

## Bulk-scale laboratory experiments of re-entering a sealed heating

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**ABSTRACT:** Anecdotal evidence suggests that re-entering a sealed heating poses a significant hazard, whereby the original heating is rejuvenated at an accelerated rate forcing withdrawal and re-sealing of the area. Bulk-scale laboratory experiments using a two-metre column confirm these mine site observations. A high volatile bituminous coal from New South Wales, Australia was allowed to develop a significant hot spot before being inerted with nitrogen and allowed to cool. Air was then allowed back into the coal after the nitrogen was turned off and a hot spot developed almost immediately at the same location as the original hot spot before it quickly migrated towards the air source within a day. Two more re-entries were simulated. Each successive re-entry developed a broader hot spot and took longer to reach thermal runaway. These results clearly show the behaviour that can be expected when trying to recover a section of an underground coal mine that has been sealed due to a spontaneous combustion event.

### 1 Introduction

Coal self-heating leading to spontaneous combustion continues to be a hazard that must be managed appropriately in underground coal mines. Incidents from the past and anecdotal evidence suggest that the recovery of an area that has been subjected to a heating is a very difficult proposition to manage. More often than not any attempt at re-entry has resulted in a more vigorous heating developing that cannot be controlled.

Bulk-scale, self-heating tests have been used to provide experimental results on the general nature of spontaneous combustion and in particular hot spot development (Li and Skinner, 1986; Akgun and Arisoy, 1994; Chen and Stott, 1997; Arief, 1997; Beamish et al, 2002; Beamish and Jabouri, 2005; Hancock, Kizil and Beamish, 2005). In addition, numerical models have been developed to provide important findings from parametric studies of coal spontaneous combustion (Schmal, Duyzer and van Heuven, 1985; Arisoy and Akgun, 1994; Monazam, Shadle and Shamsi, 1998; Akgun and Essenhigh, 2001). However there is no published information on the nature of coal self heating under the boundary conditions of re-entering a sealed heating that has cooled down.

This paper presents the results of experimental studies of a high volatile bituminous coal that has undergone an initial hot spot development and then been inerted with nitrogen, followed by resupply of air to simulate multiple re-entries. The equipment used for these experiments was a two-metre column that enabled the coal to react with the air in an environment similar to a large coal pile, hence the results that are obtained are as close to operational circumstances as possible.

### 2 Column Self-Heating

#### 2.1 Equipment

Beamish et al, (2002) describe the basic operation of the UQ two-metre column, which has a 62L capacity, equating to 40 – 70 kg of coal depending upon the packing density and particle size used for testing. The coal self-heating is monitored using eight evenly spaced thermocouples along the length of the column that are inserted into the centre of the column. A port for gas extraction is located adjacent to each thermocouple. Eight independent heaters correspond to each of these thermocouples and are set to switch on and off according to balancing equations which ensure that heat losses are minimised and semi-adiabatic conditions are maintained radially. Figure 1 shows a schematic of the UQ column.

#### 2.2 Sample Preparation

A coal sample was obtained from a Hunter Valley mining operation for testing in the UQ two-metre column. The coal was crushed to an average particle size of less than 12.7 mm. This facilitated easy handling of the sample, particularly with regards to loading the column and insertion of the coal thermocouples. Three samples were taken at this stage to obtain data on the as-received moisture content of the coal, which was determined to be 9.3%.

#### 2.3 Test Procedure

The coal was loaded into the column with three 20L plastic buckets. A total of 51kg of coal was loaded. The lid was then secured and nitrogen flushed through the

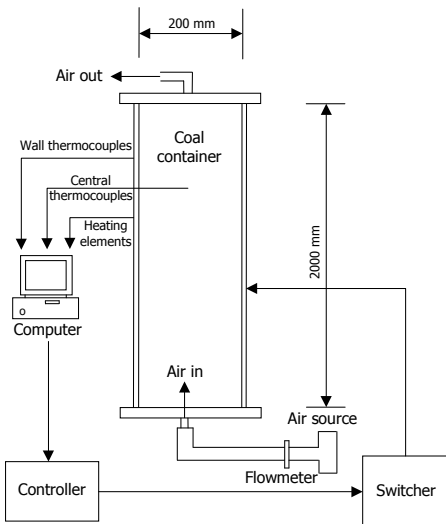


Figure 1. Schematic of UQ two-metre column.

column at 0.5L/min and the heaters used to set the starting coal temperature, which in this case was initially 40°C. Once the coal temperature had stabilised the nitrogen was switched off and air was then introduced to the coal at a flow rate of 0.5L/min. A computer recorded all the data at ten-minute increments. When the temperature of the hot spot exceeded 250°C the coal was inerted with nitrogen and cooled down to 40°C. Air was then reintroduced to the column at 0.5L/min to simulate re-entering a sealed heating. This process was repeated for two more simulated re-entries. The column has several safety devices including computer-controlled trips on the external heaters. These were set to ensure maximum safety during operation of the column.

### 3 Results Of $R_{70}$ and Column Testing

#### 3.1 $R_{70}$ Value of The Column Sample

The  $R_{70}$  testing procedure is described by Beamish, Barakat and St George (2000). Essentially, a 150 g coal sample is crushed to less than 212  $\mu\text{m}$ , dried under nitrogen at 110°C and then tested under oxygen in an adiabatic oven. The  $R_{70}$  value is simply the average rate of heating of the coal from a starting temperature of 40°C to 70°C and is expressed in units of °C/h. Figure 2 shows the self-heating curve obtained in the UQ adiabatic oven for the sample taken whilst loading the column. The  $R_{70}$  value determined from this test was 3.12°C/h. The rating of the coal is considered to be high propensity under Sydney Basin conditions and very high propensity under Bowen Basin conditions. Give the start temperature of the test was 40°C this would equate to Bowen Basin conditions.

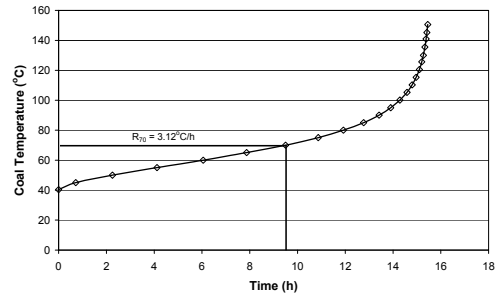


Figure 2. Adiabatic self-heating curve for a Hunter Valley high volatile B bituminous coal.

#### 3.2 Hot Spot Development Behaviour

For the initial test the hot spot developed at the downstream end of the column, before moving forwards towards the air source. In the downstream region the coal only reached 100°C due to the moisture in the coal retarding the heating. The hot spot moved forward towards the air source for two reasons: the coal had dried out more in this region and the hot spot began to starve for oxygen due to the coal upstream stripping it from the air supply. This is typical of column tests and is consistent with numerical modeling of spontaneous combustion (Schmal, Duyzer and van Heuven, 1985; Akgun and Arisoy, 1994). Figure 3 shows the temperature profile of the column at various stages during the initial test.

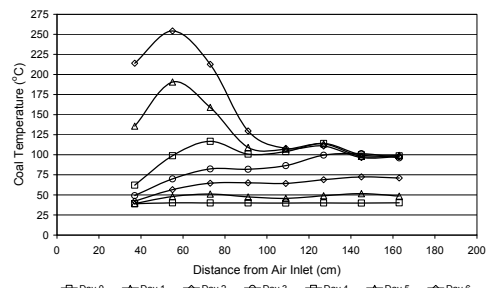


Figure 3. Temperature profile of the column at various stages during the initial test

Once the column had been inerted with nitrogen and cooled down to 40°C, air was again supplied to the column. This was repeated two more times to simulate repeated re-entries. The maximum temperature recorded during each test, including the initial test is shown in Figure 4. The initial test took approximately 4.5 days to reach thermal runaway at a temperature of 150°C. It took a total of 6 days to reach 250°C before the column was inerted. The first re-entry shows that the coal reached thermal runaway extremely rapidly (within a day). This clearly demonstrates that re-entering a previously sealed heating is potentially very hazardous.

Two more re-entries were simulated: Re-entry 2 and Re-entry 3. Each re-entry took progressively longer to reach thermal runaway. Re-entry 2 took a total of 2.5 days to reach 175°C which is just over half the time taken for the initial heating to reach the same temperature. Re-entry 3 took 6 days to reach 175°C which is approximately one day longer than the initial heating.

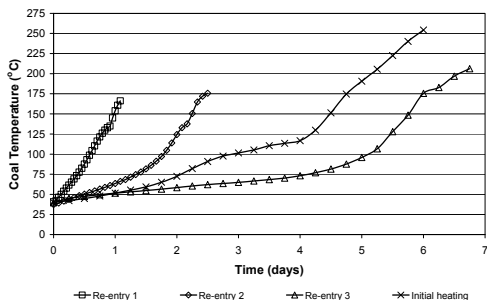


Figure 4. Maximum coal temperature history for the initial test and subsequent re-entries

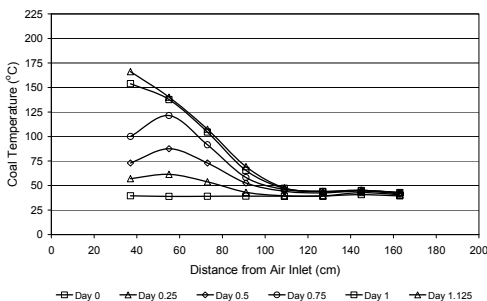


Figure 5. Temperature profile of the column at various stages during Re-entry 1

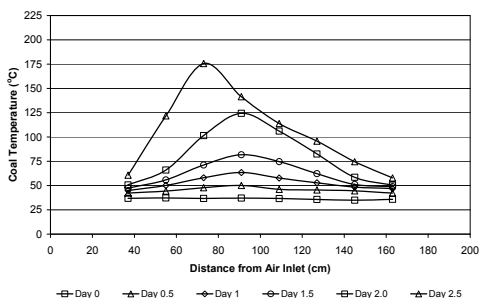


Figure 6. Temperature profile of the column at various stages during Re-entry 2

When the temperature profiles for the initial test and each re-entry as shown in Figures 3, 5, 6 and 7 are examined the reason for these time/temperature differences

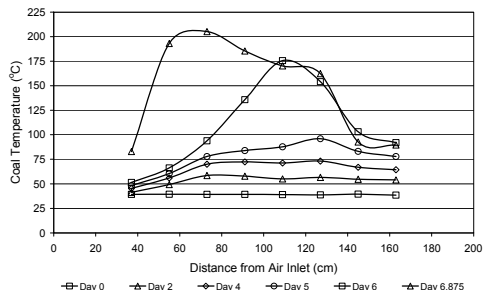


Figure 7. Temperature profile of the column at various stages during Re-entry 3

is more readily apparent. Previous research (Cliff, Rowlands and Sleeman, 1996; Ren, Edwards and Clarke, 1999; Beamish, Barakat and St George, 2000) has shown that the heating rate is affected by several factors, two of which are very significant in this instance: moisture and previous oxidation. During the initial test moisture was transferred by evaporation and subsequent condensation from the upwind to the downwind end of the column. The heat of wetting caused the downwind end of the column to heat first whilst the evaporation at the upwind end of the column caused it to remain cool. After a period of time, the downwind end of the column was restricted from passing beyond approximately 100°C due to the moisture content in the coal. The moisture had been removed from the coal upwind of this region, however, so the hot spot developed there. During the first re-entry, the coal at the upwind end of the column was already dry, whilst the coal downwind was still moist. Therefore, there was no cooling effect from evaporation of moisture in this region and the heating developed rapidly.

When the second re-entry was simulated, the coal at the inlet had already been heavily oxidised by the initial test and Re-entry 1. Previous research (Ren, Edwards and Clarke, 1999; Beamish, Barakat and St George, 2000) has shown that the previous oxidation or weathering of coal significantly retards its self-heating rate. Therefore the coal temperature did not initially rise quickly in this region as it had previously. The coal further downstream towards the centre of the column was slightly moist, which had a small retarding effect whilst the coal downstream of the centre of the column was very moist which heavily retarded this region. It can be seen in Figure 6 that after the hot spot had developed in the slightly moist region, it then migrated upwind due to oxygen deprivation. Due to the fact that this region was previously oxidized the rate of temperature increase was not as fast as Re-entry 1.

During the third re-entry, the effects of previous oxidation were very significant and the heating developed more slowly than even the initial test. Once again, however, moisture at the far downstream end of the column prevented this region from increasing in temperature above 100°C. With each successive re-entry the size of the hot spot increased significantly.

#### 4 Conclusions

Bulk-scale testing has shown that when a sealed heating in a high volatile B bituminous coal is re-entered the coal enters into thermal runaway extremely rapidly, reaching a temperature of 150°C within a day. This is due to the moisture having been removed from the coal by the initial heating and thus the coal has been preconditioned. Each subsequent re-entry was slower than the previous one due to the combined effect of previous oxidation and moisture remaining in the coal. The results of these tests appear to agree with anecdotal evidence of attempts to recover an area that has been subjected to a heating. Clearly staged re-entry is a preferred option for recovery.

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