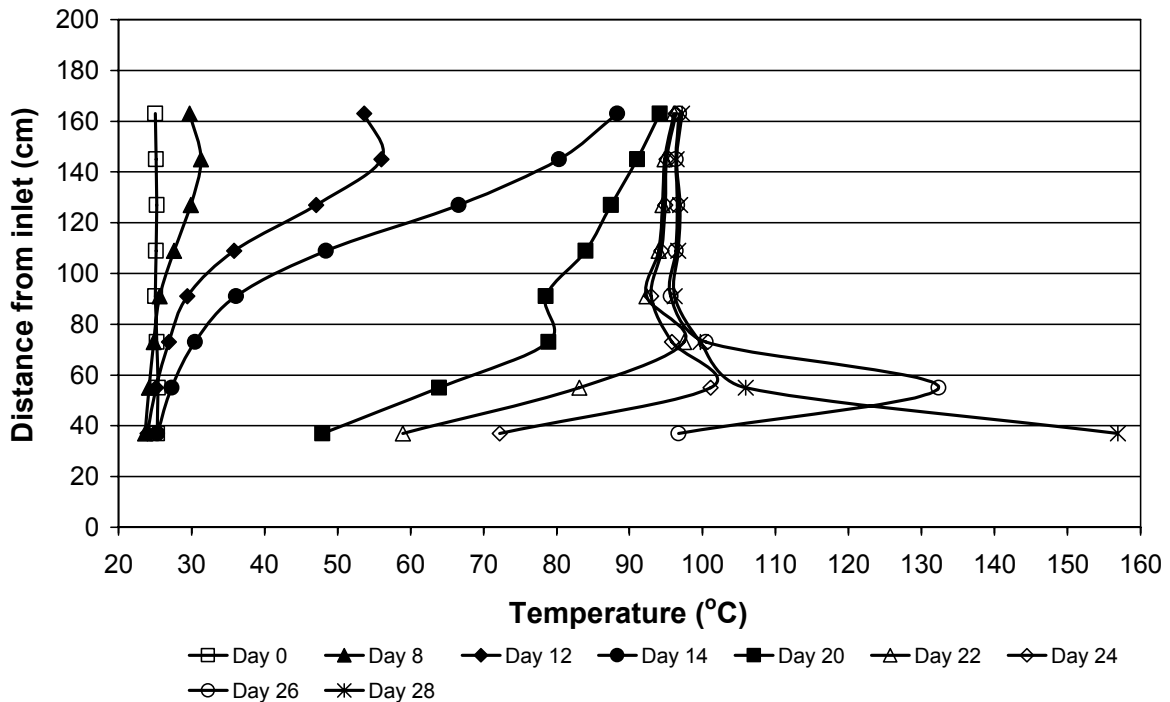


Figure 3 - Self-heating profile showing hot spot development in Spring Creek bulk coal

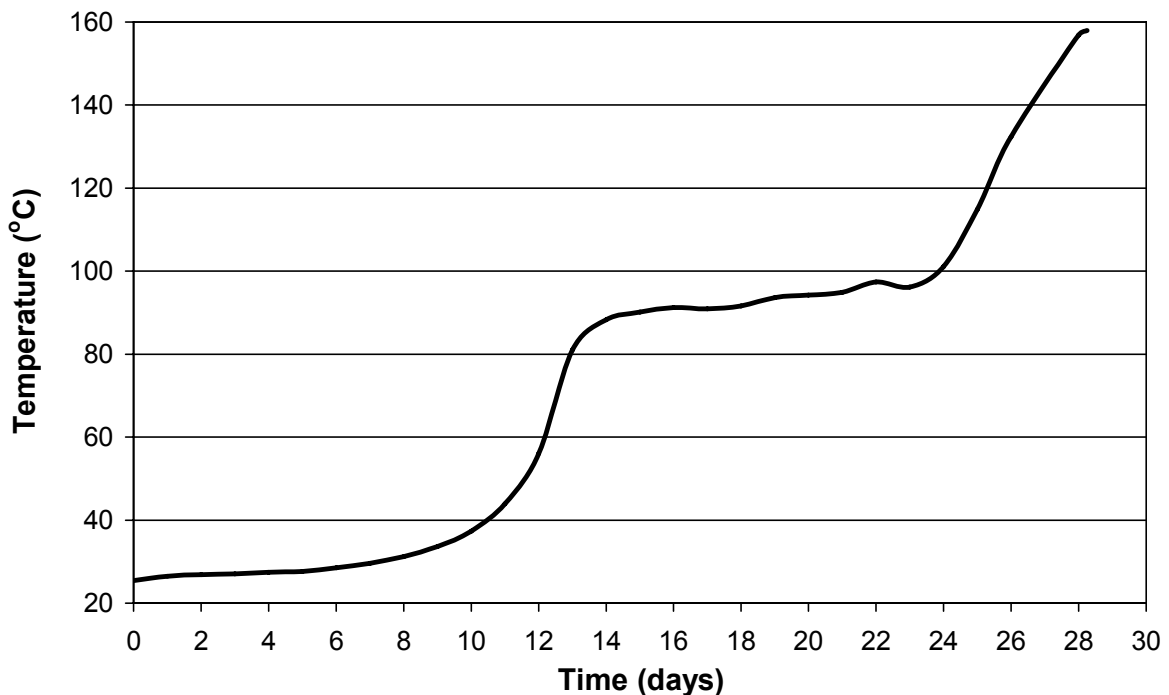


Figure 4 - Maximum self-heating temperature showing stages of hot spot development

For safety reasons, the hot spot is not allowed to progress beyond this point in the column. Instead, the heater at 55 cm from the air inlet was set at 200°C to heat the coal at this point in the column to obtain further gas evolution data. This had the effect of reactivating the hot spot at the 37 cm level in the column and a final maximum temperature of 202°C was achieved, before the test was terminated.

### Gas evolution under static conditions at 25°C

The initial equilibration of the coal in the column to the start temperature of the test is equivalent to sealing the coal in a large gas desorption canister. Hence, the results obtained indicate the presence of any seamgas in the coal. The ROM sample still contained a substantial amount of seamgas, which was predominantly methane (8.3 %) with a minor amount of carbon dioxide present (1.7%) at 25°C. Subordinate amounts of ethane (25ppm), carbon monoxide (294 ppm) and hydrogen (58 ppm) were also present. The carbon monoxide and hydrogen can be considered to be products of low temperature coal oxidation. However, the ethane is present as seamgas. The oxygen content in the column had fallen to 5.4%, indicating the coal had used up a substantial amount of the air present, which is consistent with the high reactivity of the coal shown by the R<sub>70</sub> test results.

### Gas evolution during hot spot development

The evolution patterns of the major gases and spontaneous combustion indicator ratios corresponding to the column self-heating are shown in Figure 5. Both methane and carbon dioxide show a gradual decline in concentration during the early part of the test as the coal initially warmed. This is consistent with seamgas desorption. Similarly, ethane disappeared altogether in the early stages of the test. However, both carbon monoxide and hydrogen consistently increased as the temperature of the coal increased even in the early stages of the self-heating.

The carbon monoxide evolution closely tracks the hot spot development and even plateaus in response to the hot spot reaching the stage where moisture needs to be removed from the coal for further hot spot development and migration to take place. Similarly, the Graham's Ratio (carbon monoxide/oxygen deficiency) follows the progress of the heating.

The carbon dioxide evolution also closely tracks the hot spot development once the initial gas desorption phase dissipates. Unfortunately, the carbon monoxide/carbon dioxide ratio appears anomalous in responding to the self-heating, but this is masked by the falling carbon dioxide concentration in the early stages in response to gas desorption.

The hydrogen evolution shows a significant maximum evolution at the point where the hot spot begins to plateau, but then begins to increase again once the hot spot begins to migrate towards the air source. Hitchcock, Cliff and Beamish (2008) have shown that this pattern is consistent with zones of hydrogen evolution in response to initially being generated in an oxygen rich environment followed by generation in an oxygen deficient environment. More detailed studies of this effect are in progress.

The appearance of ethylene is very distinctive and only occurs once the temperature of the hot spot exceeds 90°C. In this case it appears several days after the hot spot reaches the moisture plateau. As such it is a good indicator of advanced hot spot development and clearly if it shows a sustained accelerating trend then the hot spot is rapidly migrating towards the air source at elevated temperatures in excess of 120°C.

Ethane and methane evolution patterns are strongly controlled by gas desorption mechanics. Both show a rapid decline in the early stages of the heating, but at approximately 40°C the methane begins to increase and the presence of ethane is again detected and the concentrations of both gases rise sharply from this point until the moisture plateau is reached. The sympathetic relationship between these two suggest that there is a fundamental physical change in the coal pore structure in this temperature range that reactivates the gas desorption of these two gases. The increasing temperature of course exacerbates this mechanism. There appear to be several cycles of this phenomenon as the hot spot migrates towards the air source. It is interesting to note that on each successive cycle the methane evolution decreases, whereas the ethane evolution increases slightly or reaches a similar maximum level on each cycle. This may be a function of differential desorption between the two gases. Given the characteristic behaviour of these two gases for this particular coal they can be used as early warning indicators of a heating event.

It is also, interesting to note that as the methane evolution is decreasing in the latter half of the column, the hydrogen evolution is increasing. It has been suggested that the hydrogen response may be simply a gas density separation mechanism because the column is operated in a vertical mode. However, due to the fact that methane (another lighter than air gas) is decreasing and carbon dioxide (a heavier than air gas) is increasing, density separation of the gases in these experiments is clearly

not happening and the observed gas evolution is simply responding to the general body airflow through the coal allowing the oxidation reactions to take place.

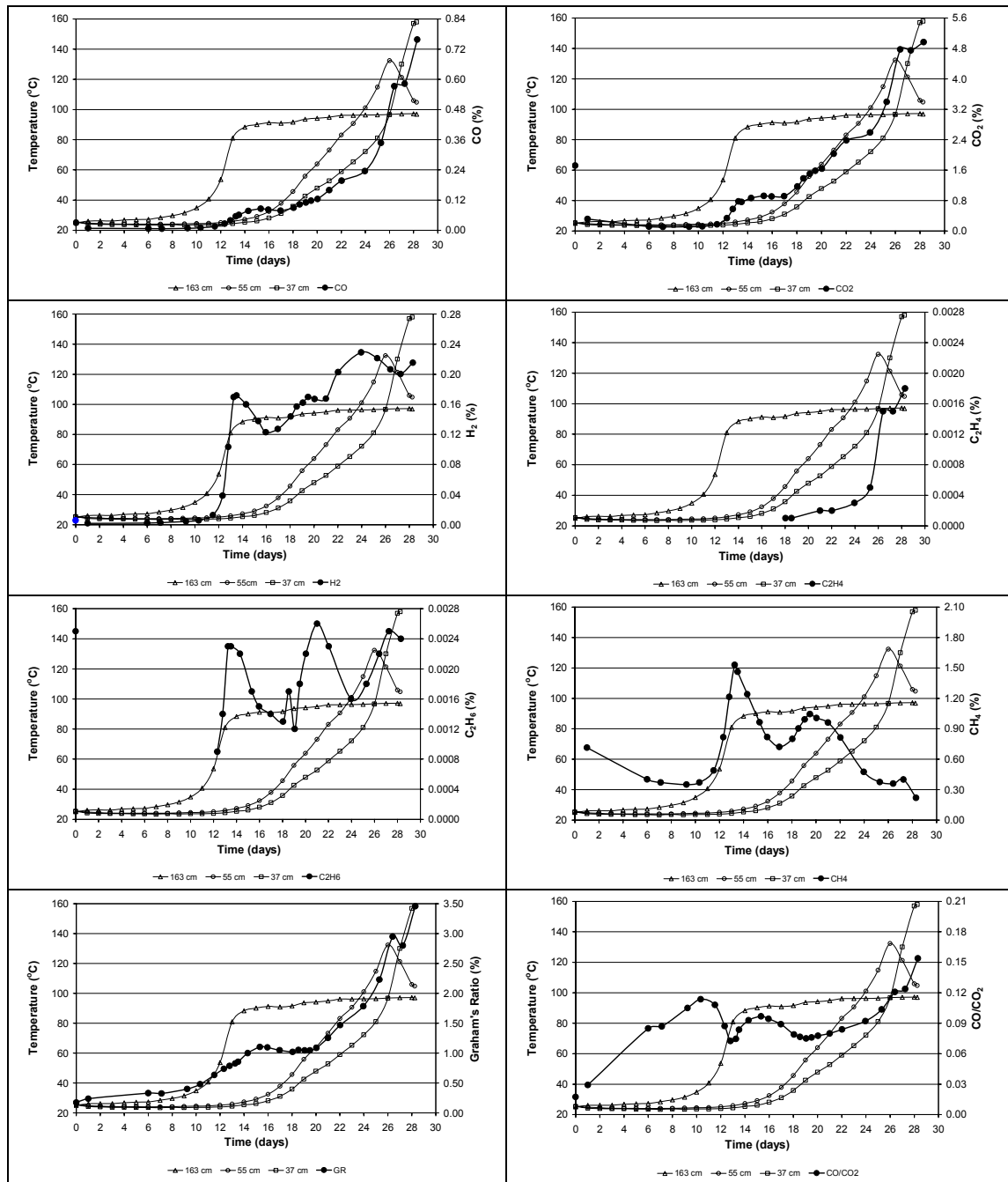
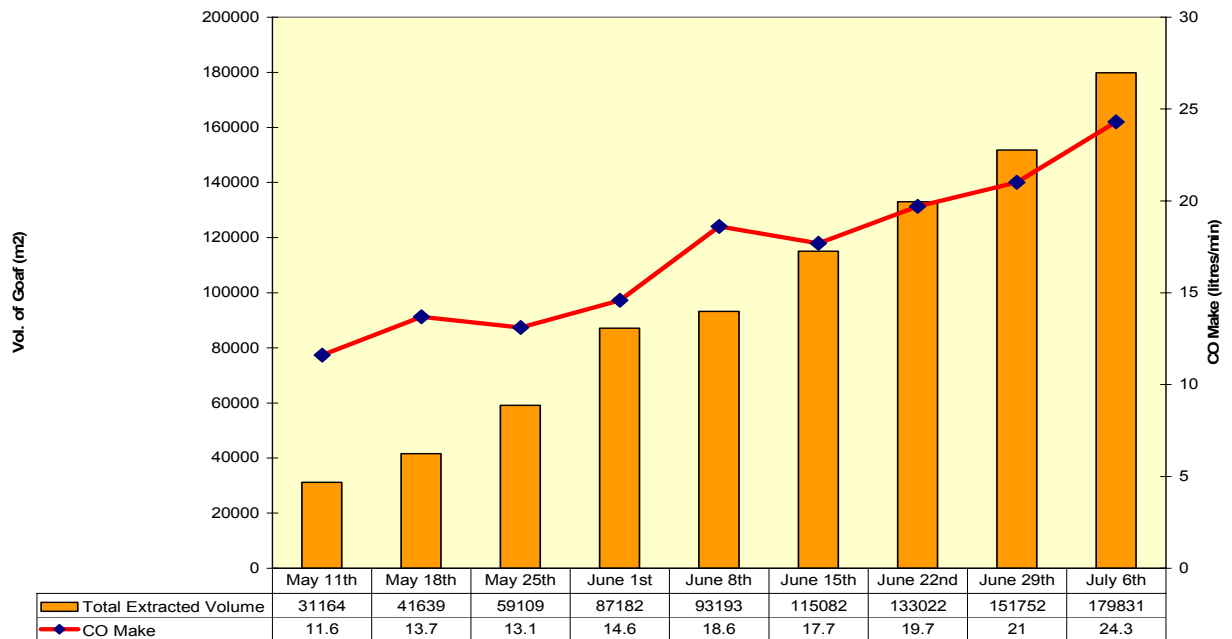


Figure 5 - Gas evolution patterns from Spring Creek bulk coal self-heating

**Spring Creek minesite experience**

Prior to the commencement of extraction at Spring Creek mine, tubes are set up in the intake (1 point) and the return (2 points) and data collection via Safegas software begins immediately. Gasbags are taken from the extraction section return and the Main return weekly in the initial stages of extraction, then daily as the goaf size increases. The information is used to trend a number of indicators: Graham's Ratio, Jones-Trickett Ratio and CO/CO<sub>2</sub> Ratio. For Spring Creek conditions, CO make is not a good indicator of sponcom and is clearly a function of goaf size with 35 – 40 litres/minute being recorded in previous panels nearing completion. This point is illustrated in Figure 6.



**Figure 6 - Comparison of goaf size and CO Make**

Information from regular gasbag sampling is compared closely to the results from the 2-metre column test carried out in March 2005. Of particular interest is the appearance of ethane and hydrogen. While ethane is a seam gas, it is undetectable in the gasbag samples at ambient temperatures. The appearance of ethane is coincident with an increase in return air temperature and the 2-metre column test indicates that the coal sample has reached 40°C. Although there are a number of variables that may affect this information, it offers the earliest indicator of a potential heating for Spring Creek and allows time for appropriate intervention. Further, the 2-metre column test has provided certainty around the appearance of ethylene. The ethane and ethylene plots from the July 2008 event are shown in Figure 7. Hydrogen in the gasbag samples under such circumstances is a clear cause for concern and significant acceleration of hydrogen evolution becomes apparent following the appearance of ethane (ie at 40°C) as shown in Figure 8.

The sponcom event in July 2008 occurred 60 days after the commencement of the extraction of old mains that had been developed four years earlier. The event was dealt with initially by reducing the ventilating pressure to minimise the flow of air through the goaf, and by short circuiting the air at the panel entries to allow the goaf area to inertise itself naturally. These actions successfully terminated the event and based on the UQ 2-metre column test this was achieved while the heating was still in the moisture plateau stage, just before it could migrate towards the outer surface of the coal pile where thermal runaway to ignition would have been inevitable.

Mining has now moved to another extraction area and samples are being tested at UQ for gas evolution and hot spot development patterns in combination with a new adiabatic oven testing procedure for as-mined coal. This information will be used to modify interpretation of minesite behaviour due to any changes detected in the coal performance.



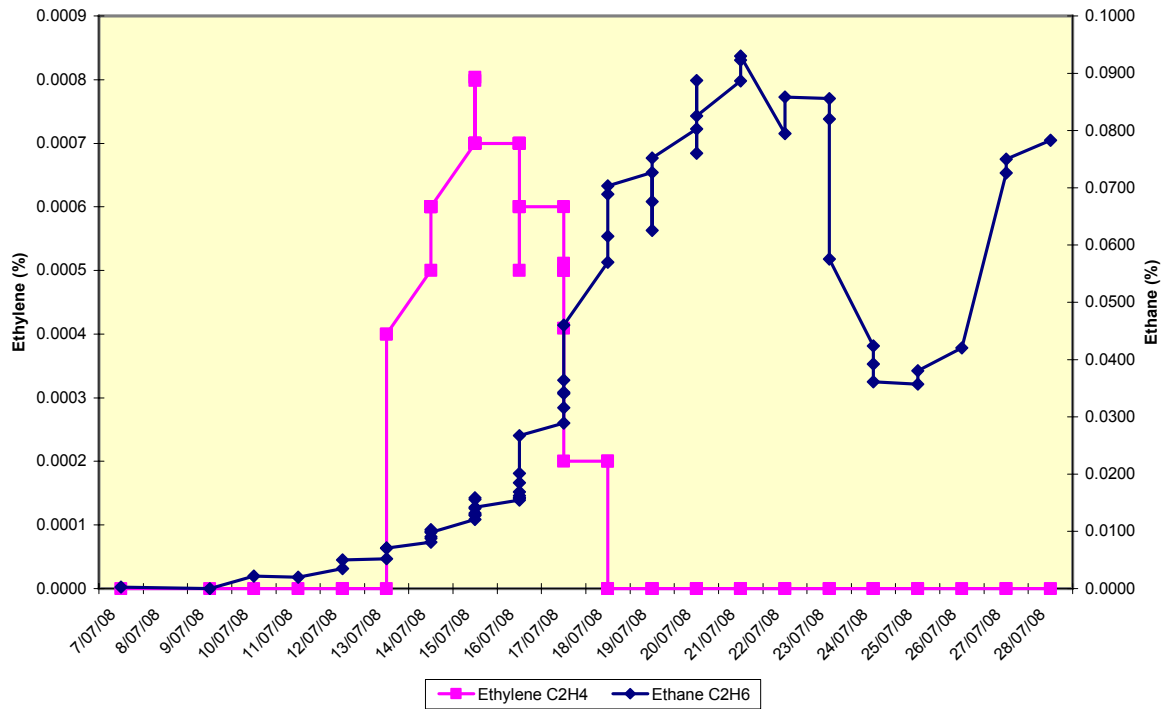


Figure 7 - Ethane and ethylene in static atmosphere throughout the sponcom event

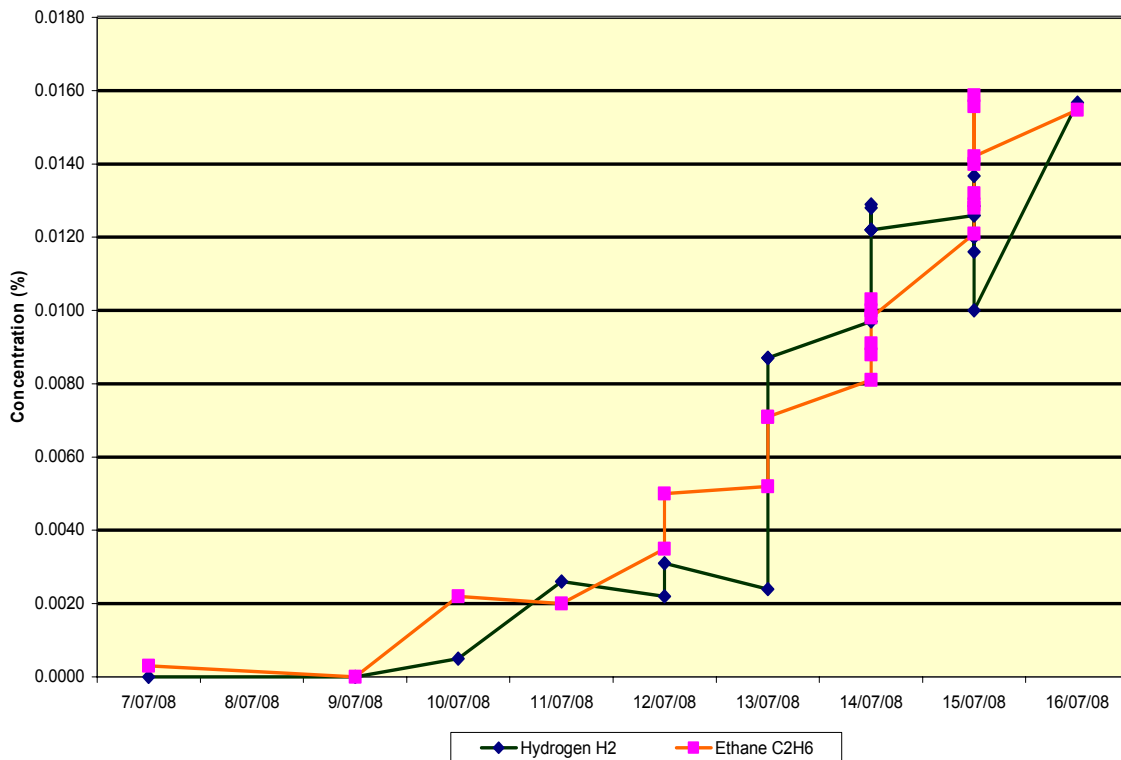


Figure 8 - Hydrogen and ethane evolution during the July 2008 heating at Spring Creek Mine

### CONCLUSIONS

The occurrence of spontaneous combustion events in gassy mines often have severe outcomes with major disruption to production and in some cases, loss of life, loss of resource, loss of equipment and the loss of the mine. At Spring Creek the preparation for such an eventuality through detailed risk assessment and well communicated response plans proved to be crucial. An understanding of the intrinsic characteristics of the coal seam was at a level that provided recognition of the onset of

spontaneous combustion at the earliest possible stage of self-heating. This, in turn, allowed for an intervention that resulted in minimal loss of coal (<2000 tonnes) and minimal loss of time to recommence production (16 days). The results from the 2005 UQ 2-metre column test provided management with information that was not obtainable by any other means. This allowed a high level of confidence in the decision to inertise the affected area by natural means.

More detailed laboratory testing of Spring Creek coal is in progress and new results from this work is providing the opportunity for accurate benchmarking to assist the coal industry maintain leading practice in spontaneous combustion management planning.

### ACKNOWLEDGEMENTS

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