

Effect of intrinsic coal properties on self-heating rates

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ABSTRACT: Over the past seven years a large database of coal self-heating rates under adiabatic conditions has been developed at The University of Queensland. Coals have been tested from Australia (Queensland and New South Wales), New Zealand (North and South Island), Indonesia and more recently the United States. As a result of this work, definitive relationships and trends have been established for the effects of various intrinsic coal properties on self-heating rates and anomalous coals have also been identified. Previously held views on the effects of coal rank, type and inorganic constituents are examined in this paper. Many of the published relationships do not hold true in terms of coal self-heating rates. A propensity rating scheme has also been developed which is routinely used in Australia for assessing coals and identifying appropriate mining analogues for spontaneous combustion management planning. A selection of examples will be presented in the paper, which shows the significance of this assessment strategy.

1 Introduction

The self-heating of coal is due to a number of complex exothermic reactions. Coal will continue to self-heat provided that there is a continuous air supply and the heat produced is not dissipated. The intrinsic coal properties that control propensity for self-heating have been the subject of many investigations. Relationships between these properties and self-heating indices have been published in a number of studies (Humphreys et al., 1981; Moxon and Richardson, 1985; Singh and Demirbilek, 1987; Smith and Lazzara, 1987; Barve and Mahadevan, 1994; Beamish et al., 2000, 2001; Beamish, 2005; Beamish and Blazak, 2005; Beamish et al., 2005; Beamish and Clarkson, 2006).

This paper presents results from the large R_{70} self-heating rate index database that has been developed at The University of Queensland for coals from both Australia and other countries. These results show coal quality trends that can be used to infer R_{70} values for coals with no previous testing history. Furthermore, a discussion is presented on the possible interpretations that need to be considered when using this parameter to evaluate the propensity of a coal to self-heat.

2 Coal Samples and R_{70} Testing Procedure

2.1 Sample Characteristics

The coal samples tested at The University of Queensland's Spontaneous Combustion Testing Laboratory are supplied either as fresh cores from exploration and mining areas or as fresh lumps from developing mine faces or newly built stockpiles. They cover a wide rank range from sub-

bituminous C to low volatile bituminous. A selection covering the full rank suite is listed in Table 1. The low rank sub-bituminous and high volatile C bituminous coals are from Indonesia (Coals A and B) and New Zealand (Coals C and D). Coal E is from the United States and the rest of the coals are from Australia.

Table 1. Analytical and rank data for coal samples.

	IM (%, adb)	Ash (%, db)	VM (%, dmmf)	CV (Btu/lb, mmmf)	ASTM Rank
Coal A	19.0	2.0	48.9	9311	subC
Coal B	17.2	1.2	50.5	10235	subB
Coal C	13.0	1.8	45.1	11188	subA
Coal D	13.1	1.3	46.7	11635	hvCb
Coal E	6.5	3.1	42.8	13084	hvBb
Coal F	4.5	5.4	40.8	13999	hvBb
Coal G	2.5	4.5	35.0	14488	hvAb
Coal H	1.9	15.7	31.4	14827	hvAb
Coal I	0.8	10.1	20.6	15404	mvb
Coal J	0.8	6.8	14.8	15500	lvb

When viewed on a Suggate rank plot (Suggate, 1998 and 2000) these same samples range from 3.8 to 17.0 (Figure 1). The majority of the samples plot within the New Zealand coal band, except for three of the Australian coals. Suggate (1998) attributes this to the presence of

inertinite in the Australian coals. One of the Indonesian coals plots just below the upper boundary of the New Zealand coal band and Suggate (1998) attributes this to the presence of liptinite.

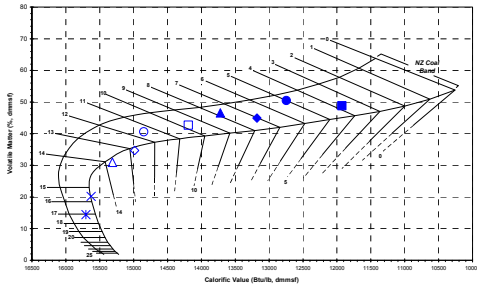


Figure 1. Suggate rank plot of coals ranging in rank from sub-bituminous C to low volatile bituminous. Note the higher the Suggate rank number the higher the rank of coal. The legend for each of the coals can be found in Figures 2 and 3.

2.2 R₇₀ Test Procedure

The R₇₀ 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 R₇₀ index, which is in units of °C/h and is a good indicator of the intrinsic coal reactivity towards oxygen. In addition, the data from this test can be used to obtain kinetic parameters for the coal self-heating up to the trip temperature, which is set at 160°C. These kinetic parameters can be used as input to numerical models (Arisoy et al., 2006; Arisoy et al., 2007; Arisoy and Beamish, 2008).

3 Effect of Intrinsic Coal Properties on Self-heating Rates

3.1 Coal Rank

Adiabatic self-heating curves for each of the coals in Table 1 are shown in Figures 2 and 3. Two figures are required to cover the complete range of the tests, which for a high rank coal can take almost 240 hours (10 days) to reach thermal runaway.

A comparison between the R₇₀ self-heating rate values for each of these coals and the minimum self-heating

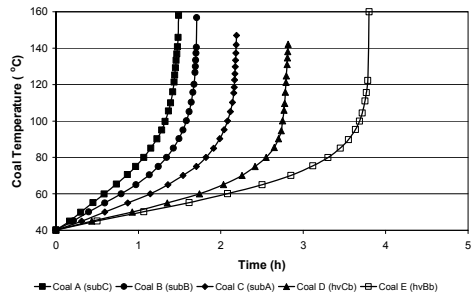


Figure 2. Adiabatic self-heating curves for coals ranging in rank from sub-bituminous C to high volatile B bituminous.

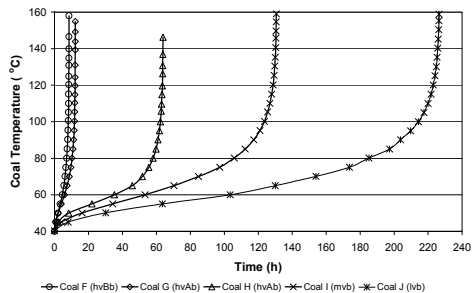


Figure 3. Adiabatic self-heating curves for coals ranging in rank from high volatile B bituminous to low volatile bituminous.

temperature (SHT) calculated from the equation of Smith and Lazzara (1987) shows a significant difference in the rank effect (Figure 4). The relationship between SHT and coal rank is linear, as expected from the equation, which uses the oxygen content of the coal on a dry, ash-free basis. However, the relationship between R₇₀ and coal rank is clearly non-linear and is best defined by a third order polynomial as seen in Figure 4. This feature of the R₇₀ index helps to highlight the importance of coal rank when assessing propensity and as a result a new rating scheme has been developed that takes this into account (Table 2). In addition, the scheme has been devised to take into consideration the difference in start temperature of the coal that is likely to occur between New South Wales and Queensland, which overcomes one of the previous shortcomings of the index.

As the R₇₀ value is obtained on a dry basis, the best way to graphically represent the data for ply results from the same seam is to plot it against the ash content (on a dry basis, Figure 5).

3.2 Mineral Matter and Coal Type

By doing this, any variations within the seam will become immediately obvious and consequently coal type and mineral matter effects can be distinguished.

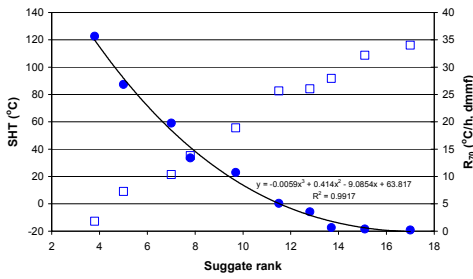


Figure 4. Relationship between coal rank and spontaneous combustion index parameters SHT and R_{70} .

Table 2. Intrinsic spontaneous combustion propensity classification (ISCP), based on Queensland and New South Wales coal conditions.

ISCP Class	R_{70} value (°C/h)	Propensity rating Queensland	Propensity rating New South Wales
I	$R_{70} < 0.5$	low (L)	low (L)
II	$0.5 \leq R_{70} < 1$	medium (M)	low-medium (LM)
III	$1 \leq R_{70} < 2$	high (H)	medium (M)
IV	$2 \leq R_{70} < 4$	very high (VH)	high (H)
V	$4 \leq R_{70} < 8$	ultra high (UH)	very high (VH)
VI	$8 \leq R_{70} < 16$	extremely high (EH)	ultra high (UH)
VII	$R_{70} \geq 16$	exceptionally high (XH)	extremely high (EH)

The ash content of coal is closely related to the mineral matter present, which is the inorganic constituents of the coal that modify the coal behavior in many combustion processes. In the case of the coal self-heating, the mineral matter has generally been considered a diluent, effectively creating a heat sink due to its heat capacity (Humphreys et al., 1981; Smith et al., 1988). However, mineral matter may also create blockage of access to oxidation sites, lowering the self-heating rate of the coal even further (Beamish and Arisoy, 2008).

A general trend of decreasing R_{70} value with increasing ash content can be seen in Figure 5 for all of the seams. In particular, Seams G and H show a gentle linear trend with ash content, which corresponds closely to that expected for a simple heat sink effect. However, Seams B and D show a much steeper relationship with ash content. A simple explanation for this would be that there is a difference in coal type influencing the self-heating rate. In the case of Seam B this is possible as there is a significant increase in vitrinite content for the higher ash content sample. This would appear contrary to published effects of maceral composition (Walters, 1996). However, Seams E

and F correspond to premium coking coals from New Zealand and New South Wales respectively and it is clear that these coals have a substantially lower self-heating rate than their steaming coal rank equivalents. Again, the fundamental difference here is that the steaming coals contain a higher proportion of inertinite and the coking coals are predominantly vitrinite-rich. The New Zealand premium coking coal (Seam E) is particularly anomalous in this regard and is almost pure vitrinite. Hence, the higher the vitrinite content of the coal ply the lower the self-heating rate, particularly if this is combined with an increased ash content as seen in the case of Seam B.

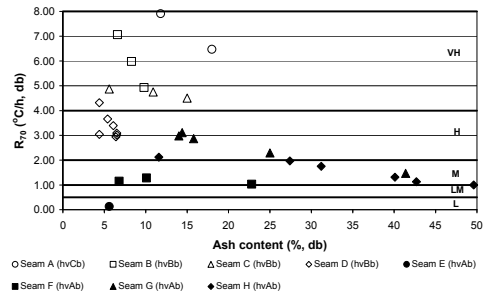


Figure 5. Relationship between ash content and R_{70} self-heating rate index for seam ply samples of high volatile bituminous coals with intrinsic spontaneous combustion propensity classes from Table 2 superimposed.

The same explanation cannot be used for Seam D. There is no change in coal maceral composition for the plies from this seam. Therefore, the cause of the steep ash content trend for these samples can only be linked to the mineral matter type. Beamish and Sainsbury (2008) showed that results from an ash analysis of these samples yielded a strong association with sodium content, which has been identified in the form of the sodium zeolite mineral analcime ($\text{NaAlSi}_2\text{O}_6 \cdot \text{H}_2\text{O}$). Further work is progressing on this association to confirm the effect that has been observed in the dramatic drop in self-heating rate due to the presence of this mineral.

New work is also in progress on coals from the Surat Basin in Queensland that have high liptinite contents. Earlier work by Beamish et al. (2000) showed that the presence of resinite in New Zealand low rank coals lowered the self-heating rate of the coal. This same effect has been noted in follow-up tests on coals from the Huntly North Coalfield in New Zealand and preliminary results on Indonesian coals of similar rank. Initial testing of Surat Basin coals has recorded similar findings.

4 Application of Spontaneous Combustion Propensity Assessment

4.1 Indexing From Coal Quality

This form of assessment is usually done at an early stage

prior to coal samples being available for any testing. A range of index parameters can be applied from the literature. As shown in this paper a more encompassing predicted index value can be obtained for the R_{70} self-heating rate of the coal that covers a rank range from sub-bituminous C to low volatile bituminous. However, the variations due to mineral matter and coal type require samples to be tested to obtain true site-specific relationships and more realistic interpretations of spontaneous combustion propensity.

4.2 Mining Analogue Application

Knowing the intrinsic spontaneous combustion propensity of a coal with respect to other known coals is a good starting point to assess the risk of spontaneous combustion. Consequently, Figures 4 and 5 also provide the opportunity to identify mining analogues that can be used to assist with future spontaneous combustion management planning. For example, Seam A (Figure 5) comes from a longwall mining operation in the Hunter Valley Coalfield of the Sydney Basin that has a history of self-heating events. Seam C (Figure 5) is from a Greenfield site in the Hunter Valley and consequently, spontaneous combustion management plans are already being developed from the test data obtained to date for proactive goaf inertization based on the mining analogy with Seam A. Leading practice in goaf inertization is already being used by San Juan Coal Company (Bessinger et al., 2005). Other practices are also being developed in Australia to suit local conditions.

4.3 Modifying Influences on Spontaneous Combustion Risk

The modifying influences of other factors, such as coal start temperature, particle size and moisture content also need to be considered when assessing the meaning of an R_{70} value in terms of hot spot development. For example, Seam G is from a new longwall mining operation in the Newcastle District of the Sydney Basin. To date there has been no history of self-heating incidents, consistent with previous experience of mining this coal. Bulk testing of this coal also indicated a low propensity to develop a hot spot. Given the R_{70} rating of the coal (Class IV – high propensity) this appears to be anomalous. However, given the R_{70} test is a measure of the coals reactivity to oxygen at fine particle size, it must be remembered in bulk coal, hot spot development is dependent on a much larger particle size. Seam G has a very low Hardgrove Grindability Index (HGI). Consequently, production of a large volume of coal fines is reduced. Hence, hot spot development is inhibited as a result of this additional factor. There are other high R_{70} coals in the UQ database that are showing a similar relationship with HGI and this is being investigated in more detail.

The competing influences of coal start temperature and moisture content on hot spot development are best examined using numerical models. Preliminary work has begun using data from the R_{70} self-heating curves to

extract kinetic parameters as input to a moist coal model (Arisoy et al., 2006; Arisoy et al., 2007). Further refinement of this work is in progress using data from coals in the UQ R_{70} database.

5 Summary and Conclusion

Adiabatic testing of a wide range of coals has established significant relationships exist between coal self-heating rate and intrinsic coal properties of coal rank, mineral matter composition and coal type. The relationship with coal rank is non-linear and can be expressed in the form of a third order polynomial for coals ranging in rank from sub-bituminous C to low volatile bituminous.

The effect of mineral matter on coal self-heating rates can either be in the form of a simple heat sink effect or a more complex physico-chemical inhibition of access to oxidation sites. These effects can only be determined by actual testing of the coal, and hence a coal ply sampling strategy is recommended to obtain site specific data. Additional coal analyses such as ash analysis and coal mineral matter identification may be needed to obtain a fuller interpretation of the self-heating rate data.

Coking coals have lower self-heating rates than steaming coals due to their higher percentage of vitrinite. This is contrary to earlier research findings on coal spontaneous combustion. Self-heating rates of liptinite-rich coals appear to be lower than expected for their rank. Again this is contrary to earlier research, although Beamish et al. (2000) showed that this could indeed be the case.

The large database of R_{70} values enables test results to be compared and mining analogues can be identified that assist with spontaneous combustion management planning. This ensures that leading practice can be applied to any mining operation, thus minimizing the risk of an unwanted spontaneous combustion event.

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