The implications of large scale tests for the detection and monitoring of spontaneous combustion in underground coal

by

David Cliff, QMC and

Fiona Clarkson, Ray Davis and Tony Bennett, SIMTARS

Abstract:

The large scale testing of the 15 tonne samples of Dartbrook coal indicates that it would be extremely difficult to detect the early stages of a spontaneous combustion event. Indeed it is most likely that detection will be delayed until the event has passed the point where it can be easily controlled. The emphasis thus must clearly be on prevention rather than detection and control.

Introduction:

This paper outlines key aspects of the final report of a three year research project testing the spontaneous combustibility of Australian coals under large scale laboratory conditions. The experimental details have been previously reported (Cliff, Davis, Bennett, Galvin and Clarkson, 1998 and 1999), and will only be briefly detailed here.

Typically laboratory assessment of the spontaneous combustibility of a coal is restricted to small scale (approximately 70 g) testing, whether it be R_{70}, Self Heating Temperature, Crossing Point Temperature or gas evolution rates (Cliff, and Bofinger (1999).). The validity of extrapolating these tests to full scale mines has not been established. In an effort to link small scale tests to the real world SIMTARS constructed a large scale reactor.

A number of large scale heating tests using approximately 15 tonnes of coal have been carried out at SIMTARS . The coal was arranged in a pile 2m wide, 2m high and 4m long in a reactor that could be sealed. Air was passed through the pile in an attempt to produce a spontaneous heating.

Approximately 15 tonnes of either crushed or run of mine coal was placed between the two block walls. Five layers each of 50 thermocouples were used to monitor the temperature throughout the pile and fifteen gas sampling tubes were inserted into and across the central axes of the reactor. Air was passed from one end to the other. Internal air flow was varied over the range of approximately 50 to 180 litres/minute.

The apparatus included a thermal cover in an effort to reduce the heat losses and facilitate the self heating of the coal and a series of heaters in the area between the reactor and the cover to preheat the air to approximately the edge temperature of the coal (Figure 1).

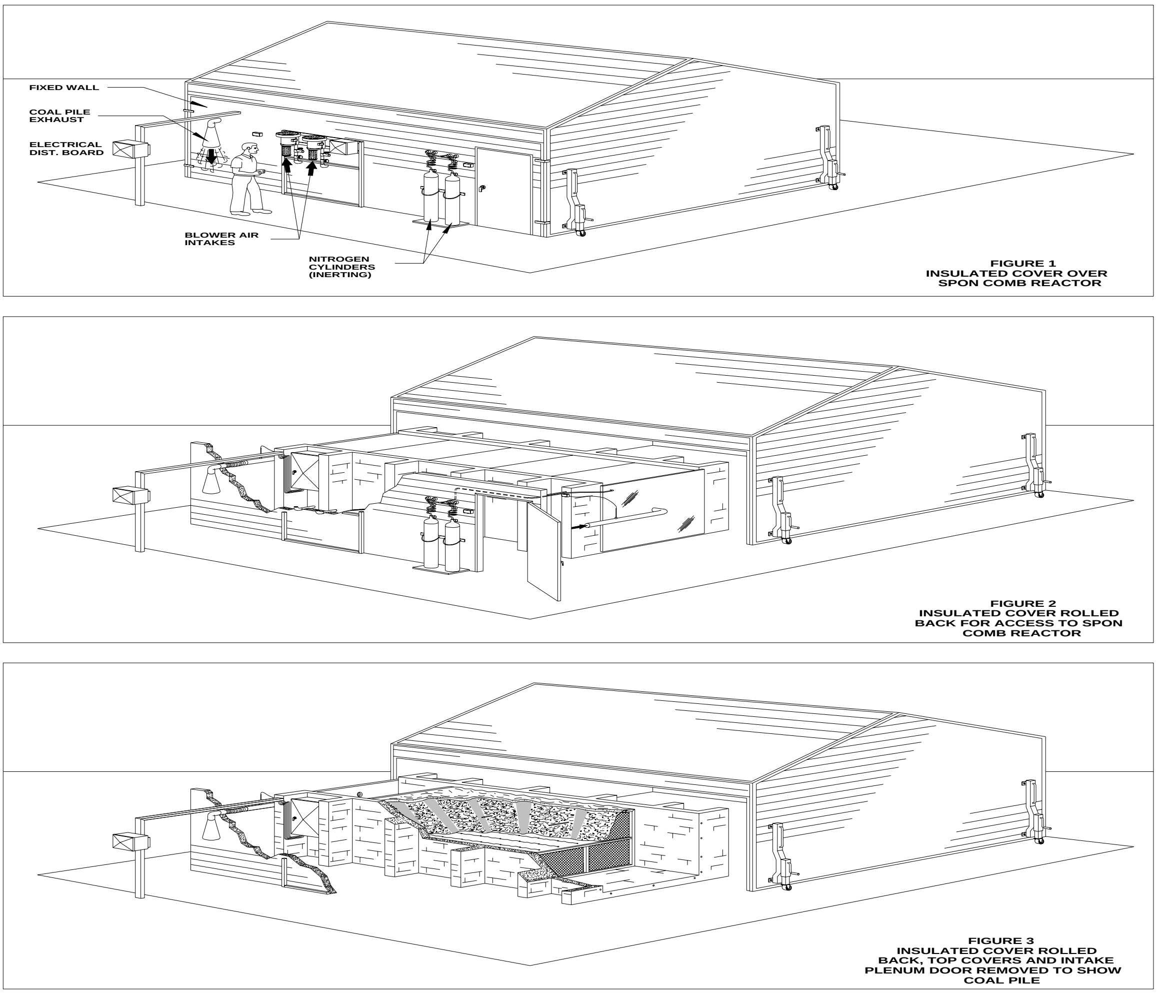

Figure 1. Large Scale test apparatus

Results And Discussion:

Self heating was obtained for two samples of Dartbrook coal, one crushed and one run of mine. They exhibited a number of differences in behaviour and a number of similarities.

The crushed sample of coal packed much more tightly into the reactor and air flow through the reactor was restricted, with a pressure difference across the reactor of up to 100 pa. In contrast the run of mine sample had no detectable pressure difference across it. This meant that the residence time of air inside the crushed coal was much greater than for the run of mine sample, facilitating secondary reactions and reabsorption of gases into the coal.

Both samples were observed to self heat once the coal had dewatered, indeed it was concluded that the process of removing the water from the coal was the rate limiting step in the self heating process.

The key observations from the self heating experiments are summarised in the table below.

Observation	Crushed sample	Run of Mine sample
Exponential Temperature rise	No - stepped increase initially	Yes
Time taken to initiate self heating	172 days to thermal runaway	149 days to thermal runaway
Comparison with small scale tests	Good at Hot spot deviation further away	Excellent correlation
Odour	Consistent with small scale tests - not fire stink	Consistent with small scale tests - not fire stink
CO Make	Est 0.5 l/min at 120 °C Est 1.0 l/min at 200 °C	1.2 l/min at 120 °C 2.5 l/min at 250 °C
Size of hot spot	Approx 400 mm radius	Approx 400 mm radius
Location of hot spot	Middle layer, at inlet face	Middle layer 1 m from inlet

Table 1. Summary of experimental results

The temperature time profiles for both experiments are shown in the figure below.

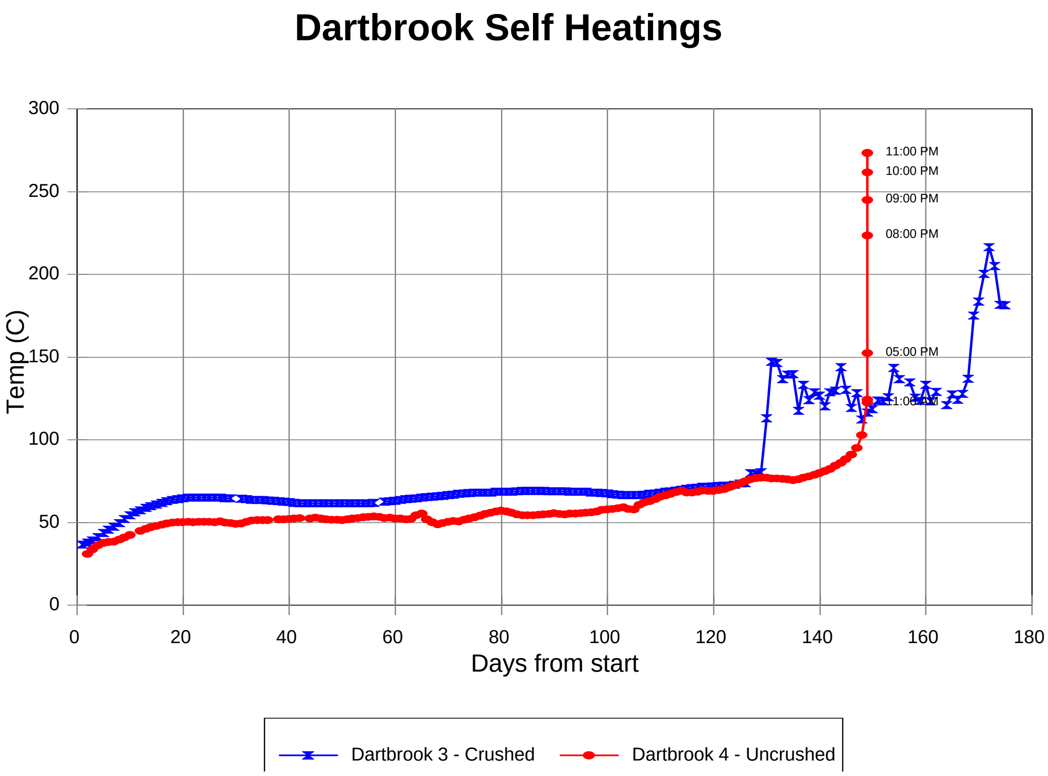

Figure 2. Hot spot temperature vs time plots

The hot spot size is illustrated by the figure below taken from the final Dartbrook uncrushed sample test.

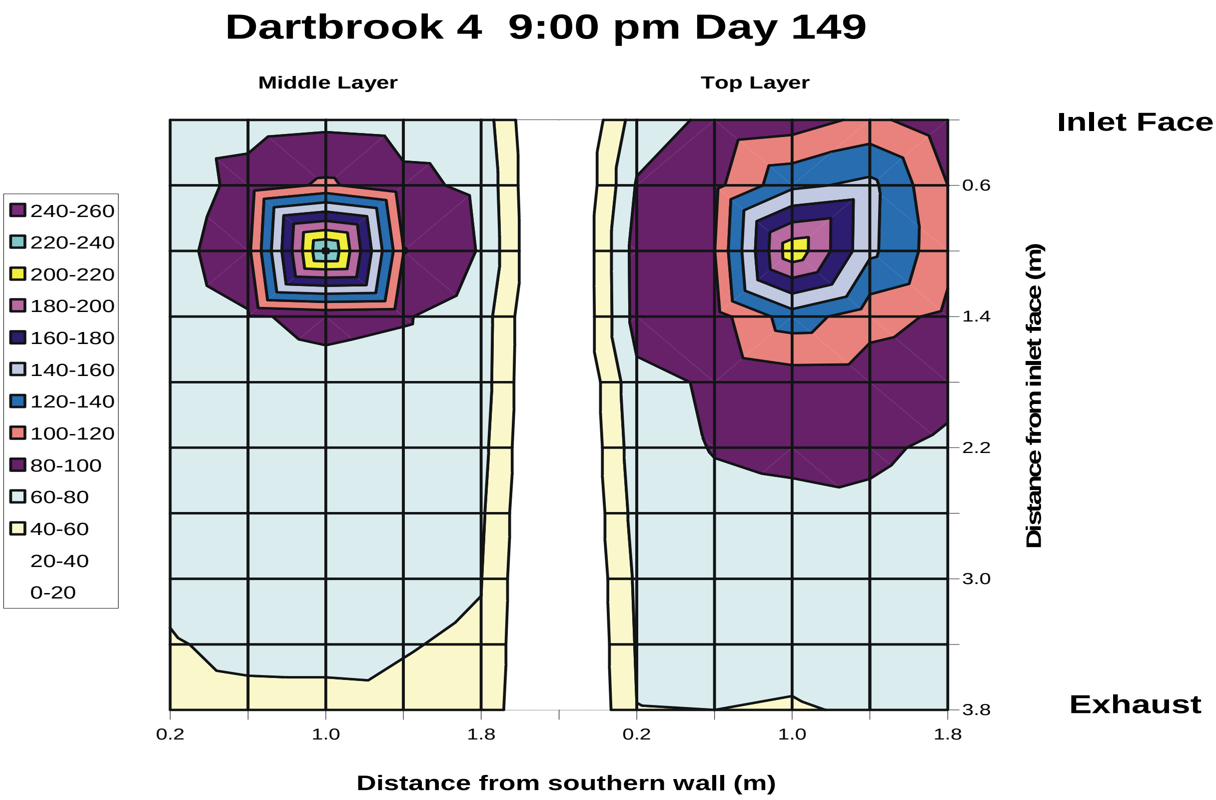

Figure 3. Temperature distance plots for hot spot

The exit CO make as a function of time for the last experiment is shown in Figure 4 below.

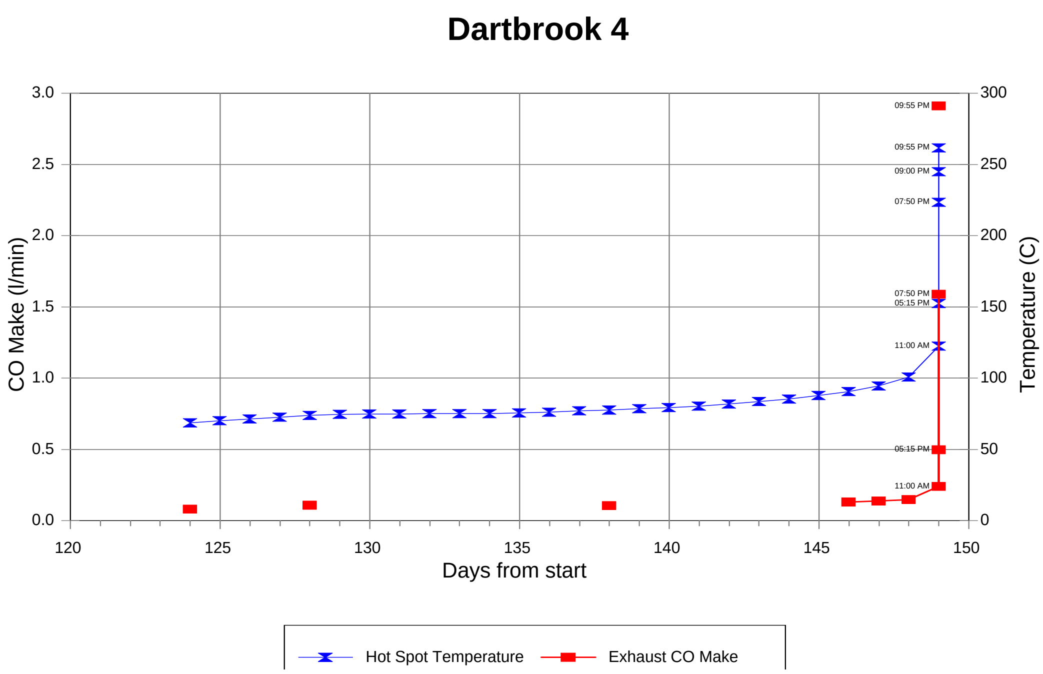

Figure 4. Temperature and CO profiles for the hot spot.

Conclusions:

Spontaneous combustion is essentially a simple process. Coal reacts with oxygen to produce water vapour, carbon dioxide and carbon monoxide and heat. If the heat is retained by the coal then it gets hotter and reacts faster , ultimately reaching open flame - a self heating. If the heat produced is completely removed then no self heating occurs. In the case of the above experiments the heat loss process, although including losses due to radiation, convection and conduction, was dominated by evaporation of moisture in the coal until all moisture in the coal was driven off. Once this heat sink was removed self heating began. Indeed the moisture content of the coal determined the "incubation" period for the sample, rather than the inherent reactivity of the coal.

If the data from the large scale tests is extrapolated to goafs and pillars, then it is clear that heatings can develop and worsen in confined areas involving a few tonnes of coal. This heating will be difficult to identify remotely due to dilution effects. If monitoring can be carried out on top of a heating then the data consistent with that obtained from the small scale laboratory tests will be found. The further away from the heating monitoring is carried out and the more dilute or mixed with other gas streams the products of oxidation become, the less reliable is the ability to identify the heating as illustrated below in figure 5 below.

Monitoring in roadways with 10's of m^3 per sec of air flowing in them will make detection very difficult until the heating has reached a very advanced stage. However in this situation, as the heating will be near the surface, heat detection equipment, such as infrared cameras, and thermography may be effective.

Using standard CO make values is meaningless. As soon as the CO make significantly exceeds the background level investigation should begin, not at 10 or 15 or 20 l/min. CO Make is still a better indicator than CO concentration as it
removes the vagaries of dilution.

Graham's ratio is unlikely to be of any practical value in roadways as the heating products will be swamped with fresh air until it is a major heating, thus giving no meaningful oxygen deficiency.

It has been shown before that the detection of significant concentrations of hydrogen or higher hydrocarbons is consistent with a high temperature heating (Cliff and Bofinger, 1999).

Smell may be of use as human beings are sensitive to very low concentrations of odiferous gases, however care must be taken to identify the smell and allow for the difference in sensitivity between individuals and the subjective description of the smells. The future use of electronic noses holds promise but much work needs to be done in making them routine analysis devices and improving their sensitivity and ability to discriminate between similar smells. Such devices would have to be calibrated with individual coals as the cocktail of hydrocarbon fragments evolved from the coals varies greatly from one coal to the next, depending on the sulphur and oxygen concentration.

Goaf monitoring needs to be carried out as comprehensively as time and resources allow so that all potential heating sites are monitored as close to them as possible. Heatings can only occur where there is sufficient oxygen, the coal is dry and the heat balance is in favour of heat retention.

This last statement is amply validated by the history of heatings at Dartbrook, North Goonyella and Moura No.2 mines.

Other events with high concentrations of CO have demonstrated that high CO can be obtained without any real heating occurring if there is an absence of ventilation - eg Dartbrook and Crinum.

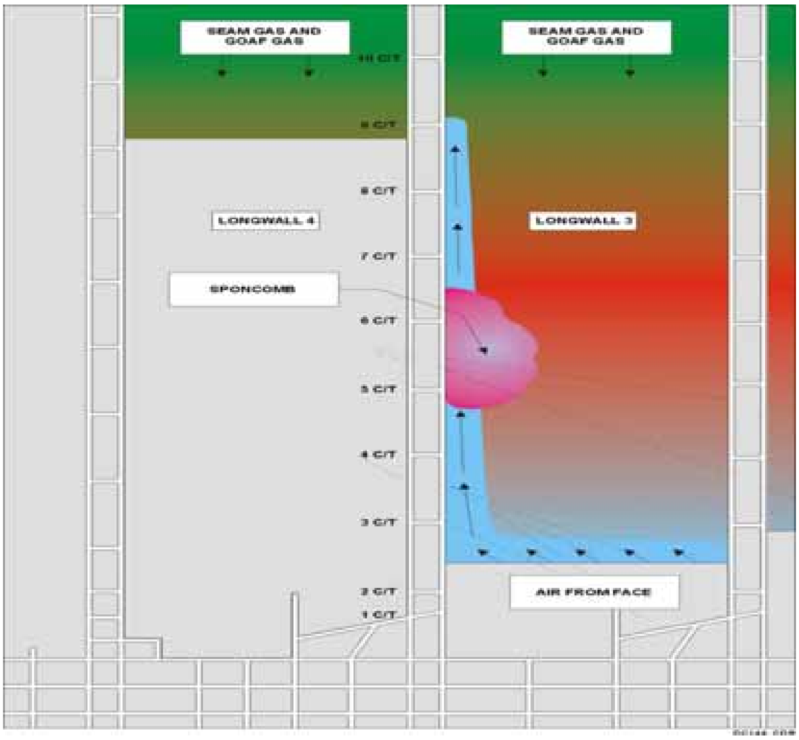

Figure 5. Remote detection of a goaf heating

Recommendations

1. Detection future

- Effort should be put into making electronic noses more robust and discriminatory.
- For pillar heatings infrared cameras and thermography may be more sensitive than gas detection.
- To minimise difficulties in sampling - care should be taken to allow for remoteness of sampling and the inherent limits to reliability and detectability
- Analysis must allow for contributions from seam gases, goaf gases etc.
- The best indicators of spontaneous combustion are those that are independent of the air flow i.e. CO make and Graham's ratio, but even these have grave limitations and we should be aware of what they can and cannot do. We need to specify accuracy limits
- We need to recognise the common fallacy about CO make and not rely on text book values, which as described above, would trigger a response corresponding to a large scale heating, often too late to treat.
- Where airflow is limited gas evolution may be valuable, but there is substantial variation between coals and we need to know individual coal behaviour - for CO, H_2 and CO_2 particularly.

2. Education

- The workforce needs to be educated to look for the signs of spontaneous combustion and the potential for spontaneous combustion, not just gases, but the other indicators and the potential for unwanted and unintended airflows.
- Much more attention needs to be placed on sampling reliability and representation.

3. Prevention

Most importantly, prevention is far more important than cure so more emphasis needs to be placed on:

- The use of inertisation technology to remove oxygen and thus the potential for spontaneous combustion of goafs should be encouraged. This requires suitable monitoring protocols to be developed to ensure that the inertisation is effective, and remains effective.

- Where pillar heatings are possible, the use of sealants to eliminate oxygen coal interaction should be undertaken.

- Ventilation must be better controlled to minimise leakage. This requires good seals and proper ventilation monitoring, both pressure quantity surveys on a regular basis and inspections of seals. The use of continuous velocity or pressure sensors is desirable. This would enable abnormal airflows to be identified before they are a problem.

- Mine design should include the evaluation of pressure differences and leakage to identify the potential hotspots for spontaneous combustion.

4. Incubation period

- The concept of incubation period should be completely disregarded as these large scale tests have shown that reactivity can lie dormant for long periods only to be activated after the coal dries and finds oxygen. This is also consistent with recent experience at Laleham No.1 colliery.

Future research

- Further research should be carried out in the large reactor to establish whether or not it is a capable of determining the relative propensity of a coal to spontaneously combust.

- Research in the reactor should be extended to study the effects of the different types of inertisation, including sealants, water and self inertisation, on spontaneous combustion, thus optimising the ability to control heatings. This research could should also look at the ability of coal to retain heat, and the time taken for the coal to become unreactive rather than just starved of oxygen.

- Gas chromatographs should be developed with increased detection sensitivity for hydrogen, and the higher hydrocarbons. Rapid analysis has been shown to dramatically improve the quality and quantity of data available to allow interpretation of spontaneous combustion events and treatments.

- The role of water in the chemistry of spontaneous combustion merits more study.

- Research in small scale studies does not allow for the complexities of the real world such as heat loss, and water content. It is only good for inherent reactivity measurement, gas evolution behaviour.

- Electronic nose technology, including neural networks and multifactorial analysis, should be utilised in monitoring systems, once it has demonstrated sensitivity, discrimination and robustness.

Acknowledgements:

This work was carried out at SIMTARS. The authors gratefully acknowledge the support of ACARP for this project and also the permission of the Director of SIMTARS to publish this paper. The support of Dartbrook Coal is also gratefully acknowledged.

References:

Cliff D, Davis R, Bennett A, Galvin G, and Clarkson F (1998), *Large Scale Laboratory Testing of the Spontaneous Combustibility of Australian Coals ,* in Proceedings of the Queensland Mining Industry Health and Safety Conference, Yeppoon, pp 175 - 179

Cliff D, and Bofinger C (1999). *Spontaneous Combustion A Review 1998.* A report submitted as part of ACARP project c6001 final report, SIMTARS, Ipswich, Queensland.