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EXPERIENCE WITH USING A MOIST COAL ADIABATIC OVEN TESTING METHOD FOR SPONTANEOUS COMBUSTION ASSESSMENT

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ABSTRACT: Many small-scale coal spontaneous combustion tests exist, but none of these appear to be comprehensive and definitive in terms of assessing the self-heating behaviour of coal at low temperatures from ambient to thermal runaway. Within this low temperature region there are a number of competing influences on the tendency of the coal to continue to gain heat. One of the key influences is the presence of moisture in the coal as this contributes to heat loss from evaporation. The presence of disseminated pyrite can contribute to heat gain from the additional exothermic reaction with oxygen in the presence of moisture. A new moist coal adiabatic oven test has been developed that can measure the influence of these parameters on the low temperature self-heating of coal. Examples of the experience gained from using this test clearly show the effects of moisture and pyrite on coal self-heating leading to thermal runaway. The results obtained have major consequences for the operational planning and management of the spontaneous combustion hazard.

INTRODUCTION

The influence of moisture on coal self-heating has been investigated in 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 (Hodges and Hinsley, 1964; Guney, 1971; Bhattacharyya, 1971, 1972; Bhat and Argarwal, 1996). 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. The presence of pyrite may also complicate the heat balance situation and is identified under certain circumstances as a heat contributor.

Development of a standard laboratory test to benchmark moisture or pyrite 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 adiabatic oven R_{70} self-heating rate test (Beamish, Barakat and St George, 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) and mineral matter (Beamish and Blazak, 2005; Beamish and Sainsbury, 2008; Beamish and Arisoy, 2008b). 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 reactivity rating scale has been developed for both New South Wales and Queensland conditions using this parameter.

Recent studies by Beamish and Hamilton (2005) and Beamish and Schultz (2008) have re-emphasised the importance of moisture on coal self-heating. As a result of these studies, Beamish and Beamish (2010) proposed a new moist coal adiabatic oven test that can be used to benchmark laboratory performance 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. Since introducing this test to the coal industry a number of additional benchmark coals have been added to the database and tests have been conducted that show this new method is extremely accurate and definitive for assessing the

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spontaneous combustion risk of coal in a range of environmental situations. Some specific examples of this more recent testing technique and highlights the significance to operational planning and management are presented.

ADIABATIC OVEN TESTING

Coal samples

Details of the samples used in this study are contained in Table 1. The three major benchmark coals are Kideco (Indonesia), Spring Creek (New Zealand) and Rocglen (Australia). The Bowen Basin test samples were received as fresh core samples from exploration boreholes. They were appropriately sealed in gladwrap to prevent oxidation and tightly bound with duck tape to maintain sample integrity as solid cores. Representative splits were taken from each core length for testing.

Sample BBHVB01 was from the uppermost part of the seam in one borehole and sample BBHVB07 was from the equivalent horizon in another borehole from the deposit. Samples BBHVB08 and BBHVB10 were from lower horizons in the seam of the same borehole as BBHVB07. All of these samples have an ASTM rank of high volatile C bituminous based on the volatile matter and calorific value of the coal.

Table 1 - Coal quality data and test parameters for benchmark and Bowen Basin coal samples

Sample	R_{70} (°C/h)	Volatile matter (%, dmmf)	Calorific value (Btu/lb, mmmf)	ASTM rank	Ash content (%, db)	Sulphur content (%, db)	Moisture content (%)	Start temperature (°C)
Benchmark coals								
Kideco	28.57	51.6	9755	subC	1.8	0.10	24.0	24.4
Spring Creek	5.87	41.3	13749	hvBb	1.2	0.30	11.7	27.0
Rocglen	3.18	45.8	14664	hvAb	4.9	0.45	3.0	27.5
Bowen Basin high volatile bituminous coal								
BBHVB01	7.00	35.7	12653	hvCb	2.3	0.38	10.9	27.0
BBHVB07	6.02	38.0	12885	hvCb	7.3	4.54	9.8/9.3#	27.2
BBHVB08	7.98	32.6	12845	hvCb	4.9	0.56	12.0	27.0
BBHVB10	6.83	34.7	12882	hvCb	5.9	0.45	6.9*	29.1

Moisture contents of initial/repeat test; ***** 5% moisture removed from sample

Self-heating test procedure

The R_{70} testing procedure essentially involves drying a 150 g sample of <212 μm crushed coal at 110 °C under nitrogen for approximately 16 h. 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_{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 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.

RESULTS AND DISCUSSIONS

R_{70} self-heating rate values

The R_{70} self-heating curves for each sample are shown in Figure 1. Their respective R70 values are contained in Table 1. It can be seen that Bowen Basin samples have a very high intrinsic spontaneous combustion reactivity rating that is slightly higher than Spring Creek. These values and rating are generally consistent with the rank and coal type of the Bowen Basin coal.

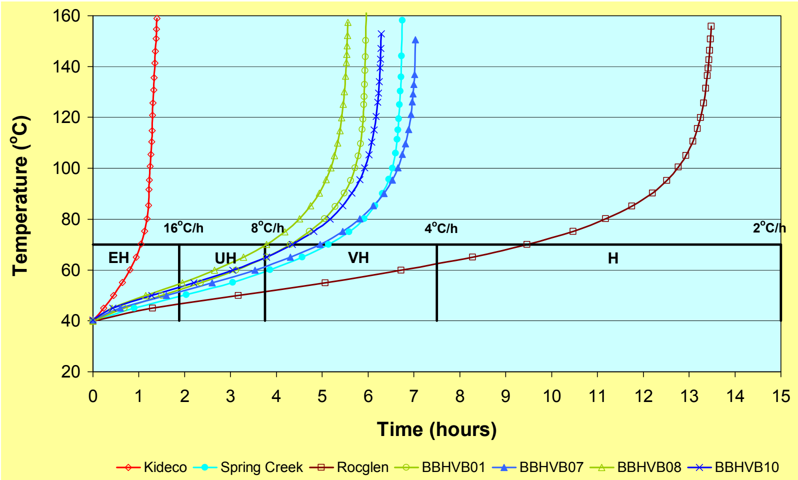

Figure 1 - Adiabatic self-heating curves for samples tested using the normal R_{70} test procedure, showing intrinsic spontaneous combustion reactivity ratings based on Queensland conditions (H = High, VH = Very High, UH = Ultra High, EH = Extremely High)

Sample BBHVB07 has a significantly higher sulphur content compared to the other samples (Table 1). Analysis of the forms of sulphur for this sample shows that 42% is due to the presence of pyrite, 54% is organic sulphur and 4% is sulphate sulphur. This equates to less than 2% pyrite present in the sample as tested. A visual inspection of the sample revealed traces of fine pyrite stringers spread throughout the core. The R_{70} values of the cores do not appear to make any clear distinction in the self-heating performance of this sample compared to the others. In fact it has the lowest R_{70} value, presumably due to its higher mineral matter content (ash content). Given the long held view that presence of pyrite increases spontaneous combustion propensity, this result seems to be contradictory. However, it must be remembered that the key exothermic pyrite reaction takes place with oxygen in the presence of moisture. As the R_{70} test is performed on a dry basis this additional reaction does not take place and hence the additional exothermic reaction that may be attributable to the presence of pyrite is not measured by the test.

Moist coal performance and benchmark comparison

Results of tests using the new moist coal adiabatic method are shown in Figure 2. The results for the typical coal cores from the deposit (BBHVB01 and BBHVB08) show that the moisture content of the coal significantly inhibits the coal self-heating. To emphasise this, sample BBHVB10 had 5% of its moisture content removed and when tested under the same start temperature conditions showed a rapid progression to thermal runaway. At this level of moisture, no temperature plateau was recorded. Therefore the moisture state of the coal from the mine face to the stockpile will be an important parameter in determining the overall spontaneous combustion risk of the coal. A site investigation of this effect is underway.

The most important result of this study is the self-heating behaviour of sample BBHVB07. This result is the fastest of any sample tested to date. It reaches thermal runaway in half the time taken by the low rank Kideco coal and indicates the possible risk of the coal creating a spontaneous combustion event in approximately five days based on the benchmark comparison (Figure 2). The accelerated self-heating of this sample compared to all of the others can only be attributable to the presence of the pyrite in the coal reacting with the oxygen and moisture. It is quite a dramatic effect and one that has not been documented so clearly in experimental work before. To prove that the test was not just an artefact, a repeat sample was tested and the results are shown in Figure 3. This clearly shows that the experimental procedure is very repeatable and that differences between samples can be identified with confidence.

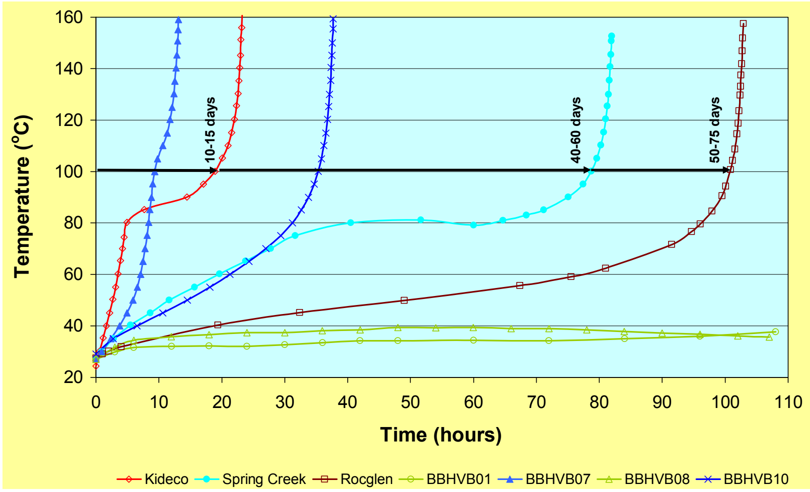

Figure 2 - Moist coal adiabatic self-heating curves for high volatile bituminous coal samples from the Bowen Basin compared with benchmark coals (Note: the case history typical minimum number of days to reach thermal runaway for each of the benchmark coals is shown)

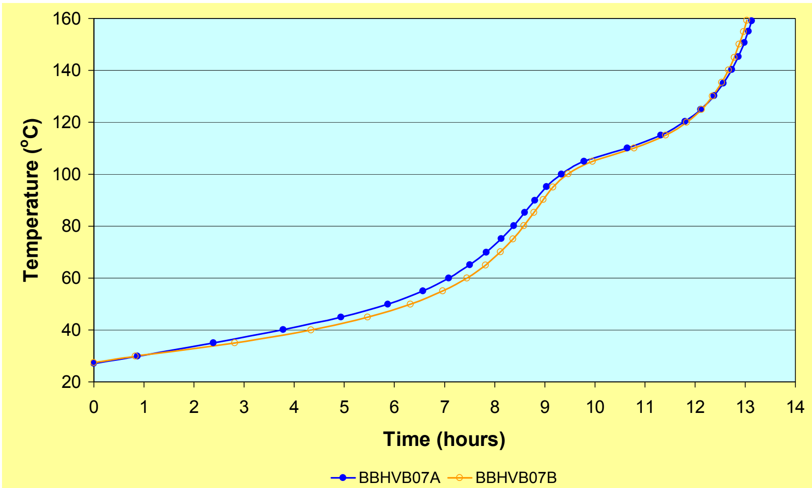

Figure 3 - Repeat moist coal adiabatic testing of a pyrite-rich coal ply from a Bowen Basin coal deposit

The identification of this reactive layer in the deposit is a key feature that can be used for spontaneous combustion hazard mapping purposes. Further detailed geotechnical investigation is underway to assess both the vertical and lateral extent of the influence this may have on mine planning and stockpile management of the coal. This work will commence in early 2011 as the geological model of the deposit is refined and further testing is warranted to identify the extent of the pyrite effect on the coal self-heating performance.

CONCLUSIONS

The new moist coal adiabatic testing method is proving invaluable to the assessment of coal spontaneous combustion for hazard management planning. Coals of similar intrinsic reactivity show quite dissimilar behaviours in terms of time taken to reach thermal runaway from low ambient temperatures due to the moderating influence of moisture present in the coal. This effect has been documented in earlier moist coal testing on low rank coals and it is clearly shown for a high volatile bituminous coal from the Bowen Basin. It is therefore quite important to understand and document any moisture changes in coal from the mining face to the stockpile environment.

Pyrite has often been cited as an accelerant in the coal self-heating process. This effect is dramatically illustrated by the moist coal adiabatic oven test as the pyrite reaction involving oxygen and moisture is measured. Tests on borehole cores from a Bowen Basin coal deposit have identified a particular seam horizon where the pyrite accelerated coal self-heating is prevalent. This feature of the coal deposit is under further investigation and will be incorporated into the hazard management planning of the operation.

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