Management of spontaneous combustion in coal overburden spoil piles

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Abstract

Laboratory testing was undertaken to examine the spontaneous combustion propensity of some of the coal seams being mined at Leigh Creek. Tests indicated that while carbonaceous rocks retained a fuel load, in isolation, these did not have the capacity to reach thermal runaway. However, the potential existed for heat from another source, such as coal, to raise the temperature of these rocks to above the threshold for thermal runaway (>100 °C).

The mine closure plan submitted to the regulator (Department of Premier and Cabinet, South Australia) incorporated a monitoring trial of the selected spontaneous combustion management rehabilitation strategy to demonstrate its effectiveness. The strategy included reducing batter slopes of waste spoil piles and the application of an inert cover. The trial was established in June 2017 in a location with active combustion immediately prior to rehabilitation treatment. Measurements of temperature and oxygen concentrations within the spoil pile over twelve months show that oxygen is consumed within 1 m of the outer surface of the waste, while maximum spoil pile temperatures have been decreasing, indicating a net heat loss from the trial spoil pile area. No spontaneous combustion outbreaks have occurred in the trial area since the trial commenced. Characteristics of the trial area materials, the management strategy, and outcomes from the field trial measurements are presented.

Introduction

The Leigh Creek Coal Mine, located approximately 500 km north of Adelaide in South Australia, operated between 1944 and 2015. During operations, localised spontaneous combustion occurred on numerous occasions in the overburden spoil piles containing relatively small volumes of coal (about 0.8%). The majority of the overburden sequence consisted of sandstones and carbonaceous mudstones. Samples of overburden rocks had total sulfur and total organic carbon present at up to 2.2 wt% and 14 wt% respectively. The coal at Leigh Creek mine is a low rank, sub-bituminous brown coal that is prone to selfheating and spontaneous combustion. Spontaneous combustion also occurred in the spoil piles throughout the decades of the mining operation. Consequently, spontaneous combustion management strategies suitable for short-term control were developed, but were not specifically tailored for long-term closure. The Alinta Energy Board announced the closure of the Leigh Creek Coal Mine in June 2015. The announcement was preceded by a brief period of internal planning for closure. Coal mining operations ceased in November 2015.

A swift decision to close, followed by a short mining operations shutdown period, presented significant technical and regulatory challenges for both the mine operator and regulators. Subsequent to the decision to close, a joint risk mapping process was undertaken by the operator, Flinders Power, and the South Australian mining regulators to obtain objective evidence to inform the risk profile and risk management strategies for closure. Spontaneous combustion occurrences in the waste spoil piles were identified as a significant risk.

Three factors potentially contributing to and/or suitable for the management of spontaneous combustion were identified as requiring further investigation during the risk assessment:

- The coal and the carbonaceous mudstone overburden both have the ability to self-heat to the point of thermal runaway.
- The ability of coal and mudstone to self-heat to the point of thermal runaway reduces with time of exposure.
- Reducing the batter angle of the spoil pile and covering with a layer of fine inert material would reduce the risk of spontaneous combustion.

Material characterisation

Characterisation of the overburden materials at Leigh Creek was conducted in two separate stages.

The initial stage involved the collection of grab samples from various locations across the mined-out area covering a range of overburden rock types and ages, including aged coal. Geochemical analysis of the total organic carbon and total sulfur contents of the non-coal overburden samples was conducted to provide a preliminary assessment of their potential to spontaneously combust and to help select appropriate samples for more specific testing. The sulfur content was found to range up to 2.2% total sulfur and the organic carbon ranged up to 14%. The high total sulfur contents in this series of samples were identified from XRD analysis to be associated with gypsum.

The R70 self-heating rate (Beamish, Barakat and St George, 2000) was determined for selected coal and non-coal overburden samples. The results are shown in Figure 1. All of the non-coal overburden had R70 values less than 0.35° C/h, placing them in the 'Low' intrinsic spontaneous combustion propensity rating (Beamish and Beamish, 2011). These samples had ash contents in excess of 75% (Figure 1) and spoil with these ash contents would require an external heat source, or the presence of reactive pyrite, to elevate the temperature of the material to the point where thermal runaway would be possible.

The aged coal had R70 values much lower than the equivalent fresh coal samples (Figure 1) due to in situ oxidation. The values correspond to a 'Low-Medium' to 'Medium' intrinsic spontaneous combustion propensity rating. In this oxidised state, the coal does not have sufficient intrinsic reactivity to overcome the heat loss associated with evaporation of moisture. This heat balance effect (Beamish and Theiler, 2015) is demonstrated for fresh Leigh Creek coal samples tested at two different moisture contents (Figure 2).

From these initial results it was determined that, historically, the most likely source of spontaneous combustion in the overburden spoil piles at Leigh Creek was fugitive coal mixing with the carbonaceous non-coal overburden and forming hot spots sufficient to initiate sustained self-heating in the overburden pile.

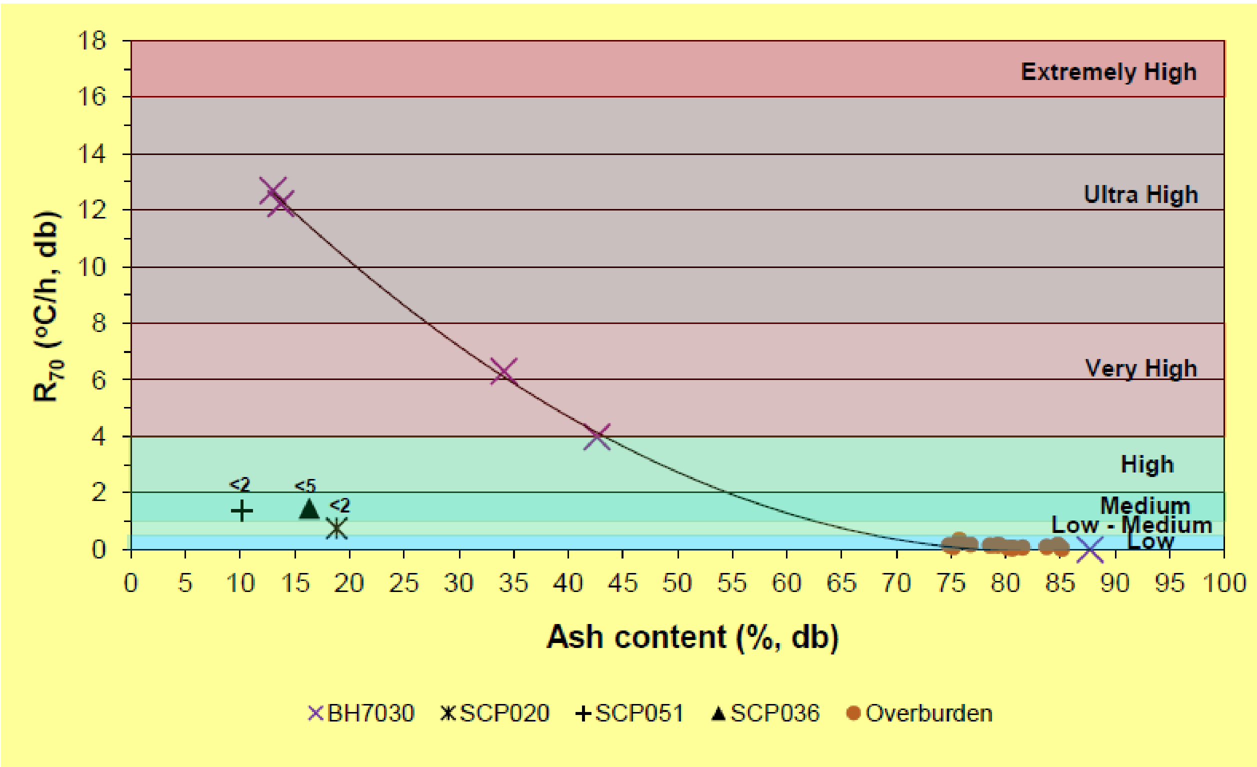


Figure 1: Self-heating relationship with ash content for fresh coal sample (BH7030) compared against aged coal (SCP020, SCP051 and SCP036) and non-coal overburden strata from Leigh Creek Mine. Annotation above aged coal samples is in years.

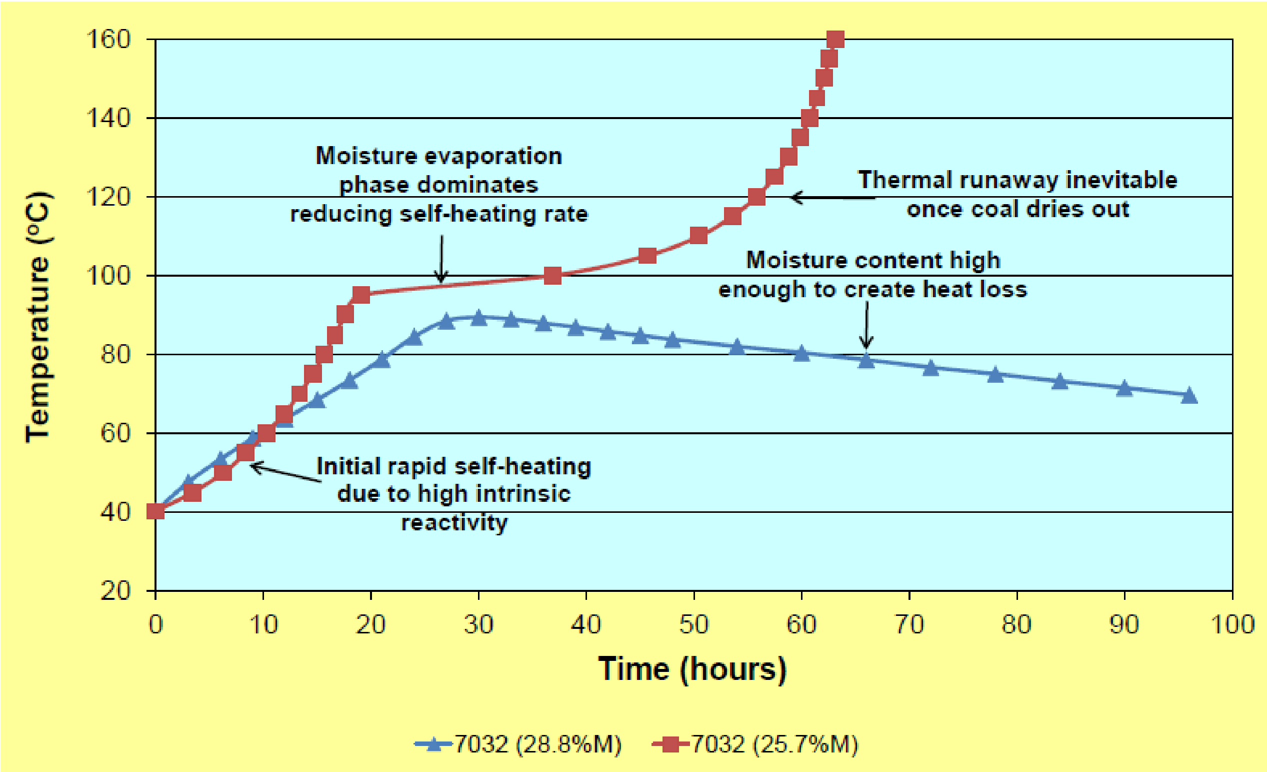


Figure 2: Coal self-heating curves for Leigh Creek coal sample at two different moisture contents showing the balance between intrinsic reactivity and moderating effect of moisture

The second stage of characterisation was conducted on drilled samples from the rehabilitation trial area on the spoil pile. The results are shown in Figure 3.

One of the samples returned a total sulfur content of approximately 4% (the two values in Figure 3 are repeat measurements on the same sample). The pyritic sulfur content of the sample was approximately 3.5%, as determined from XRD analysis, present predominantly as marcasite (6.4%) and, to a lesser extent, pyrite (3.8%) contained in stringers cutting through siderite nodules (Figure 4). The total organic carbon content of the sample was approximately 2% and consequently, the R70 value was effectively 0.

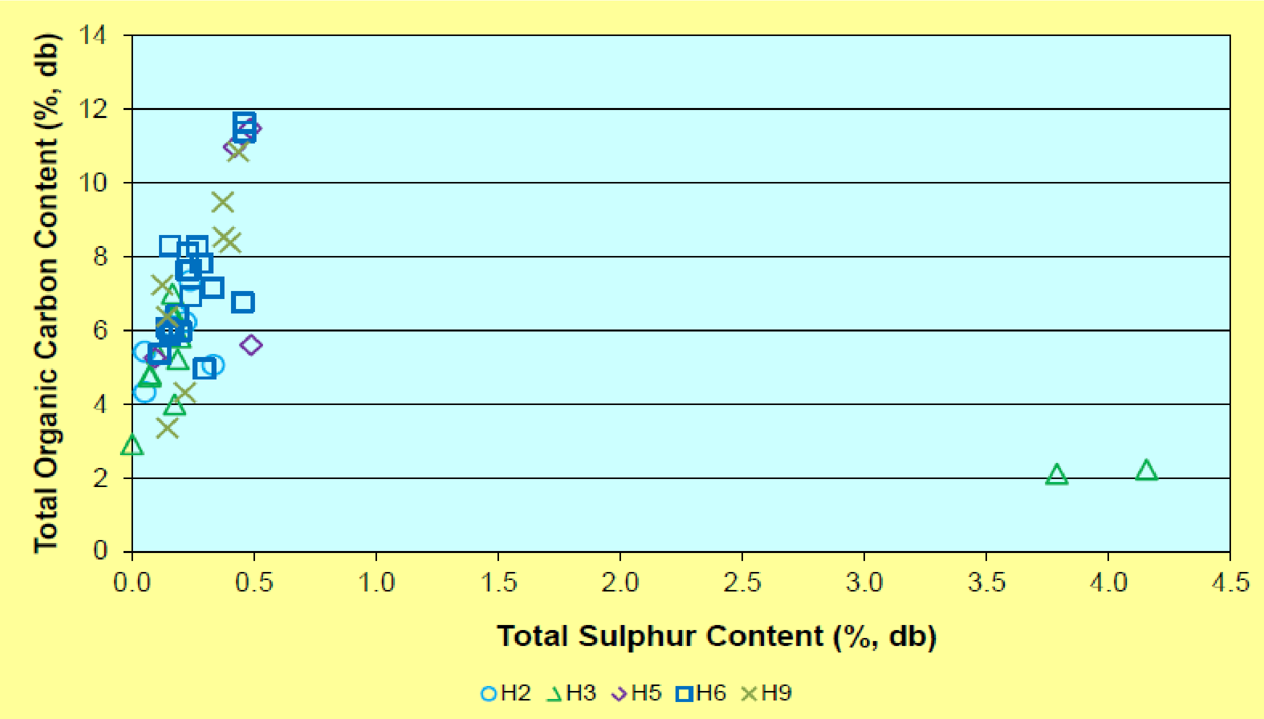


Figure 3: Relationship between total sulfur content and total organic carbon content of rehabilitated overburden samples from Leigh Creek Mine

Figure 4: Photograph of siderite nodules containing marcasite/pyrite stringers

Incubation self-heating test results are shown in Figure 5. The majority of the overburden samples lost heat due to evaporation of residual moisture and therefore thermal runaway is not possible in these types of spoil unless they are in contact with other material at temperatures in excess of 100 °C. Sample H6-28 was at an elevated temperature of 110 °C in the spoil pile; consequently, if it was exposed to an air source it could easily progress to thermal runaway. The sample containing marcasite/pyrite (H3-4) was tested at two moisture contents (3.6 wt % and 11.0 wt %). At the elevated moisture content, the sample rapidly self-heats from the marcasite/pyrite oxidation reaction, but then reaches the point where heat loss from moisture evaporation takes over and the sample eventually cools down.

At the lower moisture content, however, the sample rapidly self-heats then slows as it begins to liberate and evaporate moisture, but then reaches the point where the organic carbon begins to oxidise and sufficient heat is generated to progress to thermal runaway. This situation is very localised in the overburden spoil pile (detected in one of approximately 200 samples) and can only occur if the pyrite is liberated from the siderite nodules. This could only take place if, for example, heavy machinery crushed the nodules during emplacement or re-profiling of the overburden spoil pile, since the siderite nodules are extremely hard.

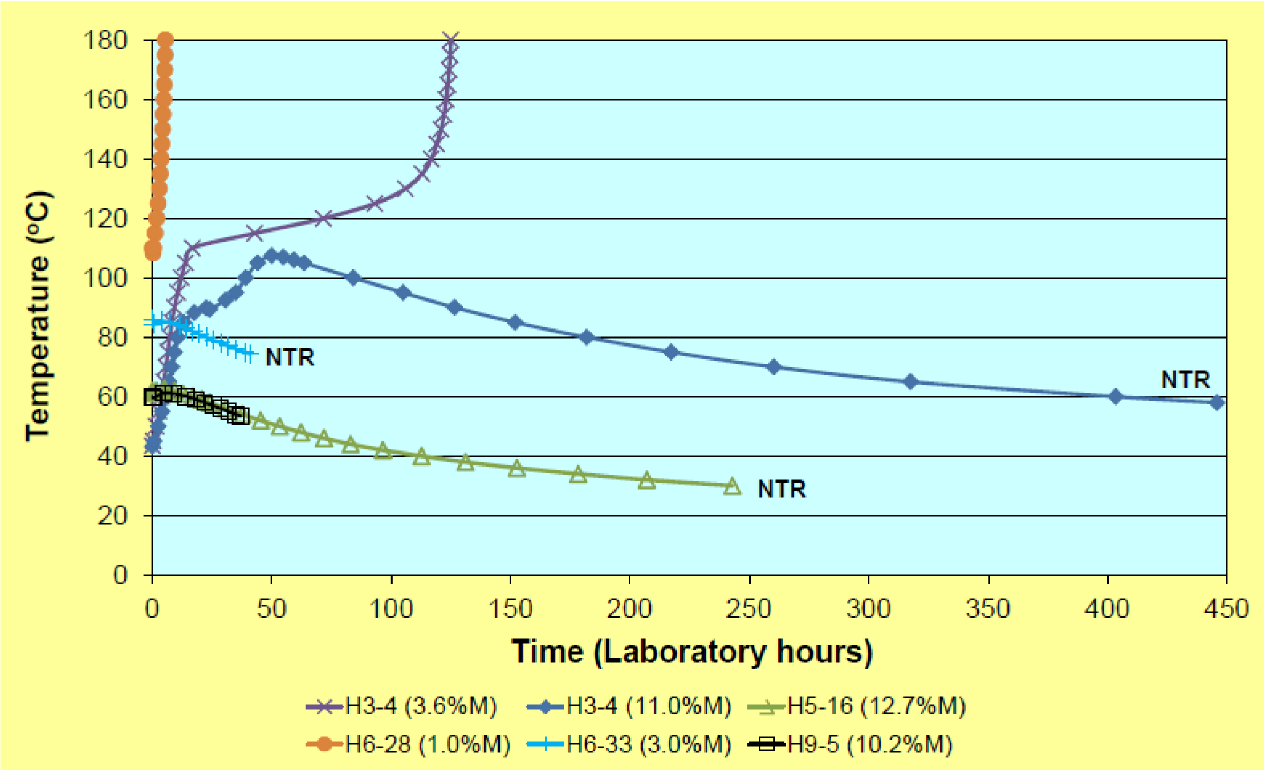


Figure 5: Incubation test results for rehabilitated overburden samples from Leigh Creek Mine

Gas transport

Three mechanisms, diffusion, convection and advection, can transport significant quantities of oxygen from the surface to the interior of an overburden spoil pile. Diffusion is driven by a gradient in the partial pressure (or concentration) of oxygen within the spoil pile. Advection and convection are driven by spatial gradients in the total gas pressure and buoyancy, respectively. Causes of advection include wind or atmospheric pressure variations. Buoyancy arises due to temperature gradients within the spoil pile and is most readily established in the batter of a spoil pile where warmer rising pore gases are more readily replaced with air lower in the spoil pile. Therefore, reducing the batter slopes tends to reduce the likelihood of convection.

The material property that controls advection and convection is the intrinsic permeability; the property that controls oxygen diffusion is the effective oxygen diffusion coefficient. Compaction of spoil may provide a significant reduction in the intrinsic permeability but is less effective in reducing the effective oxygen diffusion coefficient. The effective oxygen diffusion coefficient decreases significantly as the degree of moisture saturation of the material increases above 0.85.

Management strategy

The management strategy selected for the spoil piles at risk of spontaneous combustion was to reduce the batter slopes by incrementally pushing waste from the crest to towards the toe using D10 bulldozers. Multiple dozer movements also affected a reduction in the permeability of the near-surface waste. The slopes were then covered with a compacted layer of inert soil materials sourced locally. The batter slopes were reduced from approximately 1:1.3 (V:H) to within the range of 1:4.5 to 1:5.0 (V:H). The single layer soil cover, after compaction, had a minimum thickness of 1.2 m.

Field trial

A field trial to quantify the effectiveness of the management strategy was established on the batter of a spoil pile representative of spoil piles at risk of spontaneous combustion, as indicated by elevated surface temperaures. The trial area was resloped on 24 May 2017 and covering was undertaken between 14 and 19 June 2017. After resloping and before covering, the highest measured surface temperature was 121 °C. No cover was placed on the horizontal bench above the trial batter.

Instruments were installed along five vertical drill holes (Figure 6) to measure pore gas oxygen and carbon dioxide concentrations and spoil pile temperatures. Four of the locations were on the batter and the fifth was in the flat top of the spoil pile. The monitoring equipment configuration for each drill hole is illustrated in Figure 7. Small diameter gas sampling tubes were installed to extend from the spoil pile surface and terminate at different depths. A string of temperature sensors was hung permanently inside the pipe (approximately 45 mm diameter). Oxygen and carbon dioxide concentrations were determined by pumping small volumes of pore gas from the spoil pile via the gas sampling tubes to portable gas analysers. Measurements were made multiple times in the week after instrument installation and then approximately monthly thereafter.

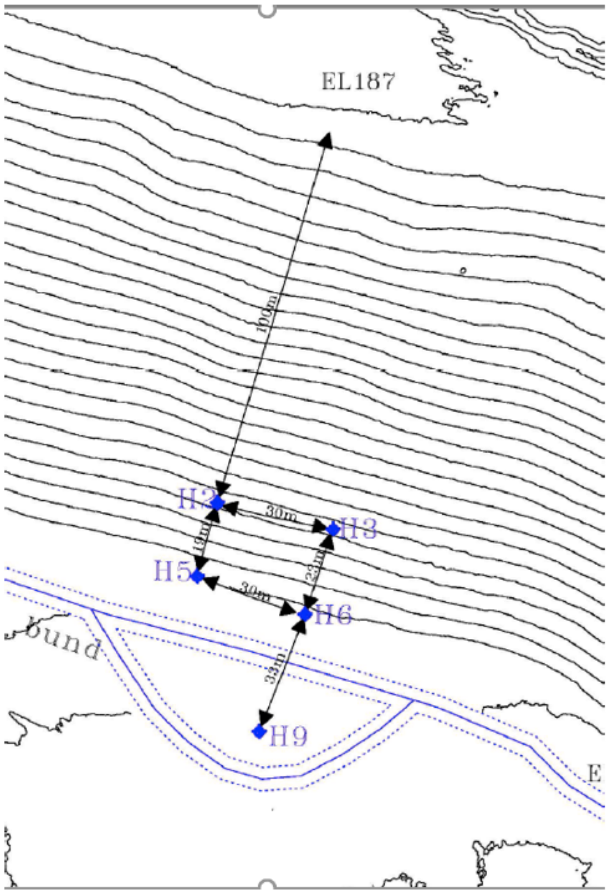


Figure 6: Monitoring locations in plan view designated H2 to H9

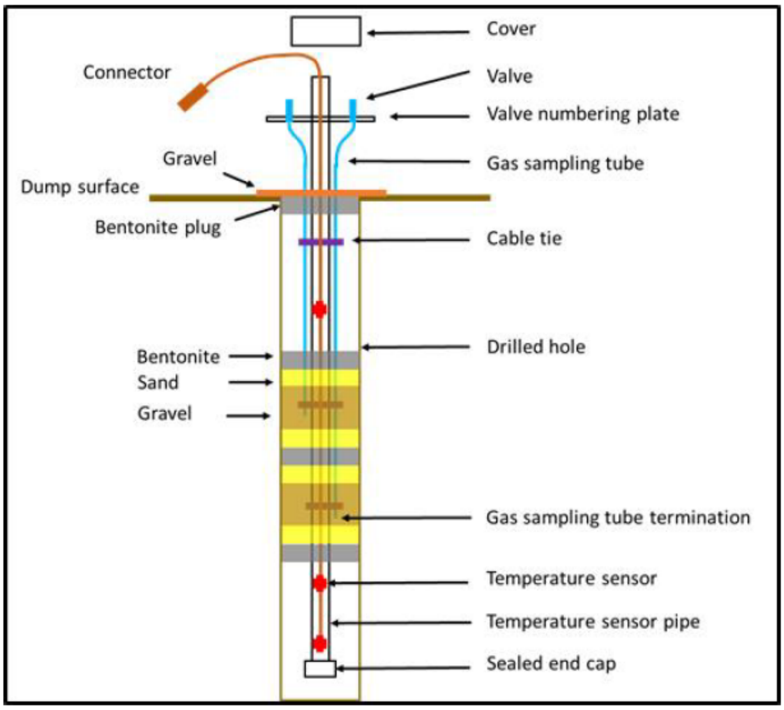


Figure 7: Schematic of monitoring equipment installed in a drill hole

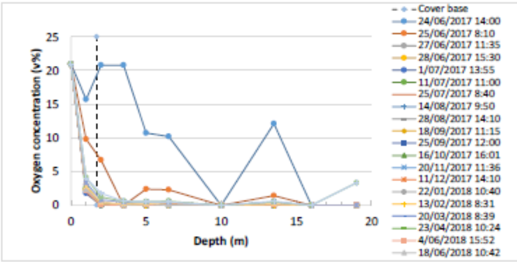
Waste spoil pile results and interpretation

Oxygen introduced to the waste during sonic drilling of the instrumentation drill holes penetrated to about 15 m (Figure 8a, 24/6/2017) and most was consumed within a week. Subsequent oxygen concentration profiles show that oxygen ingress was limited to approximately 0.5 m below the cover, consistent with oxygen supply into the dump by diffusion and oxidation occurring in the 0.5 m of layer of waste below the cover contact. One week after installation, the oxygen concentrations were steady (Figure 8b).

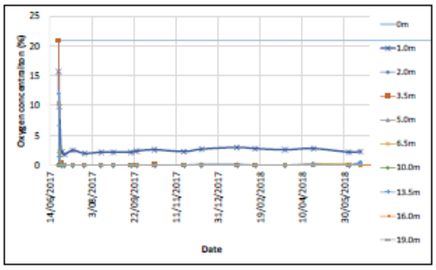
The highest temperature of 138 °C was measured about 13 m below the surface at location H6 (Figure 8c). The absence of oxygen at this location indicates that oxidation was occurring at this depth before the monitoring began. Furthermore, the decrease in temperatures at all depths at location H6 over time (Figure 8d) indicates heat loss from this region and that the overall oxidation and heat generation rates have decreased or ceased. The time for the maximum temperature to decrease below 100 °C, the temperature required for thermal runaway, was estimated from measured temperatures to be about 460 days after the first measurements.

Carbon dioxide concentrations were high throughout (Figure 8e). The sharp change in the CO2 concentration gradient at about 1.5 m indicates that CO2 was produced at about this depth. This is consistent with the depth at which oxygen was being consumed. The approximately constant CO2 values below 1.5 m indicate that the likely rate of CO2 production is low or zero below this depth.

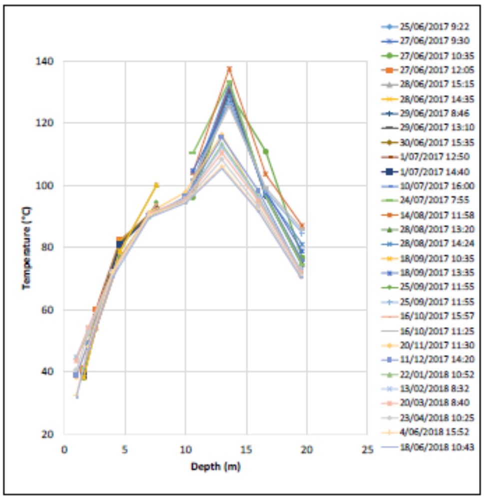
Inferred oxygen concentration contours for the cross section of the spoil pile through H3, H6 and H9 (Figure 8f) are consistent with oxygen supply by diffusion to the outer 2 m layer of the spoil pile. Temperature contours (Figure 9) indicate the presence of a hotter volume at about 14 m below the surface. That volume has cooled due to heat loss to adjacent spoil material and loss from the upper and lower boundaries (surfaces).



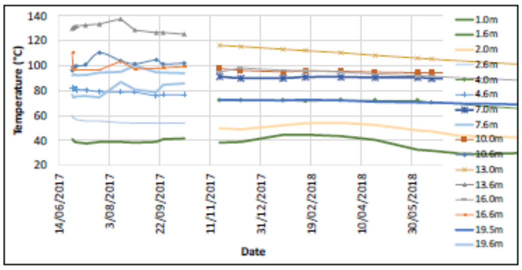
(a) Oxygen concentrations versus depth



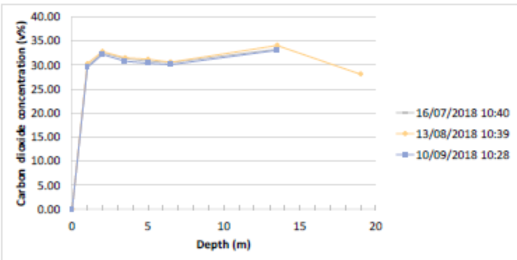
(b) Oxygen concentration versus time



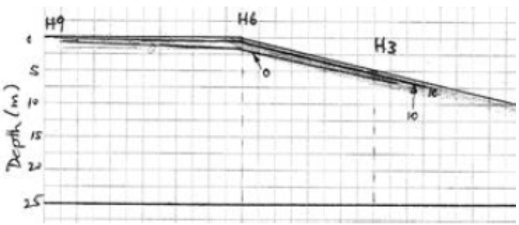
(c) Temperature vs depth



(d) Temperature vs time

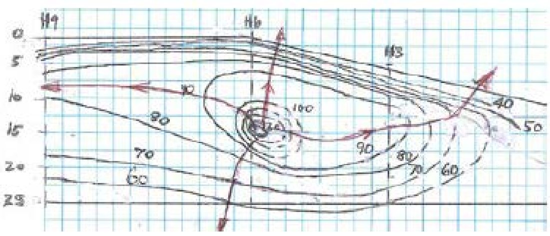


(e) Carbon dioxide vs depth

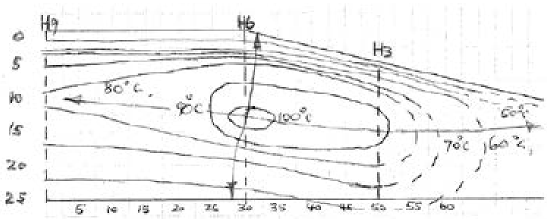


(f) Oxygen concentration (v%) contours (July 2017)

Figure 8: Oxygen carbon dioxide concentrations and temperatures measured at location H6



(a) June 2017



(b) June 2018

Figure 9: Inferred temperature contours in a trial area cross section

Summary and conclusions

Samples of the small quantites of aged coal in the spoil piles had ‘Low-Medium’ to ‘Medium’ intrinsic spontaneous combustion rating (much lower than the equivalent fresh coal samples), and did not have sufficient reactivity to overcome the heat loss associated with moisture evaporation. Therefore, it is concluded that the coal in the spoil piles would be not likely to reach thermal runaway via self-heating.

Most non-coal spoil is carbonaceous mudstone. The carbonaceous mudstone presents a fuel load, but would require an external heat source, or heat from the oxidation of reactive pyrite or maracsite, that may raise temperatures to in excess of 100 °C, for thermal runaway to occur. Occurrences of the sulfide minerals pyrite and marcasite are infrequent (1 in 200 samples) and typically are bound within high strength siderite nodules. Should the siderite nodules be crushed and the sulfide minerals become exposed to oxygen, it is possible that, at certain moisture contents, sulfide oxidation could raise the temperature enough for the organic carbon to selfheat and possibly reach thermal runaway.

Oxygen concentration and temperature distributions were not measured before the batter of the trial region was resloped and covered. However, elevated temperatures within the trial area (up to 138 °C) are evidence of combustion prior to establishment of the trial area. Since the resloping and covering, oxygen penetrated less than 1 m into the waste below the cover. The observations indicate that the dominant oxygen supply mechanism is diffusion, with no evidence of convection being observed within the monitored region.

A consequence of limited oxygen ingress is the cooling of the hot volume within the trial region. Based on cooling rates estimated from the observed temperature changes over time, the maximum temperature in the monitored region would be expected to decrease to below 100 °C (the trigger temperature for thermal runaway) about 460 days after the first measurements.

The monitoring results indicate that the resloping and covering have been effective in limiting oxygen supply into the spoil and have allowed temperatures in most of the underlying material to decrease, thereby reducing the likelihood of ongoing spontaneous combustion.

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