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CONTRAST IN SELF-HEATING RATE BEHAVIOUR FOR COALS OF SIMILAR RANK

Basil Beamish and Jan Theiler

ABSTRACT: Adiabatic oven testing of seven coal samples with a similar rank has been conducted, which demonstrates differences in their self-heating rate behaviours under the mine settings that they are found in. This has been achieved using a new benchmarking adiabatic test that provides an accurate means of establishing if a coal can reach thermal runaway and in what minimum timeframe. Four of the samples reached thermal runaway, but there was a considerable range in the time taken. The shape of the self-heating rate curves also showed a degree of variation. One of the samples displayed gradual self-heating over the duration of the test and would have reached thermal runaway eventually. The other two samples initially self-heated and reached a maximum temperature before the heat loss mechanism from moisture evaporation dominated and the coal temperature steadily decreased. One of these samples was retested at a lower moisture state and was able to reach thermal runaway. These results confirm the importance of testing samples to assess the risk of developing a spontaneous combustion event.

INTRODUCTION

Adiabatic oven testing has been used routinely by Australian and New Zealand coal mine operations since the early 1980's to rate the propensity of coal to spontaneously combust (Humphreys *et al.*, 1981). A relative rating scale has been applied to the R_{70} initial self-heating rate parameter normally obtained from these tests (Beamish and Beamish, 2012). This intrinsic spontaneous combustion propensity rating enables an assessment to be made of the possible risk of a spontaneous combustion event developing; however it does not provide an indication of the timeframe in which this can occur. More recently adiabatic oven testing has been applied to benchmark the time taken to reach thermal runaway (Beamish and Beamish, 2010, 2011, 2012).

R_{70} values are strongly rank dependent (Beamish and Arisoy, 2008a,b; Beamish and Beamish, 2012), with low rank coals having high R_{70} values (up to 99 °C/h for lignite) and high rank coals having low R_{70} values (less than 0.5 °C/h for medium and low volatile bituminous coals). Other coal properties such as mineral matter and coal type (dull or bright) can also affect the R_{70} value (Beamish and Blazak, 2005; Beamish and Clarkson, 2006; Beamish and Sainsbury, 2008). This paper presents examples of the self-heating behaviour of coals with a similar rank that shows considerable contrast in self-heating rates under moist adiabatic conditions.

COAL SAMPLES AND ADIABATIC TESTING

Seven coal samples of similar rank from Queensland (five samples) and New South Wales (two samples) were tested in an adiabatic oven to establish their R_{70} values and to benchmark the time taken to reach thermal runaway under conditions more closely resembling those of the mine site. The R_{70} testing procedure is described by Beamish (2005) and essentially involves testing a dried, crushed coal sample under adiabatic conditions from a fixed starting temperature of 40 °C. The benchmarking procedure, known as SponComSIM™ testing, uses the coal in its as-mined moisture state and a starting temperature that reflects the site-specific conditions. The results obtained provide both an indication of the time taken to reach thermal runaway and the characteristic behaviour of the coal as self-heating progresses. This can be compared against case history coals of known self-heating behaviour.

The coal quality details of the samples are contained in Table 1 and their similarity in coal rank is demonstrated on a Suggate rank plot (Suggate, 2000) shown in Figure 1. The Suggate rank number for the samples ranges from 11.0 to 11.5 and the samples are considered to be high volatile bituminous under the ASTM classification scheme. There is a difference in coal type from high vitrinite (QLD1 and QLD4 plotting within the New Zealand coal band) to low-medium vitrinite (QLD2, QLD3, QLD5, NSW1 and NSW2 plotting below the New Zealand coal band). Three of the Queensland samples (QLD3, QLD4 and QLD5) are from the one seam and the other two samples (QLD1 and QLD2) come from different

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mining locations. The two New South Wales samples are from the same seam with NSW1 collected from the upper part of the seam and NSW2 collected from the lower part of the seam. All of these coals are mined for thermal coal markets.

Table 1: Coal quality data for Queensland and New South Wales coal samples

Sample	R_{70} (°C/h)	Moisture content (%, ar)	Ash content (%, db)	Sulphur content (%, db)	Volatile matter (%, dmmf)	Calorific value (Btu/lb, mmmf)	ASTM rank
Queensland coals							
QLD1	2.74	7.3	8.7	0.31	40.2	13666	hvBb
QLD2	3.42	8.8	13.8	0.26	28.2	13567	hvBb
QLD3	7.35	10.0	4.6	0.33	31.3	13040	hvBb
QLD4	7.78	8.0	2.4	0.62	40.7	13346	hvBb
QLD5	6.34	12.0	4.2	0.57	36.7	12858	hvBb
New South Wales coals							
NSW1	6.76	9.1	9.1	0.38	27.8	13277	hvBb
NSW2	4.18	8.1	7.9	0.36	30.0	13541	hvBb

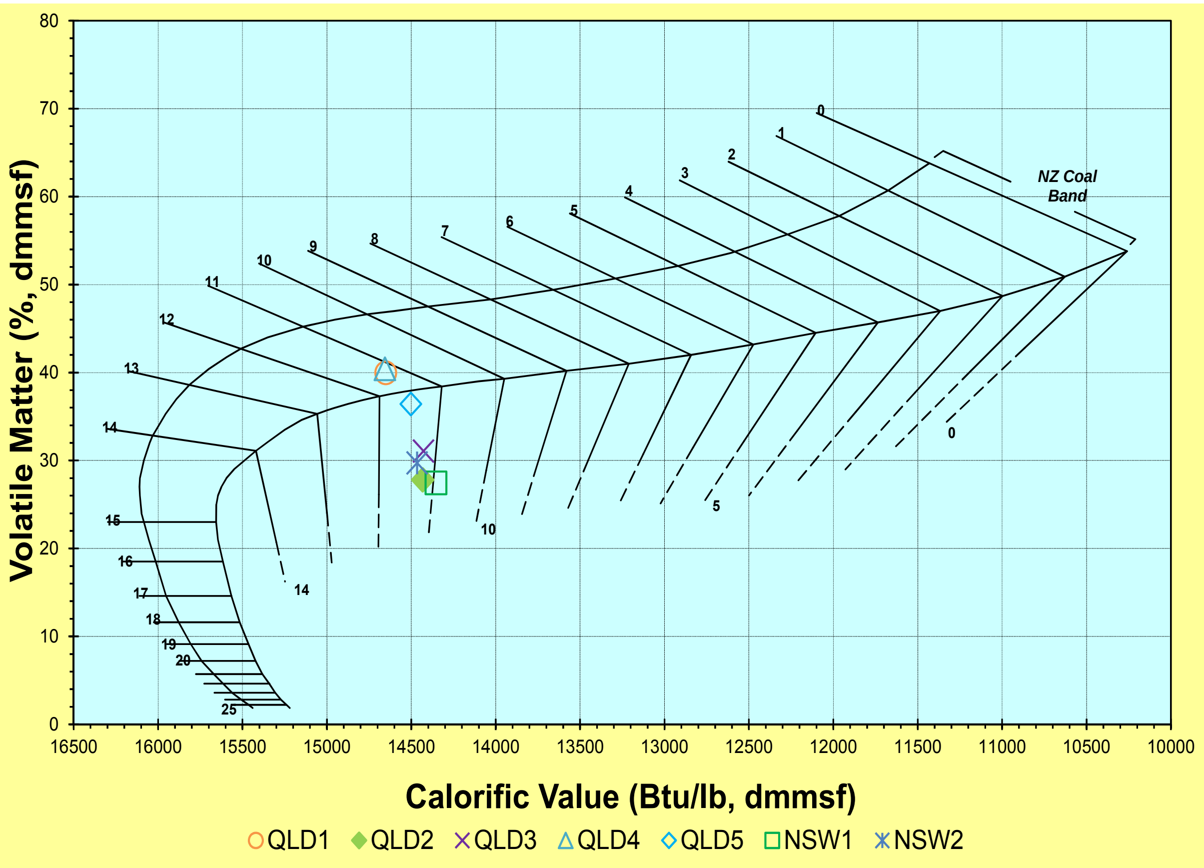

Figure 1: Suggate rank plot of coal samples used in adiabatic testing

ADIABATIC TESTING RESULTS AND DISCUSSION

R_{70} values

The R_{70} self-heating rate curves for all the samples are shown in Figure 2. The Queensland samples show a range of R_{70} values from 2.74 °C/h to 7.78 °C/h, which rates these coals as having a high to very high intrinsic spontaneous combustion propensity for Queensland conditions (Beamish and Beamish, 2012). The New South Wales samples have a narrower range and rate this coal seam as having a high intrinsic spontaneous combustion propensity based on New South Wales conditions (Beamish and Beamish, 2012). The lower R_{70} values for the QLD1 and QLD2 samples may be related to a combination of higher ash contents and a slightly elevated rank compared to the other Queensland samples. The difference in the R_{70} values of the New South Wales samples may be related to a subtle difference in the mineral matter assemblage present in each sample. The lower part of the seam is believed to contain the mineral Dawsonite, similar to other seams in this region (Zhao *et al.*, 2014), which may be acting as a natural block to oxygen availability to reactive sites.

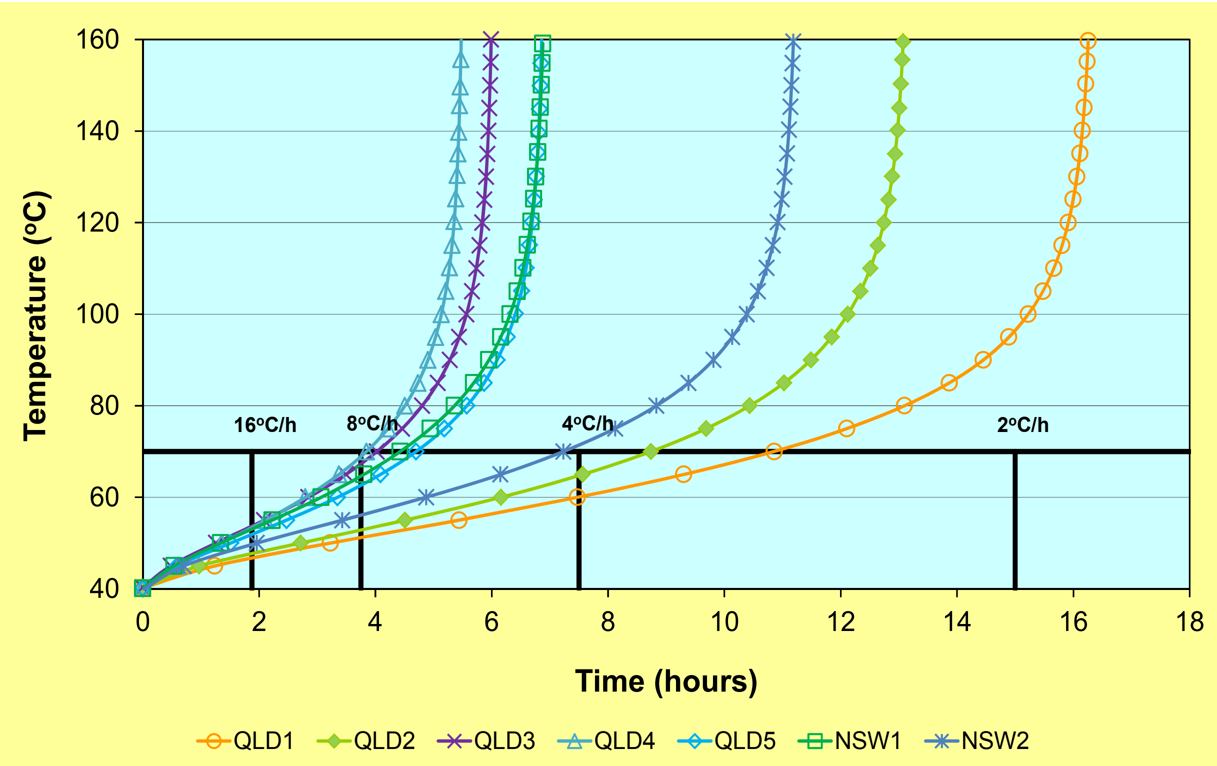

Figure 2: Adiabatic self-heating curves for a range of Queensland and New South Wales high volatile bituminous coals under dry conditions

Self-heating performance

The SponComSIM™ test results are shown in Figure 3. Despite the similarity in coal rank of the samples there is a clear set of contrasting behaviours displayed by the coals under these test conditions. Not all of the samples reached thermal runaway.

Sample QLD1, which has the lowest moisture content of the samples and the lowest R_{70} value gradually self-heats to thermal runaway (Figure 3), and the shape of the self-heating curve is similar to the R_{70} self-heating rate curve (Figure 2). The main difference is that it takes 136 hours to reach 160 °C compared with 16 hours in the dry state used for the R_{70} test.

Sample QLD2 has a higher R_{70} value than sample QLD1, but it also has a higher moisture content (8.8% cf 7.3%). In this case the increased moisture content of the coal is sufficient to provide a higher heat loss from moisture evaporation as the coal temperature increases from the oxidation reaction. Consequently, the coal initially self-heats to a maximum temperature of 53 °C before the heat loss from moisture evaporation exceeds the heat gained from coal oxidation and subsequently the temperature of the coal decreases (Figure 3). This result emphasises the importance of this heat balance mechanism in governing whether an intrinsically reactive coal can reach thermal runaway.

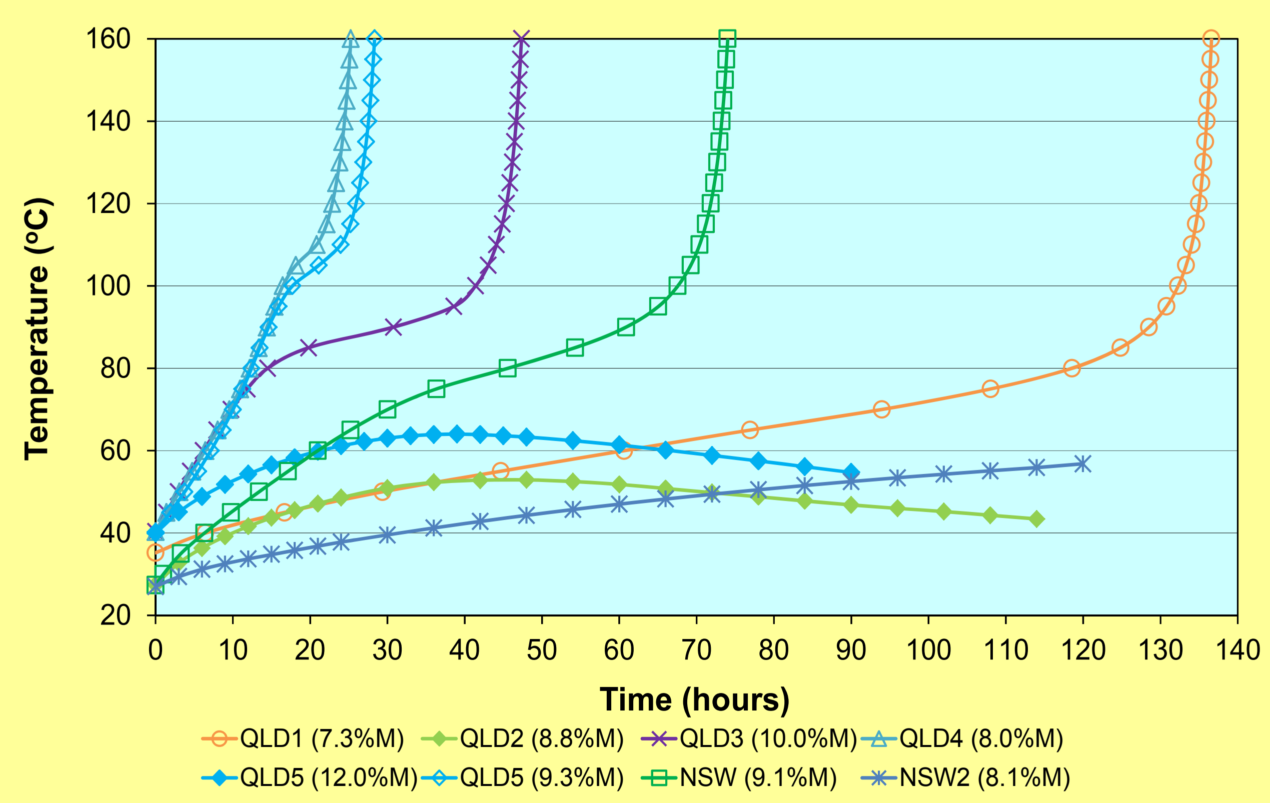

Figure 3: Adiabatic self-heating curves for a range of Queensland and New South Wales high volatile bituminous coals under moist conditions

This heat balance mechanism is further demonstrated by the self-heating performance of the QLD3, QLD4 and QLD5 coal samples. All three samples are identified as very reactive from the R_{70} test results, but it is clear that the time to thermal runaway under normal mine conditions is strongly modified by the moisture content present in the coal. In this case QLD4 reaches thermal runaway in the shortest time due to having the lowest moisture content (8.0%) and QLD5, which has the highest moisture content (12.0%) does not reach thermal runaway at all (Figure 3). Instead QLD5 displays a similar self-heating curve to QLD2 and reaches a maximum temperature of 64 °C before the heat loss from moisture evaporation exceeds the heat gained from coal oxidation and subsequently the temperature of the coal decreases. A replicate sample of QLD5 was tested at a lower moisture content of 9.3% to confirm the influence of the moisture on the coal self-heating performance. This result is shown in Figure 3 and it can be seen that the self-heating curve falls between QLD3 and QLD4, consistent with the moisture content difference between the samples.

Sample QLD3 shows a noticeable inflection in the self-heating curve once the coal temperature exceeds 80 °C. This is referred to as a moisture shoulder and is the result of the on-going heat balance response between heat loss from moisture evaporation and heat gain from coal oxidation. As the coal dries out more reactive sites become available for the oxidation reaction to continue and in this case it appears that once the coal temperature exceeds 100 °C the coal temperature rapidly progresses to thermal runaway.

The intrinsic coal reactivity of NSW1 is just over 50% higher than NSW2 as shown by the difference in their R_{70} values (Table 1). This difference is sufficient for NSW1 to reach thermal runaway in a shorter timeframe than NSW2 despite having 1% more moisture content. There also appears to be a fundamental difference between the self-heating response of NSW1 and QLD3. Despite having a higher moisture content QLD3 reaches thermal runaway in a shorter timeframe than NSW1. This may be due to subtle differences in the pore structure of the two coals as a result of their different basinal histories both during and after coalification. Reactive sites may be more readily available in the QLD3 sample than in the NSW1 sample.

CONCLUSION

Coal self-heating performance is not a simple predictable behaviour. There are many competing influences and mechanisms taking place that can moderate whether a spontaneous combustion event can take place. The overall outcome is governed by the heat balance, which is a function of the interaction between coal intrinsic properties and site-specific extrinsic factors. Coals of quite similar rank can display contrasting self-heating behaviours due to these parameters. This has been demonstrated from adiabatic oven testing of thermal coals from Queensland and New South Wales. Essentially, one of the key controls identified by this testing is the importance of the interaction that takes place between the moisture in the coal and intrinsic oxidation reaction rate.

Higher moisture content coals display an inflection in the self-heating rate curve due to the competing effects of heat loss from moisture evaporation and heat gain from coal oxidation. This prolongs the time taken to reach thermal runaway and is an important feature of coal self-heating performance that needs to be identified. In some cases the heat loss mechanism from moisture evaporation is sufficient to overcome the heat gain from oxidation and results in the coal losing temperature and therefore it is not able to achieve thermal runaway in a practical timeframe or not at all.

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