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Moisture Content Impact on the Self-Heating Rate of a Highly Reactive Subbituminous Coal

B. B. Beamish
University of Queensland

T. J. Schultz
University of Queensland

MOISTURE CONTENT IMPACT ON THE SELF-HEATING RATE OF A HIGHLY REACTIVE SUB-BITUMINOUS COAL

B Basil Beamish and Timothy J Schultz[1]

ABSTRACT: A New Zealand power station has been importing subbituminous coal, which has oocasionally created a spontaneous combustion problem at the port storage facility. Samples of the coal have been tested using an adiabatic oven to determine the self-heating rate of the coal at various moisture contents ranging from as-received to dry. Initial self-heating rates from room temperature were higher for samples containing up to 75% of the as-received moisture content compared to dry coal. However, the overall time to reach thermal runaway increased with moisture content. This paper clearly shows the highly reactive nature of the subbituminous coal as all tests would have proceeded to ignition, even those performed at close to the as-received moisture content of the coal.

INTRODUCTION

The self-heating of coal is due to a number of complex exothermic reactions. Coal will continue to self-heat provided there is a continuous supply of oxygen and the heat generated is not dissipated. Moisture content can affect the self-heating rate of coal in two ways: changing the overall heat balance; and the rate of the oxidation reaction. There have been a number of investigations to help provide a better understanding these processes (Chamberlain, 1974; Humphreys and Richmond, 1987; Smith and Lazarra, 1987; Walters, 1996; Clemens and Matheson, 1996; Vance, Chen and Scott, 1996; Bhat and Agarwal, 1996).

Many studies have also been completed examining how differing levels of coal moisture content affect the self-heating rate of coals. These have produced conflicting results. Sondreal and Ellman (1974) found that for a lignite sample there was a critical moisture content at which the rate of oxidation reached a maximum. This finding is disputed by Bhat and Agarwal (1996) who claimed that the test process used changed the subsequent low-temperature oxidation behaviour of the coal. Clemens and Matheson (1996) also reported that samples of low-rank coals containing varying amounts of moisture experienced different rates of initial self-heating, with some moist samples oxidising at a faster rate than the dry samples. Beamish and Hamilton (2005) found that for a sub-bituminous coal from the Callide Basin, self-heating was inhibited until the coal had lost approximately half its moisture holding capacity.

Adiabatic testing procedures have been used at The University of Queensland to study a highly reactive sub-bituminous coal from Indonesia. This paper presents results from the adiabatic self-heating rate tests that show the effect moisture has on the coals reactivity.

EXPERIMENTAL PROCEDURE

Coal samples

The coal sample used for test work was taken from a stockpile of imported Indonesian coal at the New Zealand port of Tauranga. The sample was 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 bucket at room temperature until the commencement of testing.

Preparation and testing of samples

The coal was split into six 250 g samples of -30 mm coal and placed into frozen storage until they were required for testing. Prior to testing, each 250 g sample was ground and screened to produce 150 g of -212 μm coal and flushed under nitrogen.

The first test, INDO1A, was prepared and tested under normal R70 conditions (dry basis), which required the test sample to be dried at 110°C for 16 hours. After this it was transferred to the adiabatic oven and the test was commenced from a start temperature of 40°C. A full description of the adiabatic testing procedure is outlined by Beamish, Barakat and St George (2000).

The remaining tests were conducted at varying moisture contents to investigate the effects of moisture content on the self-heating rate from a start temperature of ~25°C. To do this, the drying times in the laboratory oven were varied as required to allow the coal sample to attain the desired moisture content. This included a test on dry coal for comparison with the original R70 test.

[1] *School of Engineering, The University of Queensland, Brisbane Queensland*

RESULTS AND DISCUSSION

Coal quality data are contained in Table 2. As the coal was of low rank, the gross calorific value on a moist, mineral matter free basis (mmmf) was used to determine the ASTM rank classification of the coal (ASTM, 2004). The coal is borderline sub-bituminous B/C.

Table 2 - Coal quality and proximate data of INDO coal sample

	INDO1A	*INDO2A - E*
Moisture (%, ad)	17.7	17.7
Moisture (%, ar)	25.2	24.3
Ash Content (%, db)	2.0	1.8
Volatile Matter (%, dmmf)	51.6	51.6
Calorific Value (Btu/lb, mmmf)	9755	9755

The R_{70} self-heating rate index of the coal is determined by finding the average self-heating rate between 40°C and 70°C, in units of °C/h as shown in Figure 1 This was found to be 28.57°C/h, which compares favourably with an earlier result (35.11°C/h) for a different sample of the coal.

Moisture contents for the INDO2A-E replicates are contained in Table 2. These are approximates for: fully dried coal; 75% as-received moisture; 50% as-received moisture; 25% as-received moisture; and approximately as-received moisture.

Initial self-heating rate curves for the INDO2A-E replicates are shown in Figure 2 A value for the initial self-heating rate (from the room temperature start through to 70°C), has been calculated for each of the coal moisture states (Table 3) The INDO2D test sample, containing 7.3% moisture (approximately 25% of as-received moisture), has the highest value of all the tests. This suggests that there is an optimum moisture content for the coal where the initial rate of self-heating is considerably enhanced (Figure 3) It is also evident from Figure 3 that even the sample with 75% of the as-received moisture content present has an initial self-heating rate faster than the dried coal. However, the sample with close to the as-received moisture content had a slower initial self-heating rate than the dry coal.

Table 3 - Moisture content data for INDO2A-E replicates

Test Sample	*As Received Moisture (%)*	*Test Moisture Content (%)*
INDO2A	24.3	0.0
INDO2D	24.3	7.3
INDO2C	24.3	12.5
INDO2B	24.3	16.7
INDO2E	24.3	24.0

The relationship between initial self-heating rate and moisture content is very similar to that found by Vance, Chen and Scott (1996) for a sub bituminous B coal from New Zealand. Work by Clemens and Matheson (1996) on New Zealand coals of similar rank produced similar findings and they attributed the increased self-heating of the moist coal to the presence of tightly bound moisture generating radical sites in the coal (where oxidation occurs) that are more reactive than those derived from the fully dried coal.

Table 4 - Initial self-heating rates for INDO2A-E replicates

Test Sample	*Test Moisture Content (%)*	*Self-Heating Rate (°C/h)*
INDO2A	0.0	12.92
INDO2D	7.3	21.62
INDO2C	12.5	17.07
INDO2B	16.7	16.07
INDO2E	24.0	10.87

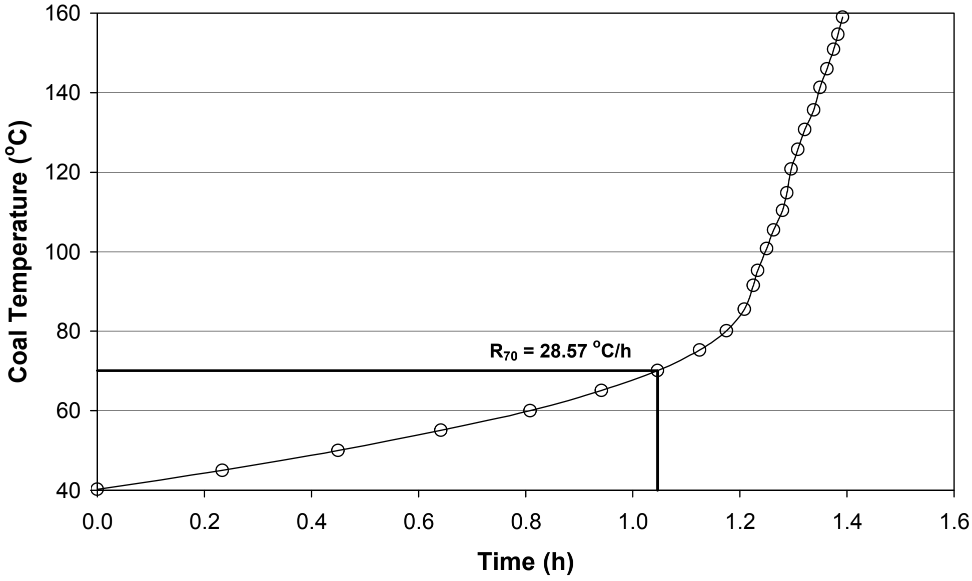

Figure 1 - R_{70} self-heating rate index for INDO1A sample

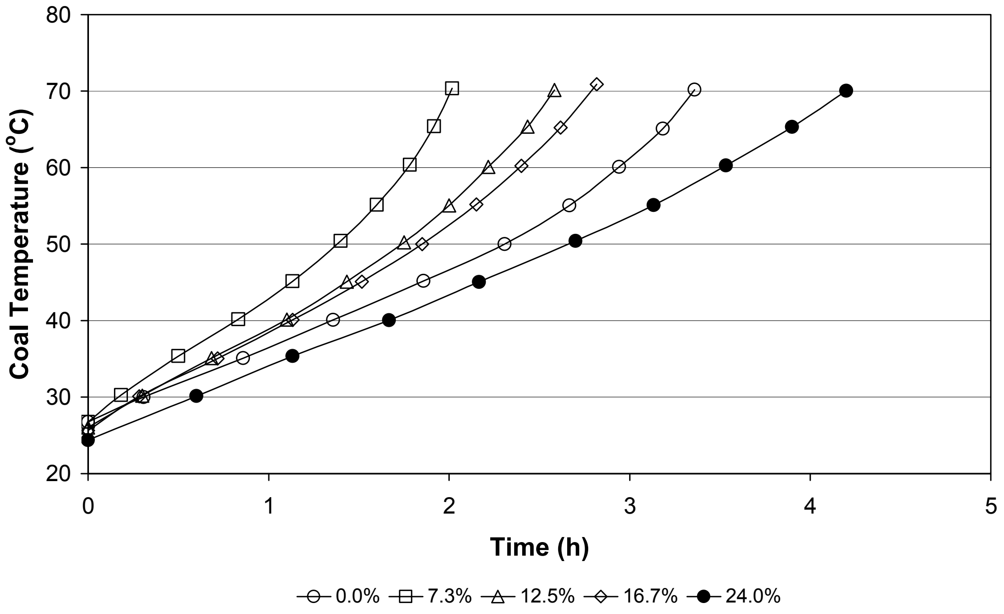

Figure 2 - Initial self-heating rate curves for the INDO2A-E replicates at different moisture content

In contrast, Beamish and Hamilton (2005) found a different relationship between initial self-heating rate and moisture content for a sub-bituminous A coal from Boundary Hill tested from a 40°C start temperature. The results of this work are compared with the Indonesian coal in Figure 3. There is a substantial difference between the two coals. The moisture activation observed in lignites and the lower rank sub-bituminous coals (B and C) may not apply to higher rank coals from sub-bituminous A upwards. Alternatively, the Boundary Hill coal has a high inertinite content that is not present in the Indonesian coal, which is rich in vitrinite. This may also explain the discrepancies noted in the literature between various moisture studies on coal self-heating.

Despite the variations in the initial self-heating rates exhibited by the changes in moisture content within the INDO2A-E replicates, it was found that the time to thermal runaway (at ~160°C) increased with moisture content (Table 4) with the fully dry INDO2A sample achieving thermal runaway in just under four hours, whilst the INDO2E sample with close to as-received moisture taking just over 23 hours. The self-heating curves presented in 4 shows the extent to which variations in initial moisture content can affect the overall self-heating behaviour of the coal sample, when starting from room temperature (~25°C). The increasing time to thermal runaway was attributed to the amount of time taken for the coal to boil off any residual moisture, thus creating a heat loss and affecting the overall heat balance of the self-heating process. Consequently, the drier the coal the faster it will reach ignition.

TABLE 5 - TIME TO THERMAL RUNAWAY FOR INDO2A-E REPLICATES

Test Sample	*Test Moisture Content (%)*	*Time to Thermal Runaway (h)*
INDO2A	0.0	3.86
INDO2D	7.3	5.22
INDO2C	12.5	8.65
INDO2B	16.7	12.15
INDO2E	24.0	23.20

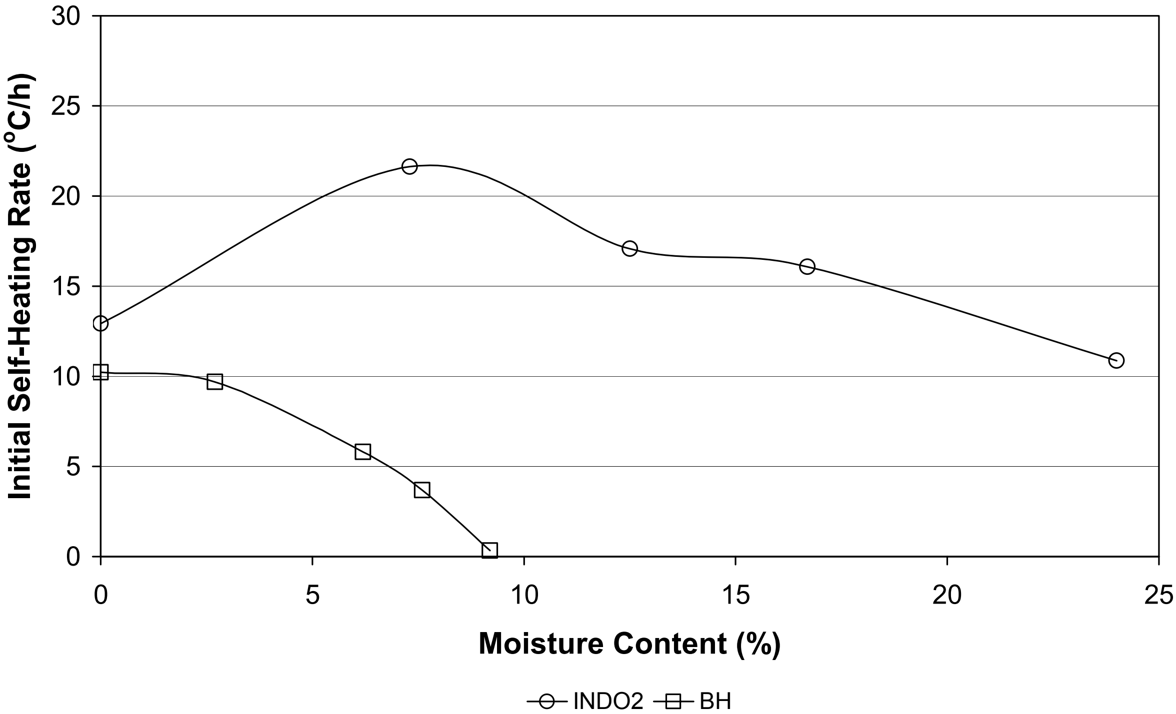

Figure 3 - Comparison between initial self-heating rates and moisture contents of INDO2 replicates and Boundary Hill coal

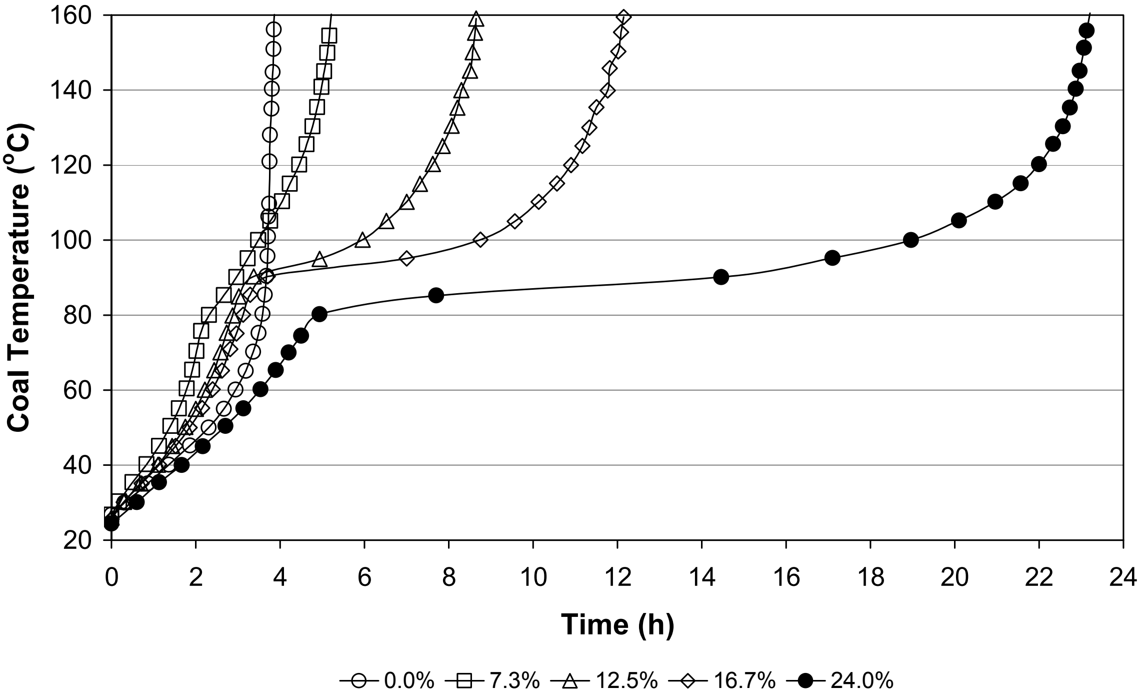

Figure 4 - Complete self-heating curves for the INDO2A-E replicates at different moisture content

CONCLUSIONS

Adiabatic testing of a highly reactive sub-bituminous coal from Indonesia has resulted in an R_{70} self-heating rate index value of 28.57°C/h. Additional testing of this coal at different moisture contents from an approximate 25°C starting temperature has produced self-heating results that are similar to previous work on coals of this rank.

Samples containing up to approximately 75 % of the "as-received" moisture content exhibited faster initial self-heating rates than the fully-dried sample. This was attributed to the enhanced reactive site theory proposed by Clemens and Matheson (1996). A maximum initial self-heating rate occurred at approximately 25 % of the "as-received" moisture content. These results are in contrast to a similar study on coal from the Callide Basin, which produced initial self-heating rates of zero until the coal moisture content fell to approximately half the moisture holding capacity.

The overall time to thermal runway (at ~160°C) however, increased with moisture content, which was attributed to the extra time required for boiling off any residual moisture contained within the sample.

These findings suggest that increasing the moisture content of this coal would not eliminate the risk of the coal self-heating whilst being transported and stored, but the self-heating data does indicate that keeping the moisture content of the coal high will increase the time to ignition. This would have to be considered on a cost benefit basis, and clearly the simplest solution is to use the coal as soon as possible.

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