R_{70} Relationships and Their Interpretation at a Mine Site

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ABSTRACT

The R_{70} test is a good indicator of coal reactivity to oxygen and is commonly used to provide a rating of propensity for self-heating. Tests performed by The University of Queensland Spontaneous Combustion Testing Laboratory have resulted in the development of a large database that shows the impact of coal quality on this parameter. From these results it is possible to infer an R_{70} value, which can be used to gain an appreciation of the intrinsic coal reactivity before it is even tested. However, any interpretation of R_{70} values must consider the influences of coal rank, mineral matter and moisture content to provide a better understanding of the spontaneous combustion risk of a particular coal.

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 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; Beamish, Barakat and St George, 2000, 2001; Moxon and Richardson, 1985; Singh and Demirbilek, 1987; Barve and Mahadevan, 1994).

Humphreys, Rowlands and Cudmore (1981) found a simple relationship between the coal self-heating index parameter, R_{70} and coal rank. However, work by Beamish, Barakat and St. George (2001) on New Zealand coals covering a wider range of coal ranks showed that the rank relationship with R_{70} coal self-heating rate is non-linear. Beamish and Blazak (in press) show that R_{70} values decrease significantly with increasing mineral matter content, as defined by the ash content of the coal.

This paper presents results from the large R_{70} database that has been developed at The University of Queensland for coals from both Australia and New Zealand. 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.

COAL SAMPLES AND R_{70} TESTING PROCEDURE

The coal samples referred to in this paper are test results from published (Beamish, Barakat and St George, 2001; Beamish, in press; Beamish and Blazak, in press) and unpublished (Hogarth, 2003; Jabouri, 2004) studies on coal self-heating. The samples range in rank from subbituminous to medium volatile bituminous and cover a wide ash content range from 0.7 to 63.9 per cent, dry basis. Several New Zealand coal regions are included in the database. These are Waikato, Reefton and Greymouth. Coals from both the Bowen and Sydney Basins have also been included.

The testing procedure essentially involves drying a 150 g sample of <212 mm 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 50 ml/min. A data logger records the temperature rise due to the self-heating of the coal. The average rate that the coal temperature rises between 40°C and 70°C is the self-heating rate index (R_{70}), which is in units of °C/h and is a good indicator of the intrinsic coal reactivity towards oxygen.

RELATIONSHIP BETWEEN COAL RANK, ASH CONTENT AND R_{70} VALUES

As the R_{70} value is obtained on a dry basis, the best way to graphically represent the data is to plot it against the ash content (on a dry basis, Figure 1), which is a standard analytical determination for coal. The ash content is closely related to the mineral matter in the coal, which is the inorganic constituents of the coal that modify the coal behaviour in many combustion processes. In the case of the coal self-heating, the mineral matter acts as a diluent.

Smith, Miron and Lazzara (1988) discussed the thermal effects of additional mineral matter in coal and pointed out that, assuming the additive is inert to the oxidiser, the additive acts as a heat sink. Consequently, the reaction rate is lowered, reducing the self-heating propensity of the coal. This is clearly seen in Figure 1 for the Trap Gully, Dunn Creek, Newcastle and Bowen Basin coals. Humphreys, Rowlands and Cudmore (1981) also proved this effect by adding ash to coals to test an equation for mineral matter-free correction of the R_{70} value. In the present study, a mineral matter-free correction is not necessary, as the pure-coal R_{70} value can be obtained from the y-intercept of the trendline equations for isorank coal from the one seam.

Figure 1 shows that the subbituminous coals have the highest R_{70} values for any given ash content. There also appears to be no major difference between the Waikato subbituminous coals and the Trap Gully subbituminous coal, this is despite there being a substantial difference in the maceral composition between the two. The Waikato coals contain very little inertinite, whereas the Trap Gully coal contains a significant amount of inertinite. This is somewhat surprising and may be an artefact of the type of sample tested. The Trap Gully samples were all fresh cores that were firstly wrapped in plastic cling wrap then aluminium foil and an outer layer of masking tape before being frozen on-site. The cores were then transported to The University of Queensland in an insulated container full of ice. On arrival, the cores were transferred to a freezer for storage until adiabatic testing took place. These precautions were taken to preserve the intact core and minimise pre-oxidation effects before testing. However, the Waikato samples were supplied from the Coal Research Ltd sample bank and may have undergone some oxidation prior to testing.

The Reefton subbituminous coal has a much lower R_{70} value compared with the Waikato coals. This may be due to the coal having a lower rank. The Reefton high volatile bituminous coal is at the lower end of the high volatile bituminous rank range and appears to have a lower R_{70} value than expected. One reason for this may be the presence of a significant amount of organically-bound sulfur in the coal, which presumably blocks access of oxygen to reaction sites.

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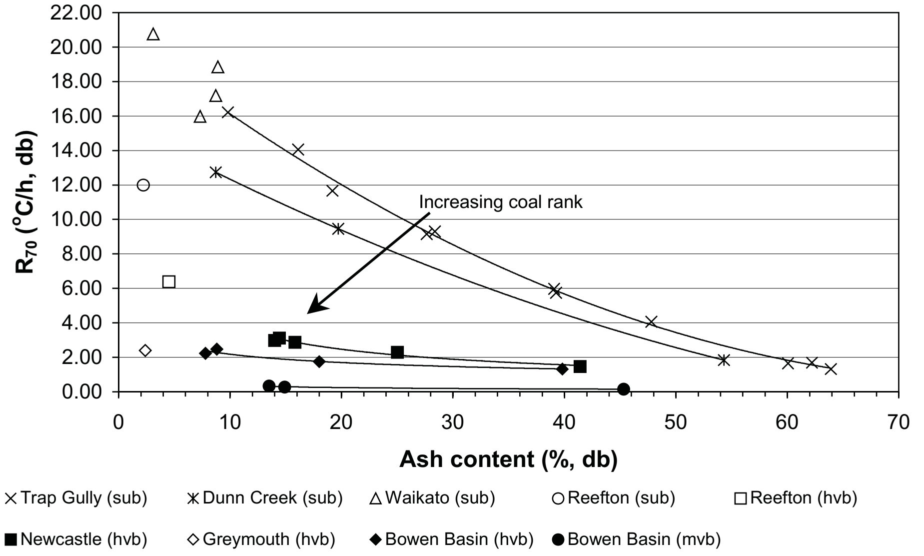

FIG 1 - Relationship between ash content, coal rank and R_{70} self-heating rate.

The rank and ash relationship shown in Figure 1 makes it possible to infer a reasonable value for R_{70} based on coal quality in areas where no test information is available. However, it should be noted that subtle differences in coal reactivity can occur due to the different types of mineral matter that are present. Consequently, in any final mine assessment there is no substitute for hard data.

INTERPRETING R_{70} VALUES IN TERMS OF PROPENSITY FOR SPONTANEOUS COMBUSTION

Interpreting the significance of the R_{70} value has often been problematical for mining operations, particularly as there is a wider range of coals being mined than when the test was first developed. This is most likely a function of the test procedure, which has a common start temperature (40°C), uses dry pulverised coal (<212 mm) and uses oxygen as the reactant at a high flowrate/mass ratio. Nevertheless, knowing the intrinsic reactivity of the coal is a good starting point to assess the propensity of a coal for spontaneous combustion.

It can be seen from Figure 1, that a low rank high ash content coal can have the same R_{70} value as a high rank lower ash content coal. The R_{70} curves for two coals that fit this criterion are presented in Figure 2. The graph clearly shows that even though both coals have the same R_{70}, the coal with the lower ash content reaches thermal runaway some six hours earlier. This is a function of the difference in heat capacities of the two coals and the heat of oxidation from the reaction. This is an important difference that must be considered when comparing coals from different mines.

The modifying influences of other factors also need to be considered when assessing the meaning of an R_{70} value. For example, Beamish and Hamilton (in press) have shown that the accelerated effect of coal reactivity does not take place until the moisture content of the coal drops to approximately 50 per cent of the moisture holding capacity. This is due to the competing influences of heat loss through evaporation and blocking of access to oxidation sites by the moisture. Figure 3 shows this effect for a subbituminous coal tested using the R_{70} adiabatic oven. The sample at zero per cent moisture is the normal R_{70} curve, but when the coal was tested at a moisture content of 9.9 per cent, the self-heating period was extended considerably, before accelerated oxidation took place. What influence does this effect have on spontaneous combustion propensity interpretation?

The Trap Gully sample with an R_{70} of 16.22°C/h has an ash content of 9.8 per cent db and a moisture holding capacity of approximately 14 per cent. The Trap Gully sample with an R_{70} of 1.69°C/h has an ash content of 62.2 per cent db and a moisture holding capacity of nine per cent. Consequently, the higher R_{70} sample has to lose seven per cent moisture before the coal reactivity can lead to intense oxidation, whereas the lower R_{70} sample only has to lose 4.5 per cent moisture to reach the same point. This 2.5 per cent moisture differential has a significant impact.

The issues of moisture and moisture movement are complex in that removal of moisture can lead to changes in coal structure that increase the available surface area for oxidation. The adsorption of moisture itself leads to heat generation, which will increase the rate of heating. These issues are best examined in large test environments.

It is apparent from comparison of the Trap Gully samples that even high ash rejects have the potential to self-heat in a relatively short period of time. Similarly, poor quality coal, on the basis of high ash content, that is left behind in a goaf area still has the potential to pose a spontaneous combustion risk.

CONCLUSIONS

The intrinsic reactivity of coal towards oxygen can be accurately measured by the R_{70} test procedure. The value of this parameter is strongly affected by rank and mineral matter. In addition, the moderating effects of moisture in the as-mined coal are not taken into consideration by this parameter, and hence there is a need to review the way in which this and other small-scale index parameters such as crossing point temperature (CPT) and minimum self-heating temperature (SHT_{min}) are used in spontaneous combustion risk assessments.

One possible solution is to use numerical modelling to scale up the results and incorporate the missing influencing factors. However, there are dangers of oversimplification of the coal self-heating processes when incorporating only small-scale data into the models. A more practical approach is to obtain results from bulk testing of coal using conditions closer to the as-mined situation and history match this data with a more robust numerical model that can incorporate the effects of moisture in particular. Preliminary work is being performed as part of ACARP project C12018 to establish if this is possible, and comparisons with the R_{70} data are being made to provide guidelines for optimal strategies of spontaneous combustion risk assessment.

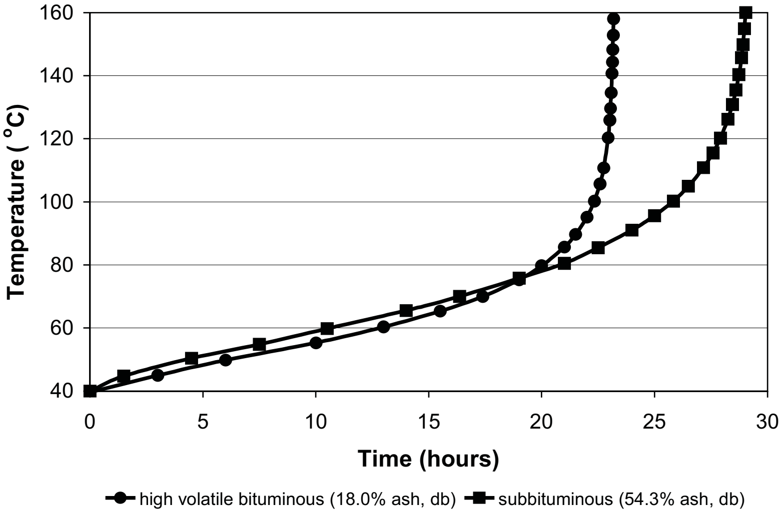

FIG 2 - Adiabatic self-heating curves for coals of approximately the same R_{70} value (1.75 and 1.84 C/h).

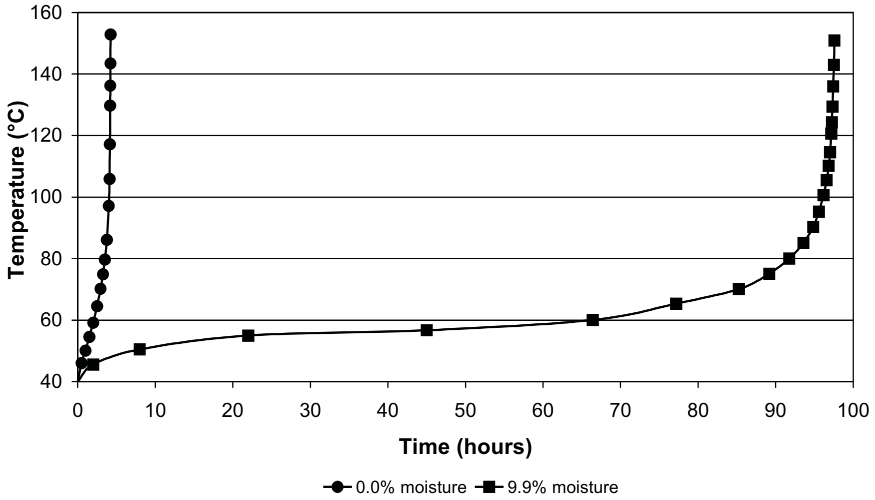

FIG 3 - Example of moisture effect on coal self-heating rate for subbituminous coal.

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