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DEVELOPMENT OF A SITE SPECIFIC SELF-HEATING RATE PREDICTION EQUATION FOR A HIGH VOLATILE BITUMINOUS COAL

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ABSTRACT: The R_{70} test was performed on a series of coal samples taken from different locations in a US longwall mine. The values obtained produced a definite relationship between R_{70} and ash content, with the exception of one anomalously low result. An ash analysis of the sample showed that it had a high sodium (Na_2O) content in response to the presence of the sodium zeolite mineral, analcime. A multiple regression of the R_{70}, ash content and sodium (Na_2O) content of the samples produced a self-heating rate prediction equation with an R^2 of 0.98. This equation can now be used to predict the R_{70} self-heating rate of the coal at any location throughout the mine, thus assisting with hazard management planning.

INTRODUCTION

Low-temperature oxidation of coal results in an exothermic reaction and without sufficient dispersion of the heat generated will eventually result in spontaneous combustion. This unwanted outcome can cause huge losses in revenue and more importantly, cause major problems with safety. In underground mining operations the combination of in-seam gas, inappropriate ventilation networks and self-heating areas of coal can equate to a catastrophic disaster. Examples of these events in Australia are recorded by Ham (2005).

The parameters that control a coal's propensity for self-heating have been the subject of many investigations. Relationships between coal properties and self-heating indices have been published in a number of studies (Humphreys, Rowlands and Cudmore, 1981; Moxon and Richardson, 1985; Singh and Demirbilek, 1987; Barve and Mahadevan, 1994; Beamish, Barakat and St. George, 2000, 2001). Humphreys, Rowlands and Cudmore (1981) found a simple relationship between the coal self-heating index parameter, R_{70} and coal rank. However, research by Beamish, Barakat and St. George (2001) and Beamish (2005) on New Zealand and Australian coals covering a wider range of coal ranks showed that the R_{70} coal self-heating rate relationship with rank is non-linear. Beamish and Blazak (2005) also showed that R_{70} values decrease significantly with increasing mineral matter content, as defined by the ash content of the coal.

This paper presents the development of a site specific equation used for the prediction of R_{70} self-heating rate of a high volatile bituminous coal that is being mined by longwall methods in the United States (US). The site specific nature of coal self-heating has been identified by earlier work on Australian coals using the R_{70} test procedure (Beamish *et al.*, 2005; Beamish and Clarkson, 2006). However, this is the first time that the R_{70} test procedure has been applied to US coals.

EXPERIMENTAL PROCEDURE

Coal samples

The coal samples used for test work were collected from the workings of an operating longwall coal mine in the United States. These samples were sent to The University of Queensland's Spontaneous Combustion Testing Laboratory, with each of the coal lumps individually wrapped in cling wrap, and stored in an air-tight sealed bag that was placed in the laboratory freezer until the commencement of testing.

R70 Test Procedure

The full adiabatic oven testing procedure is outlined in (Beamish, Barakat and St George, 2000). In preparation for the test, the coal samples are taken out of the freezer and allowed to thaw for one hour. Once the samples are thawed they are crushed and sieved to achieve a particle size of < 212 µm. This process is to be completed in as little time as possible to reduce oxidation on the fresh surface of the coal. The R70 test is carried out on a dry basis therefore all the samples are dried. 150 g of the sample is placed in a 750mL flask then in the drying oven and all the oxygen removed. The sample is kept in the oven with a constant nitrogen flow of 250 mL/min. Then it is heated to 110°C and left to dry for 16 hours.

After the drying process is complete, the sample is transferred to the 450 mL reaction vessel and placed in the adiabatic oven. Here it is allowed to stabilise at 40°C in a nitrogen-rich atmosphere. Once this was achieved,

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oxygen is then supplied to the coal at a rate of 50mL/min. For the duration of the test, the oven is put on remote monitoring where the

change in temperature of the coal is followed by the oven to minimise any heat losses from the system and the data is recorded by a computer logging system. Once the coal temperature reaches 160°C, the supply of oxygen is cut off and the oven heating elements are disengaged. The sample is then allowed to cool before being removed and the equipment cleaned and prepared for the next test.

RESULTS AND DISCUSSION

R70 Results and Ash Content Relationship

Adiabatic self-heating curves for each of the seven samples tested are shown in Figure 1. The R70 value is determined as the average self-heating rate from the starting temperature (~40°C) till the coal reaches 70°C and is expressed in units of °C/h. A plot of the R70 values against their respective ash contents is shown in Figure 2. There is a strong linear relationship evident for six of the seven samples with an R2 value of 0.97. As described by Beamish and Blazak (2005), generally as the ash content increases for a given rank of coal the R70 value decreases. In earlier work this has been attributed to the mineral matter in the coal acting as a heat sink (Humphreys, Rowlands and Cudmore, 1981; Smith, Miron and Lazzara, 1988) and thus lowering the self-heating rate of the coal. However, more recent work by Beamish and Arisoy (2008) points to the possibility of other physico-chemical mechanisms causing the decrease in self-heating rate of the coal. The slope of the relationship shown in Figure 2 is much steeper than those presented by Beamish et al. (2005) and Beamish and Clarkson (2006) for Australian high volatile bituminous coals. This steep slope is not consistent with a simple heat sink effect.

Sample 6A appears to be an outlier compared to the rest of the samples tested. This cannot be attributed to repeatability error, as samples 3A and 3B have the same ash content (6.5%) and produced R70 values of 3.09 and 3.01°C/h respectively. These values are well within the normal repeatability limits for testing of ±5%.

One possible explanation for the dramatic decrease in self-heating rate for this sample could be a difference in coal type due to a change in maceral composition. However, a Suggate rank plot (Suggate, 1998 and 2000) of the samples showed no variation in coal type between them. The only possibility left is that there is a different mineral composition present in this sample that is causing the decrease in R70.

Ash Analysis

In an effort to explain the variance observed in the R70 result obtained for sample 6A an ash analysis was conducted to identify possible mineralogical associations. The ash analysis uses a wavelength dispersive x-ray fluorescence spectrometric method which can determine concentrations of silicon, aluminium, iron, calcium, magnesium, sodium, potassium, titanium, manganese, phosphorous, sulphur, strontium, barium, zinc and vanadium.

A duplicate of each sample of coal was sent to a registered laboratory for ash analysis according to the relevant Australian Standards (AS1038.3 2000 and AS1038.14.3 1999). The results from the seven different samples have been collated in Table 1. Each sample was tested for the presence of 15 standard elements and is displayed as a percentage dry basis in oxide form.

The most striking feature about the ash analysis results for sample 6A (Table 1) is the very high sodium content (10%). This is at least three times the levels of the other samples. Having obtained this possible link to the cause of the low R70 value for the sample, the next step was to identify the mineral responsible for the sodium. A sample of the coal was anlaysed using X-Ray Diffraction (XRD) and the results obtained showed the presence of the sodium zeolite mineral, analcime (NaAlSi2O6·H2O). Initial scanning electron microscopy analysis has confirmed this and low temperature ashing of the sample is still in progress to establish any other mineral assemblage associations. The results of this additional work will be published at a later date, including a possible genesis for the presence of the analcime.

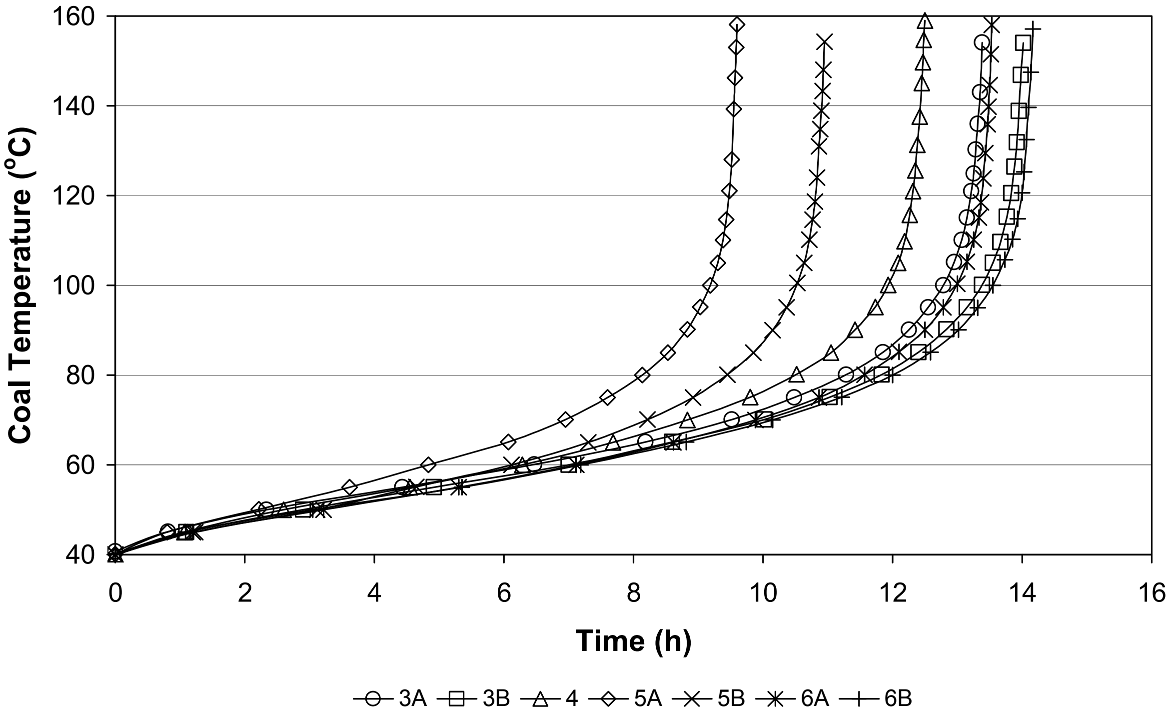

Figure 1 - Adiabatic self-heating curves for a high volatile bituminous coal

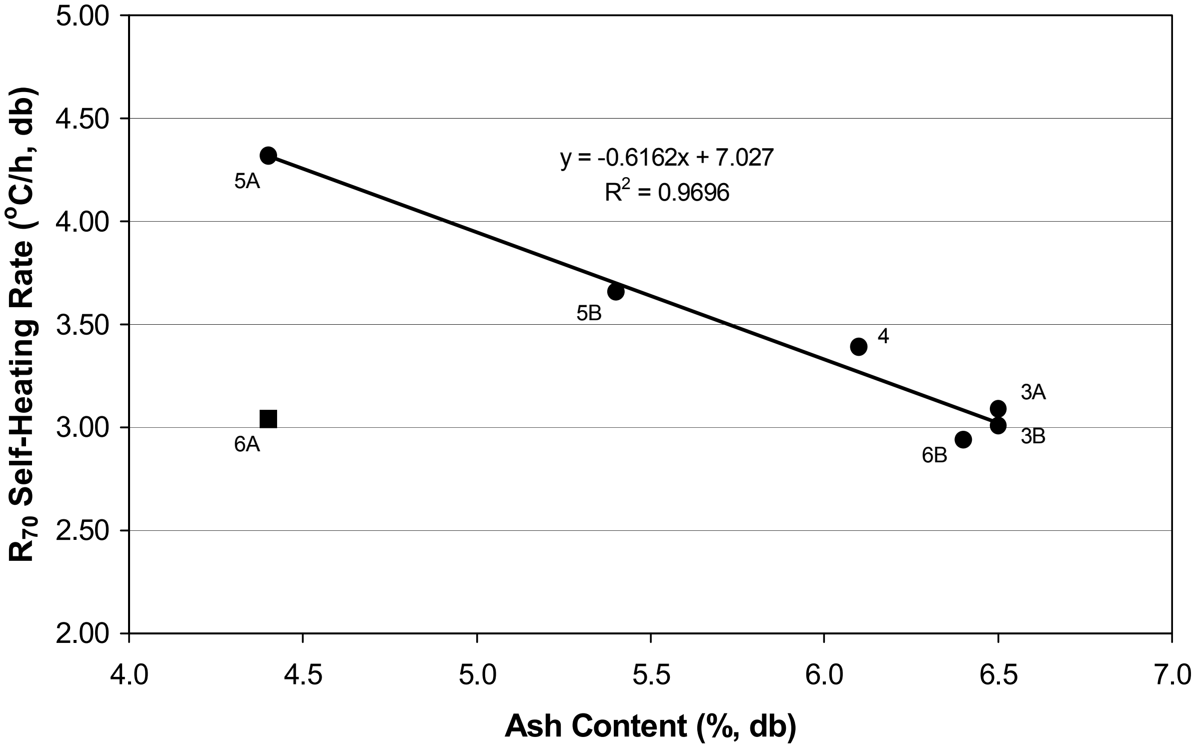

Figure 2 - Relationship between R_{70} self-heating rate and ash content

Table 1 - Ash Analysis Results

Ash Composition (%, db)	3A	3B	4	5A	5B	6A	6B
Silicon (SiO_2)	56.0	56.7	70.0	49.0	53.0	50.5	54.5
Aluminium (Al_2O_3)	30.2	31.0	18.1	28.0	27.0	25.5	23.5
Iron (Fe_2O_3)	4.6	4.8	4.7	8.3	5.4	5.2	4.0
Calcium (CaO)	0.8	0.82	1.2	4.5	4.1	4.0	4.9
Magnesium (MgO)	1.2	1.2	1.0	1.9	1.5	1.3	1.3
Sodium (Na_2O)	2.7	3.0	1.6	3.4	2.5	10.0	3.5
Potassium (K_2O)	0.47	0.48	0.41	0.47	0.63	0.44	0.38
Titanium (TiO_2)	1.5	1.7	1.7	1.4	1.4	1.4	1.7
Manganese (Mn_3O_4)	0.02	0.01	0.02	0.03	0.01	0.01	0.01
Phosphorous (P_2O_5)	0.14	0.15	0.12	0.56	1.50	1.10	1.00
Sulphur (SO_3)	0.61	0.43	0.8	2.6	2.7	1.9	3.5
Strontium (SrO)	0.50	0.35	0.30	0.40	0.19	0.51	0.01
Barium (BaO)	0.35	0.35	0.30	0.30	0.34	0.45	0.23
Zinc (ZnO)	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Vanadium (V_2O_5)	0.02	0.02	0.03	0.02	0.02	0.01	0.02

Multiple regression analysis

There appears to be two dominant factors affecting the R_{70} self-heating rate values of these samples, ash content and the amount of sodium present in the ash. To determine the influence these parameters are having a multiple regression analysis was performed with the R_{70} value as the dependent factor. The regression equation obtained is:

R_{70} (°C/h) = -0.6351xAsh – 0.1767 xNa_2O + 7.63

(R^2 = 0.98)

where, both Ash and Na_2O are in dry weight percent.

A comparison of the actual and predicted self-heating rates found that only a minor variance existed between the two values. The confidence of this equation is currently average, however a larger dataset would allow a much more precise equation to be created. Table 2 contains the calculated residual values for each of the samples. It can be seen that the difference ranges from 0.003 to 0.095 °C/h, which is extremely low and well within the repeatability limits of the test. Therefore, this equation can be used throughout the mine with an acceptable degree of confidence for predicting the R_{70} self-heating rate of the coal.

Table 2 - Comparison Actual and Predicted R70

Sample	Actual R_{70} (°C/h)	Predicted R_{70} (°C/h)	Residual (°C/h)
3A	3.09	3.02	0.069
3B	3.01	2.96	0.042
4	3.39	3.46	0.079
5A	4.32	4.23	0.089
5B	3.66	3.75	0.095
6A	3.04	3.06	0.025
6B	2.94	2.94	0.003

CONCLUSIONS

Adiabatic testing has been performed on a series of high volatile bituminous coal samples taken from different locations through an underground longwall mining operation. The values obtained produced a definite linear relationship between R_{70} and ash content. A simple heat sink effect mechanism is not evident as the decreasing self-heating rate trend for the samples is much too steep for this.
An ash analysis of the coal provided a quantitative breakdown of the major inorganic constituents within the samples. These results showed a strong negative association with sodium (Na_2O) in one of the samples which did not conform to the observed simple linear R_{70} and ash content relationship. The sodium in the sample is linked to the presence of the mineral analcime, which may be acting as a natural inhibitor to the coal oxidation process and thus reducing the self-heating rate.

A multiple regression of the R_{70}, ash content and sodium (Na_2O) content produced a self-heating rate prediction equation with an R^2 of 0.98. Similar site specific relationships are being developed for other mines throughout Australia and overseas, which can be used to assist with the mine's hazard management planning.

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