Benchmarking moist coal adiabatic oven testing

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Coal self-heating leading to spontaneous ignition is an on-going safety and environmental issue for the coal industry. To assist with developing an appropriate Spontaneous Combustion Management Plan (SCMP) it is necessary to assess the propensity of the coal to spontaneously combust. This paper presents preliminary results of a new test method that benchmarks moist coal self-heating using an adiabatic oven against actual site performance. The test is conducted on the coal in its as-received moisture state. There is a significant time separation to thermal runaway between each of the coals tested to date. Coals with moisture contents greater than 7% go through a temperature plateau region before reaching thermal runaway, whereas coals with moisture contents less than 7% steadily increase in temperature until reaching thermal runaway.

INTRODUCTION

The influence of moisture on coal self-heating has been investigated by a number of studies. It is generally accepted that there are competing influences of heat of wetting and moisture evaporation depending on the environmental circumstances of the coal (Bhat and Argarwal, 1996; Bhattacharyya, 1971, 1972; Guney, 1971; Hodges and Hinsley, 1964). Numerical model studies by Akgun and Essenhigh (2001) showed that moisture effects on self-heating in a broken coal pile situation are two-fold. In the case of low moisture content coals, the maximum temperature increases steadily with time. In the case of high moisture coals, temperature increases rapidly initially before evaporation dominates and the temperature reaches a plateau value (generally around 80-90°C). Once the coal becomes dry locally the temperature will increase rapidly towards thermal runaway. However, if the coal pile has been in a prolonged drying phase that is interrupted by a rain event and the water penetrates into the pile then additional heat can be generated from the heat of wetting effect as the coal re-adsorbs the moisture available to it. This effect can also lead to premature thermal runaway in the coal pile.

Development of a standard laboratory test to benchmark moisture effects on coal self-heating has not been achieved to date. Instead a number of tests have been developed to rate the propensity of coal for spontaneous combustion (Nelson and Chen, 2007). In the Australian and New Zealand coal industries there is one test that is routinely used. This is the R_{70} self-heating rate test (Beamish et al., 2000, 2001; Beamish and Arisoy, 2008a), which has been used to show the effects on coal self-heating rate of rank (Beamish, 2005), type (Beamish and Clarkson, 2006), mineral matter (Beamish and Blazak, 2005; Beamish and Sainsbury, 2007; Beamish and Arisoy, 2008b) and moisture (Beamish and Hamilton, 2005; Beamish and Schultz, 2008). The R_{70} self-heating rate is a low temperature oxidation spontaneous combustion index parameter that is measured on dried coal from a start temperature of 40 °C. The relationship of this parameter to thermal runaway performance of as-mined coal has been interpreted on an inferred basis by comparison with coals that have similar R_{70} values and coal characteristics. As such a propensity rating scale has been developed for both New South Wales and Queensland conditions using this parameter.

This paper presents preliminary results of a new test method to benchmark moist coal performance from adiabatic oven testing against actual site performance of a range of coals from Australia and overseas that cover the rank spectrum from sub-bituminous to high volatile A bituminous.

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ADIABATIC OVEN TESTING

Coal samples

Details of the samples used in this study are contained in Table 1. Spring Creek Mine extracts coal from the Main Upper Seam of the Greymouth Coalfield, New Zealand using a bord and pillar system and hydro-mining. Coals A, B and C are from the Sydney Basin of Australia. Coal B is currently mined by opencut methods and coals A and C are from two longwall mines still under development. Coal D is imported into New Zealand from Indonesia to supply a local power station. This coal also has a history of self-heating during storage at the New Zealand port facilities if not reclaimed within 10-15 days.

Table - Coal quality data and test parameters for high volatile bituminous and subbituminous samples

Sample	R_{70} (°C/h)	Volatile matter (%, dmmf)	Calorific value (Btu/lb, mmmf)	ASTM rank	Ash content (%, db)	Moisture content (%)	Start temperature (°C)
Spring Creek	5.87	41.3	13749	hvBb	1.2	11.7	27.0
Coal A	5.95	37.7	13298	hvBb	15.3	7.3	27.3
Coal B	3.18	45.8	14664	hvAb	4.9	3.0	27.5
Coal C	3.08	39.3	14029	hvAb	4.4	5.0	27.4
Coal D	28.57	51.6	9755	subC	1.8	24.0	24.4

SELF-HEATING TEST PROCEDURE

The R_{70} testing procedure essentially involves drying a 150g sample of <212µm crushed coal at 110°C under nitrogen for approximately 16 hours. 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 50mL/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_{70} index, which is in units of °C/h and is a good indicator of the intrinsic coal reactivity towards oxygen.

The major changes from the normal R_{70} method for moist coal testing are, testing the coal with its as-received moisture content from the ambient mine start temperature, an increased sample size of 200g and a decreased oxygen flow rate of 10 mL/min. Increasing the sample size to 200g 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.

RESULTS AND DISCUSSION

R_{70} self-heating rate values

The R_{70} self-heating curves for each sample are shown in Figure 1. Their respective R_{70} values are contained in Table 1. It can be seen that Coals B and C have a medium intrinsic spontaneous combustion propensity rating, Spring Creek and Coal A have a high intrinsic spontaneous combustion propensity rating and Coal D has an ultra high intrinsic spontaneous combustion propensity rating. These values and rating are generally consistent with the rank differences between the samples.

Moist coal performance and benchmark comparison

Results of tests using the new moist coal adiabatic method are shown in Figure 2. It is clear that Coals A, B and C are much less reactive than the Spring Creek coal sample when tested from the same start boundary conditions that incorporate the coal moisture. In addition, even though Coal D was started 3°C lower than all the other tests it is still by far the most reactive coal, consistent with its low rank and high R_{70} rating. The separation in time to reach thermal runaway between each coal is also quite distinct, as is the shape of the self-heating curves.

All of the high moisture samples (Coal D, Coal A and Spring Creek) show a visible temperature plateau region before proceeding to thermal runaway. This is consistent with the published moist coal numerical models of Schmal et al., (1985), Arisoy and Akgun, (1994), Monazam et al., (1998), and Akgun and Essenhigh, (2001). The two low moisture samples (Coals B and C) show no temperature plateau region and steadily increase in temperature towards thermal runaway. Again this behaviour is consistent with the published numerical models.

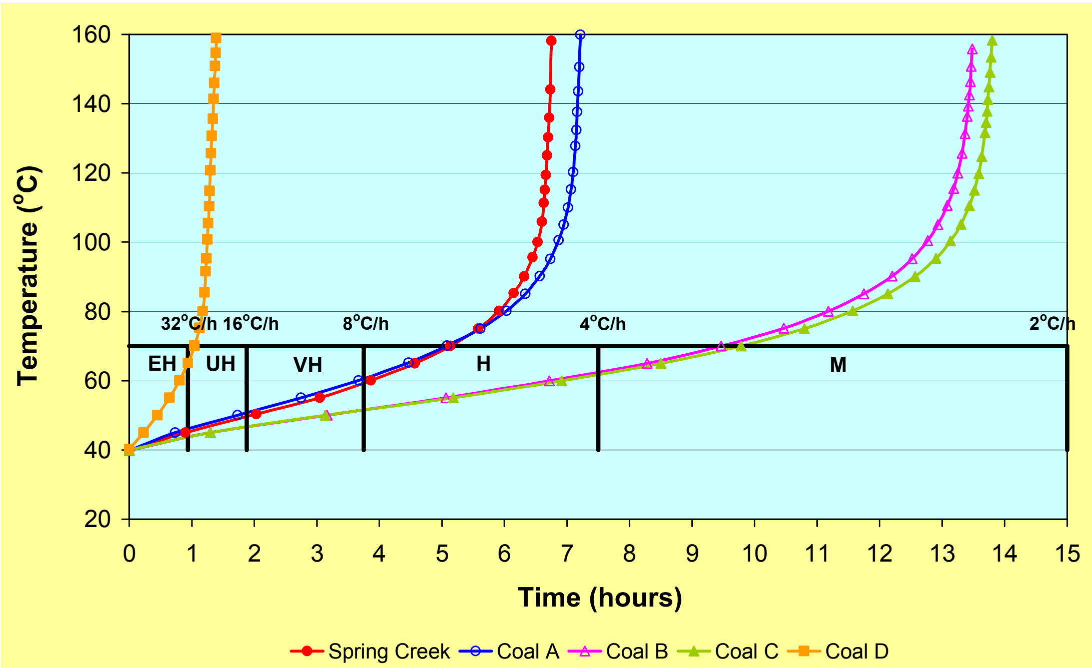

Figure 1 - Adiabatic self-heating curves for samples tested using the normal R70 test procedure, showing intrinsic spontaneous combustion propensity ratings based on New South Wales conditions (M – Medium, H = High, VH = Very High, UH = Ultra High, EH = Extremely High)

Coal A takes approximately two and a half times as long to reach a thermal runaway situation as Spring Creek coal (Figure 2) despite having a similar R_{70} value (Table 1). This is most likely a combination of both the way in which moisture is held in the pores of Coal A and the higher mineral matter content. These same coal features may also be contributing to the lower temperature plateau of 60°C for Coal A. In practical terms the prolonged temperature plateau at approximately 60°C for this coal provides a significant opportunity to detect and manage any hot spot development in loosely broken coal in an underground environment, which could be monitored based on the corresponding gas evolution pattern associated with the coal self-heating.

Coals B and C do not display a temperature plateau due to the low initial moisture content of the two coals. The time taken to reach thermal runaway for Coal B is approximately one and a half times that of Spring Creek coal. Interestingly, the R_{70} value of Coal B is half that of Coal A yet it reaches thermal runaway much sooner due to the combined effects of a lower moisture content and lower mineral matter content. Coal C however, takes approximately four times longer to reach thermal runaway than Spring Creek coal and over three times longer than Coal B, despite both Coal C and Coal B having similar R_{70} values. This may be because Coal B is slightly lower in rank than Coal C.

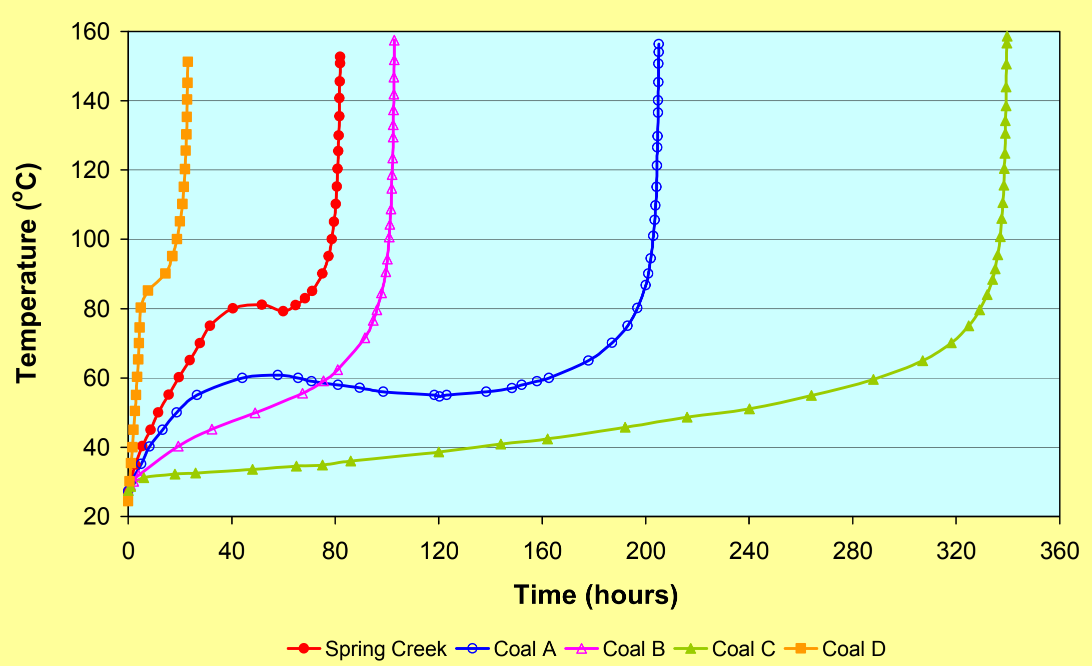

Figure 2 - Moist coal adiabatic self-heating curves for three high volatile bituminous coals from the Sydney Basin and a subbituminous coal from Indonesia compared with high volatile bituminous coal from Spring Creek Mine, New Zealand

Coal D reaches thermal runaway in approximately one quarter of the time taken by Spring Creek. Given actual heatings occur in loose stockpiles of this coal in 10-15 days it would suggest that heating issues would occur at Spring Creek between 40-60 days if a substantial broken coal pile formed. This is consistent with the mine experience of the heating that developed in July 2008 (Beamish and Hughes, 2009). The same analogy can be applied to the other coals. Therefore, Coal B would be expected to take between 60-80 days to develop a heating. Again stockpile experience with this coal confirms that heatings have not developed in less than 60 days and in fact records show that only mild warming has occurred in handling this coal to date.

CONCLUSIONS

Benchmarking moist coal self-heating performance against two known reactive coal behaviours has advanced the use of small-scale laboratory testing for rating spontaneous combustion propensity. There are clear distinctions between high moisture content and low moisture content coal behaviours. Coals tested to date with moisture contents above 7% as-received show a temperature plateau region where the balance between heat generated from coal oxidation and heat lost through moisture evaporation reaches a temporary equilibrium, until the coal becomes sufficiently dry locally. Once this stage is surpassed the coal temperature rapidly goes into thermal runaway and spontaneous ignition is inevitable. In contrast, coals with moisture contents lower than 7% appear to steadily increase in temperature until reaching thermal runaway. These differences have practical implications for spontaneous combustion management. For example, the high moisture situation appears to provide a larger window of opportunity to detect and control an underground heating.

ACKNOWLEDGEMENTS

The authors would like to thank Solid Energy New Zealand Ltd for their continued support of spontaneous combustion benchmarking and UniQuest Pty Limited for granting permission to publish this paper.

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