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# DELAYING SPONTANEOUS COMBUSTION OF REACTIVE COALS THROUGH INHIBITION

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**ABSTRACT:** A moist coal adiabatic oven test has been used to quantify the effect of applying an anti-oxidant agent to reactive coals from Australia and the US. For the dosage rate applied, the anti-oxidant significantly reduces the coal self-heating rate and extends the time taken to reach thermal runaway by a factor of three for sub-bituminous coal and by a factor of two for the same application to high volatile C bituminous coal. The laboratory result obtained for sub-bituminous coal from Powder River Basin is in direct agreement with the practical site experience of applying the anti-oxidant product as a spontaneous combustion management control. Consequently, it is now possible to benchmark the application of the anti-oxidant to any reactive coal prior to mining as part of developing a leading practice spontaneous combustion management plan.

## INTRODUCTION

Low rank coals are known to have a high propensity to spontaneously combust and the mining, storage and transport of such coals poses a significant hazard for management planning. One solution to mitigating this hazard is to apply inhibiting agents to delay the onset of thermal runaway that can ultimately lead to a spontaneous ignition event. Smith *et al.* (1988) studied the effects of a range of inhibitors on coal spontaneous combustion, with varying degrees of success. The index parameter used to quantify the effectiveness of each inhibitor was the minimum Self-heating Temperature (SHT) of the coal as defined by earlier work of Smith and Lazzara (1987). This index parameter does not provide any time perspective of the inhibition delay in reaching thermal runaway and there has been no subsequent publication of any practical application of their findings.

Recent advances in coal spontaneous combustion testing (Beamish and Beamish, 2012a, 2012b) provide the opportunity to quantify the effectiveness of applying inhibiting agents (in the form of anti-oxidants) to reactive coals to delay self-heating reaching thermal runaway. This paper presents the results of a series of laboratory trials supported by site experience of an anti-oxidant product developed the industry, which has been applied to three reactive coals of differing coal rank and geographical setting.

## ADIABATIC OVEN TESTING

### Coal samples

Details of the samples used in this study are contained in Table 1. The two major benchmark coals are Kideco (Indonesia) and Spring Creek (New Zealand), which covers a rank range from sub-bituminous C to high volatile B bituminous. Site experience with each of these coals indicates that heating events will develop in loosely piled coal in approximately 10-15 d for the Kideco coal and 40-60 d for Spring Creek coal.

The reactive coals used in this study fall within the rank range of the two benchmark coals. Sample PRB is from the Powder River Basin and the other two coals are from Australian coal basins. There is also a fundamental difference in coal type between the two Australian coal samples, which is readily identifiable from a Suggate Rank (Suggate, 2000, 1998) plot (Figure 1). Sample AUS1 is inertinite-rich as it plots below the New Zealand coal band, whereas sample AUS2 is vitrinite-rich as it plots within the New Zealand coal band as defined by Suggate (1998). The Kideco, Spring Creek and PRB coals are all vitrinite-rich.

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Table 1 - Coal quality data for benchmark and reactive coal samples

Sample	R <sub>70</sub> (°C/h)	Volatile matter (%, dmmf)	Calorific value (Btu/lb, mmsf)	ASTM rank	Ash content (%, db)	Sulphur content (%, db)	Moisture content (%, ar)
Benchmark coals							
Kideco	28.57	51.6	9755	subC	1.8	0.10	24.0
Spring Creek	5.87	41.3	13749	hVbB	1.2	0.30	11.7
Reactive coals							
PRB	23.09	47.4	9801	subB	6.8	0.62	24.3
AUS1	14.61	30.2	10540	subA	11.5	0.12	17.0
AUS2	9.38	44.5	12198	hVcB	3.9	0.72	14.1

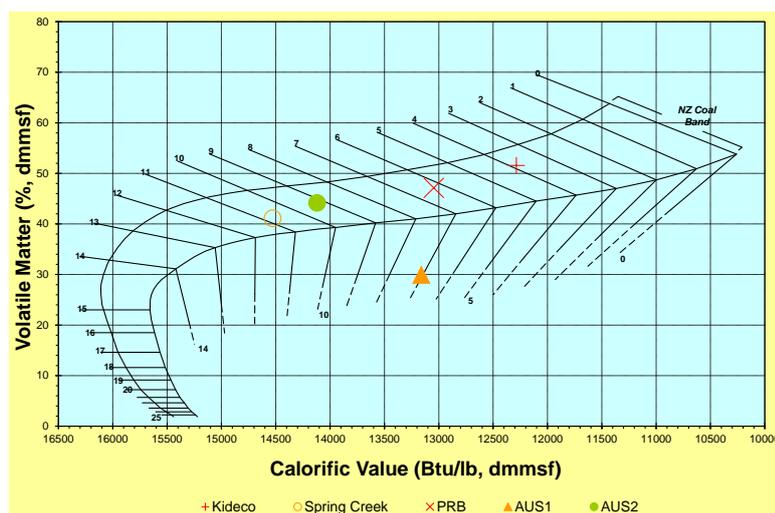


Figure 1 - Suggate rank plot of coal samples used in the study

### Self-heating test procedures

The R<sub>70</sub> testing procedure essentially involves drying a 150 g sample of <212 μm crushed coal at 110 °C under nitrogen for approximately 16 h (Beamish, 2005). Whilst still under nitrogen, the coal is cooled to 40 °C before being transferred to an adiabatic oven. Once the coal temperature has equilibrated at 40 °C under a nitrogen flow in the adiabatic oven, oxygen is passed through the sample at 50 mL/min. A data logger records the temperature rise due to the self-heating of the coal. The time taken for the coal temperature to reach 70 °C is used to calculate the average self-heating rate for the rise in temperature due to adiabatic oxidation. This is known as the R<sub>70</sub> index, which is in units of °C/h and is a good indicator of the intrinsic coal reactivity towards oxygen.

A more indicative test that quantifies coal self-heating behaviour from low ambient temperature to thermal runaway, known as Moist Adiabatic Benchmark (MAB) testing has been developed (Beamish and Beamish, 2011). The major changes from the normal R<sub>70</sub> method for MAB testing are, testing the coal with its as-received moisture content from the ambient mine start temperature, an increased sample size of approximately 200 g and a decreased oxygen flow rate of 10 mL/min. Increasing the sample size to 200 g provides a greater mass of coal to react that is still manageable without modifying the reaction vessel. Decreasing the oxygen flow rate to 10 mL/min reduces any cooling effect experienced by the coal from moisture evaporation as it self-heats. Effectively, these changes optimise the worst case scenario of developing a heating from as-mined coal.

### Anti-oxidant

The anti-oxidant applied to the coals in this study is currently being used to treat large quantities of Powder River Basin coal at an opencut mine producing 15 Mt/a. Normal treatment rates range from 45-225 g/t of coal depending on the characteristics of the coal, climatic factors and the duration of inhibition effectiveness required. Dosage requirements for solids treatment are known to be particle size

dependent, hence increased (surface area equivalent) dose rates were applied for laboratory testing to compensate for the <212  $\mu\text{m}$  crushed coal samples.

Adequate mixing is critical for effective treatment, as with all chemical applications, to ensure a uniform distribution of the anti-oxidant throughout the coal. In site applications, moisture addition can be minimised and mixing enhanced, by using specialty foam to distribute the anti-oxidant during the material handling process. Additional moisture is required under laboratory conditions, to effectively wet the <212  $\mu\text{m}$  coal and uniformly distribute the active chemical.

## ADIABATIC TESTING RESULTS AND DISCUSSIONS

### $R_{70}$ self-heating rate values and coal reactivity

The  $R_{70}$  self-heating curves for each sample are shown in Figure 2. Their respective  $R_{70}$  values are contained in Table 1. It can be seen that the Australian samples have an ultra-high intrinsic spontaneous combustion reactivity rating and the Powder River Basin and Kideco samples have an extremely high intrinsic spontaneous combustion reactivity rating based on Queensland conditions. It should be noted that this test is performed on a dry basis and it does not provide any indication of the moderating influence of the coal moisture content on self-heating. It also does not provide a reliable indication of the time taken for a coal to reach thermal runaway. In this particular example the coal reactivity is dominated by the rank order of the coals.

### Effectiveness of anti-oxidant in delaying thermal runaway

The MAB test results for raw and treated Powder River Basin coal are shown in Figure 3. The relative benchmark scale indicates that the time taken for spontaneous combustion issues in a loose stockpile of raw PRB coal would be in the order of 13 to 20 d. Actual site experience with this coal indicates that heating events at the mine can take place in 15 d. Hence, the MAB test provides an acceptable match with site experience for this coal and the PRB coal now provides a benchmark in its own right for comparing the effectiveness of spontaneous combustion inhibiting agents.

The self-heating curve of the treated coal shows the effectiveness of the inhibitor at reducing the initial self-heating rate as it reaches a maximum of 43.9  $^{\circ}\text{C}$  after 13 h and actually loses heat over the next ten h before the self-heating begins to accelerate again at a much more reduced rate compared to the raw coal. The time taken to reach thermal runaway is substantially prolonged (almost three times the raw coal) and according to the benchmark performance scale in Figure 3 the time taken for spontaneous combustion issues in a loose stockpile of treated PRB coal would be in the order of 34 to 51 d. This result is consistent with actual site experience using the anti-oxidant.

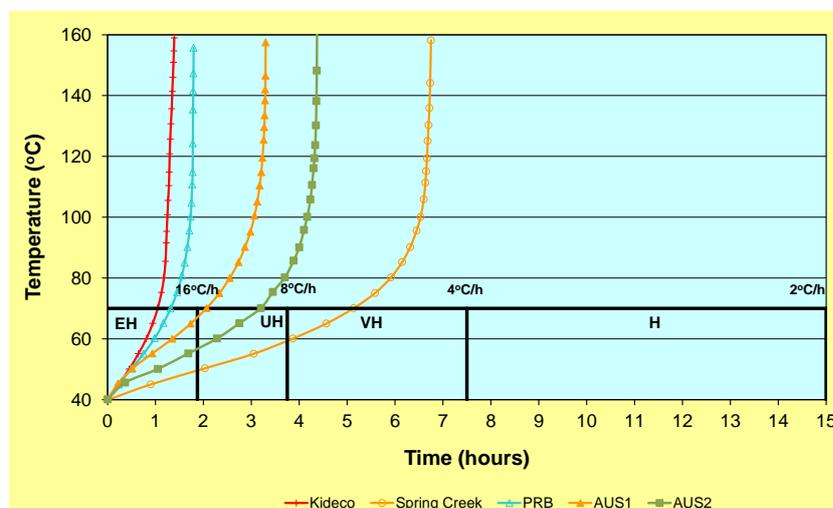
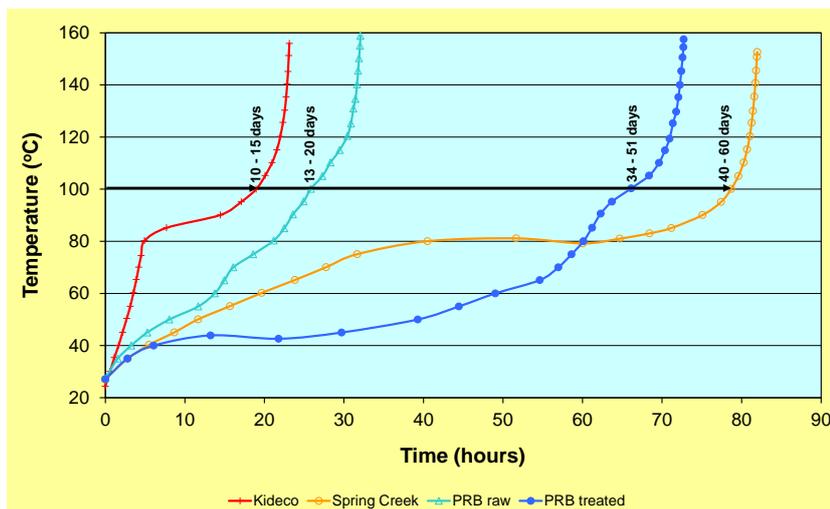


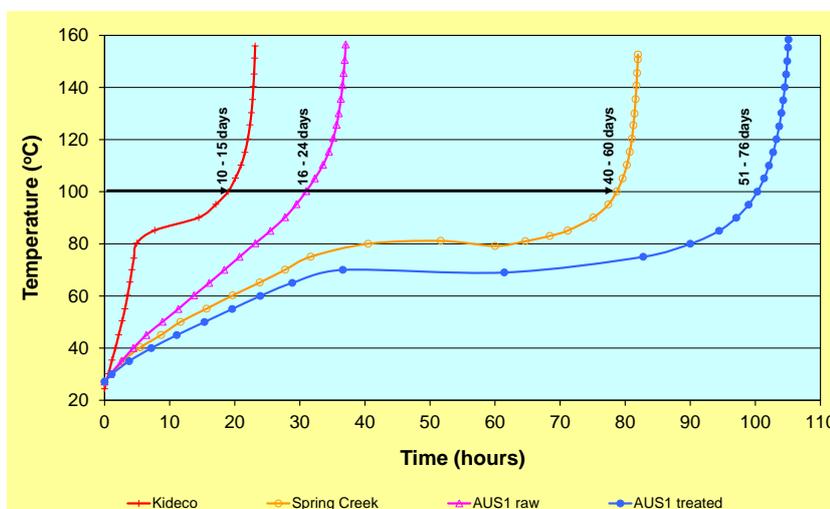
Figure 2 - Adiabatic self-heating curves for samples tested using the normal  $R_{70}$  test procedure, showing intrinsic spontaneous combustion reactivity ratings based on Queensland conditions (H = High, VH = Very High, UH = Ultra High, EH = Extremely High)



**Figure 3 - Moist adiabatic benchmark test results for Powder River Basin raw coal and treated coal using an inhibitor application of 100 g/t (surface area equivalent dose rate)**

The two Australian coals are located in areas that often experience wet season conditions and many spontaneous combustion incidents in stockpiles have been observed during this climatic period. The MAB test results for raw and treated AUS1 coal are shown in Figure 4. The relative benchmark scale indicates that the time taken for spontaneous combustion issues in a loose stockpile of raw AUS1 coal would be in the order of 16 to 24 d. This is consistent with the known behaviour of the coal in operations.

The self-heating curve of the treated AUS1 coal shows a different response to the PRB coal, as the initial delay in self-heating is not as dramatic, but as the test progresses there is a significant prolonged delay in self-heating once the coal reaches approximately 70 °C. This difference in the shape of the self-heating curve of the two treated coals could possibly be a function of the different pore structure associated with the maceral composition of the two coals. The AUS1 coal is inertinite-rich, which is usually associated with a high macroporosity, whereas the PRB coal is vitrinite-rich, which is usually associated with a high microporosity. It may also be that there is a fundamental difference in the way that each coal interacts with the anti-oxidant. Again, the time taken to reach thermal runaway is substantially prolonged (three times the raw coal) and according to the benchmark performance scale in Figure 4 the time taken for spontaneous combustion issues in a loose stockpile of treated AUS1 coal would be in the order of 51 to 76 d.

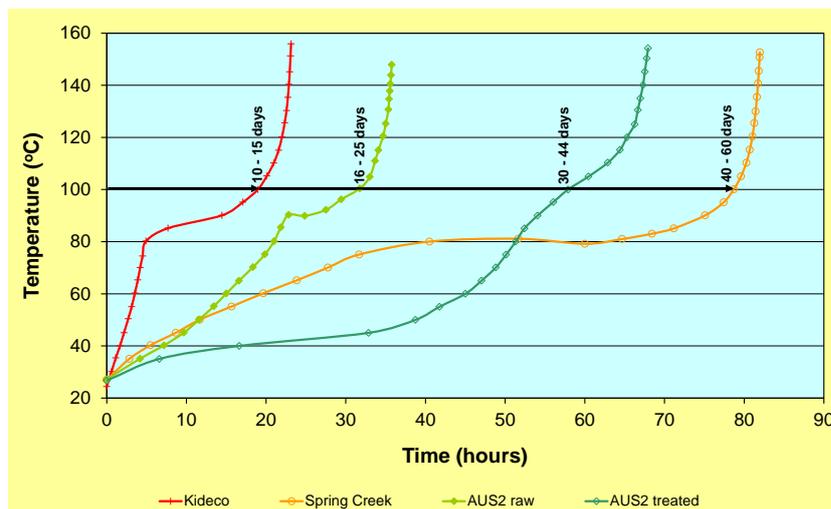


**Figure 4- Moist adiabatic benchmark test results for AUS1 raw coal and treated coal using an inhibitor application of 100 g/t (surface area equivalent dose rate)**

The MAB test results for raw and treated AUS2 coal are shown in Figure 5. The relative benchmark scale indicates that the time taken for spontaneous combustion issues in a loose stockpile of raw AUS2 coal would be in the order of 16 to 25 d. It is interesting to note that this value is almost identical to the AUS1

coal test, yet the AUS1 coal is over 50% more reactive than the AUS2 coal as shown by the  $R_{70}$  self-heating rate value. The reason for this result is that the AUS2 coal has approximately 3% less moisture and hence the heat loss from evaporation during the initial coal self-heating is less. In fact the AUS2 coal reaches 90°C sooner than the AUS1 coal as a result, but it then goes through a decrease in self-heating rate until oxidation sites become available after moisture has been evolved. Again the difference in shape between the two self-heating rate curves appears to be a function of the AUS2 coal being vitrinite-rich compared to the AUS1 coal being inertinite-rich. The increased rank of the AUS2 coal would also alter the coal microstructure.

The self-heating curve of the treated AUS2 coal shows a similar response to the PRB coal, in terms of its shape. The time taken to reach thermal runaway is approximately double that of the raw coal and according to the benchmark performance scale in Figure 5 the time taken for spontaneous combustion issues in a loose stockpile of treated AUS2 coal would be in the order of 30 to 44 d.



**Figure 5 - Moist adiabatic benchmark test results for AUS2 raw coal and treated coal using an inhibitor application of 100 g/t (surface area equivalent dose rate)**

For each of the three coals tested in this study the delay in reaching thermal runaway created by the anti-oxidant application shows that it is possible to manage each of these coals in an effective manner to mitigate the risk of spontaneous combustion related events. At this time the anti-oxidant treatment has been successfully implemented in opencut operations of the Powder River Basin. The chemical agent has an added benefit as it also acts as a dust suppressant. It would also reduce calorific value loss of the coal given the nature of its effectiveness to reduce the rate of coal oxidation.

Underground coal mines that are operating with reactive coals could also benefit from the application of this anti-oxidant to mitigate against goaf heatings. The dust suppressant aspect of the product could also benefit mines using seamgas drainage. Again this would be an added benefit since gas drainage of reactive coals increases the propensity of the coal to self-heat, as the drainage process removes both moisture and gas from the coal pore structure thus freeing up reactive sites for oxidation to take place.

## CONCLUSIONS

Mitigation of coal spontaneous combustion has been successfully practiced in the Powder River Basin for a considerable time now using the systematic application of an anti-oxidant. The effectiveness of this chemical to inhibit coal self-heating and delay thermal runaway has been quantified using adiabatic oven testing procedures, which produce results in agreement with site experience. The same laboratory testing procedures have also shown that the anti-oxidant is just as effective on an Australian sub-bituminous coal and an Australian high volatile C bituminous coal. There appears to be a relationship between rank and the delay time to thermal runaway as the higher rank coal shows a delay by a factor of two, whereas the lower rank coal shows a delay by a factor of three.

These results have significant practical implications for the successful management of mining, storage and transport of these coals. The success of applying anti-oxidants in the Powder River Basin can be

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transferred to Australian operations in a sound scientific manner by simulated laboratory testing in conjunction with closely monitored field trials.

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