LARGE SCALE LABORATORY TESTING OF THE SPONTANEOUS COMBUSTIBILITY OF AUSTRALIAN COALS

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SUMMARY

Traditional means of detecting the presence of spontaneous combustion in a coal mine are based on the measurement of various gases and the calculation of a number of ratios based on the concentration of those gases. The best indicators of spontaneous combustion have always been considered to be carbon monoxide concentration or make, and various ratios involving carbon monoxide concentration.

This paper reports the second stage of the development of a test rig for large scale experimentation on the spontaneous combustibility of Australian coals. A number of large scale heating tests using approximately 15 tonnes of coal have been carried out at SIMTARS . The coal was arranged in a pile 2m wide, 2m high and 4m long in a reactor that could be sealed. Air was passed through the pile in an attempt produce a spontaneous heating. In each test the temperature distribution in the coal pile was monitored by an array of 250 thermocouples, while gas analysis were conducted on the exit gases and the atmosphere within the pile. The apparatus has been modified in the second stage of the experiments to include an insulated cover and heating of the inlet air in an effort to minimise heat loss.

Results from the second stage of testing indicated that the spontaneous combustion process in the reactor was in the main governed by heat loss processes. In addition some of the nascent carbon monoxide produced by the initial coal hot spot, subsequently passed through pile coal at a lower temperature, was removed either through conversion to carbon dioxide or adsorption onto the coal. Any attempt to use indicators of spontaneous combustion based on CO, in the exhaust gas stream, would have resulted in significant underestimation of the intensity of the hot spot within the experimental pile.

INTRODUCTION

Most of the experiments studying the spontaneous combustibility of coal have focussed on small scale laboratory studies. These studies do not simulate the situations that occur in the mines as they do not emulate the conditions found underground and do not permit secondary reactions nor temperature and air flow variability within the reaction area.

Large scale testing of coal samples is not new, large scale tests were first carried in Australia in 1909 following the Royal Commission into Fires in Coal Bunkers of Ships, though the first recorded large scale tests were carried out in France in 1879 [1].

In the UK experiments were undertaken in the 1920's and 1930's at the Safety in Mines Research Board facility in Buxton and on one occasion succeeded in blowing up the test apparatus [2]. Ten tons of coal were placed in a chamber surrounded by 20 tons of dirt. The experiment typically then fed 15 cu ft/min of warm air (95 °F rising to 150 °F) into the coal and allowed to react over periods up of to 9 months. On one occasion after no detectable reaction had occurred for 9 months, the inlet air temperature was increased from 150 °F to 170 °F and a heating developed within 11 days. Over this period the CO concentration rose from 8 ppm in the exhaust stream to 1500 ppm, rising from 370 to 1500 in 6 hours. At this point smoke was observed and a petrolly smell was sensed. Prior to this there was a musty smell. An interesting feature of this experiment was that the heating was stalled by cutting off the oxygen supply. Three months later when the chamber was reventilated with warm air (155 °F) an intense heating was reestablished within three weeks.

Testing has been carried out in France involving approximately one to five tonne dry ground coal samples (80% < 80 μ m diameter) in insulated containers. Oxygen entered the coal pile by diffusion only from the surface of the coal. Self heating occurred within the coal at a depth where oxygen could still diffuse in sufficient concentration yet the coal surrounding the reacting coal could act as an insulator (typically 300 - 600 mm below the surface). The data obtained from the tests was then used to develop a computer simulation model [3].

More recently the United States Bureau of Mines (USBM) carried out self heating trials on 13 short tons of coal samples, using unheated air. The tests showed that the rate of self heating depends not only on the reactivity of the coal but also the particle size of the coal, the freshness of the coal surfaces and the heat of wetting effect. There is also an optimum oxygen ventilation rate [4]. This report also summarised previous large scale trials. Three coals with high propensity to spontaneous combustion were tested and only one managed to self heat.

Due to the known difference in behaviour between Australian coals and those studied overseas, a reactor very similar to the US apparatus, was constructed. The initial experiments have been reported [5]. Essentially self heating beyond 70 ° C was not obtained in the tests due to the heat losses from the reactor to the external environment. Heatings that were artificially stimulated indicated that hot spots a few hundred millimeters in diameter could develop and become extremely hot without involving the bulk coal mass.

This paper reports the second phase of these experiments where additional efforts were made to reduce the heat losses from the reactor.

EXPERIMENTATION

The original apparatus is described in Humphreys et al., (5). Only the modifications will be described here. A schematic diagram of the reactor is shown in Figure 1 below.

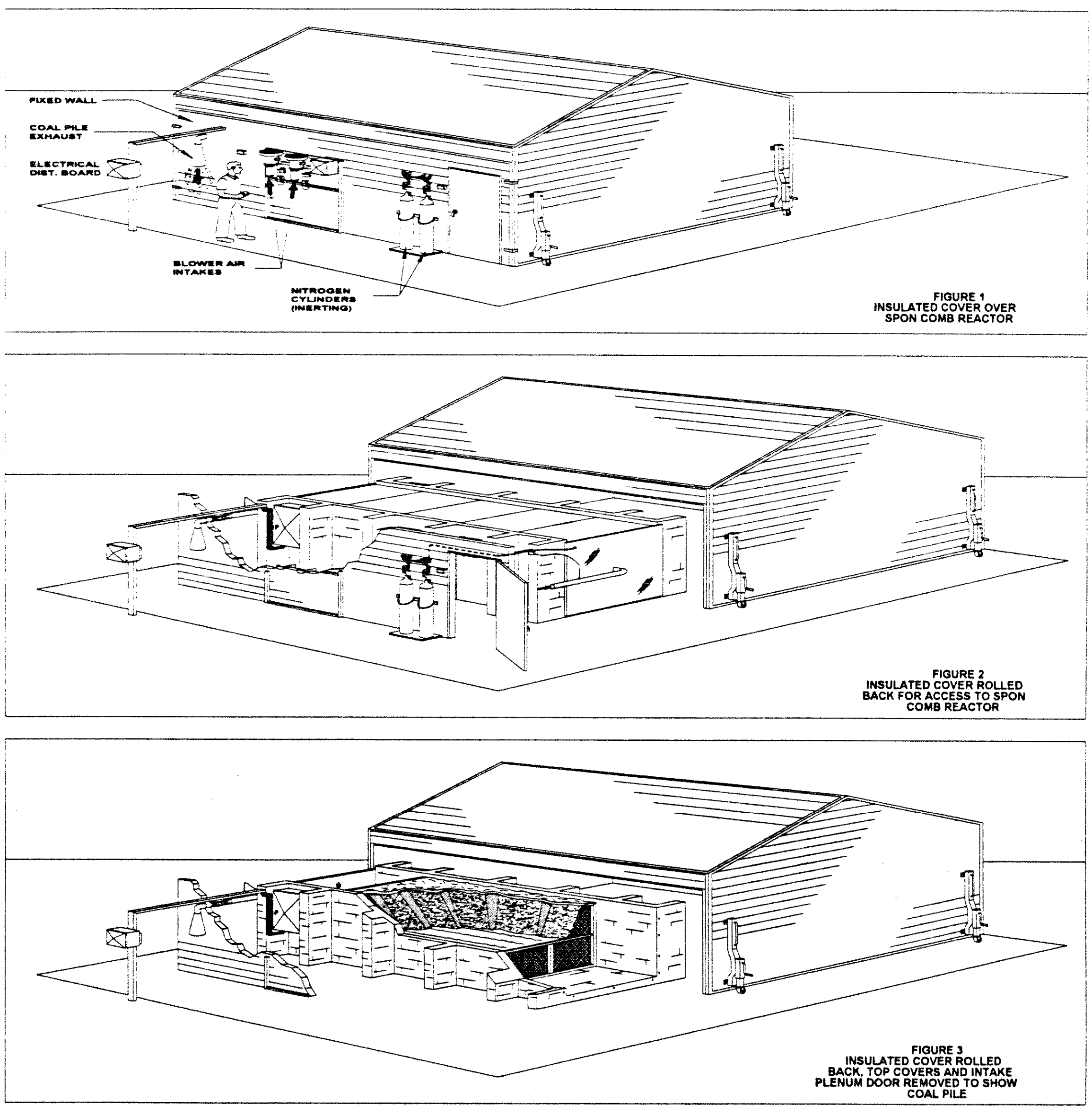

Figure 1 - Schematic Diagram of Reactor

Approximately 15 tonnes of crushed coal was placed between the two block walls. Five layers each of 50 thermocouples were used to monitor the temperature throughout the pile and nine gas sampling tubes were inserted into the central axis of the reactor. Air was passed from one end to the other. Internal air flow was estimated to be approximately 50 - 100 litres/minute.

The apparatus was modified to include a thermal cover in an effort to reduce the heat losses and facilitate the self heating of the coal. At an early stage of the experiment it was realised that despite the thermal efficiency of the cover, assistance was still required to reduce the heat losses from the reactor. A series of heaters were then installed in the area between the reactor and the cover to preheat the air to approximately the edge temperature of the coal.

Over the time scale of the experiment a number of hot spots appeared and disappeared. Over the first three months none exceeded the previous maximum of approximately 70 ° C. Temperature data indicated that despite an apparently uniform coal pile the temperature distribution was most anisotropic, indicating that there were channels within the coal mass that allowed the air to flow through the coal.

Nearly five months after the reaction was initiated a hot spot of approximately 140 ° C appeared. Figure 2 shows the temperatures at the thermocouples in the immediate area of the new hot spot. The hottest spot was located vertically in the middle of the pile but within 1 m of the inlet face.

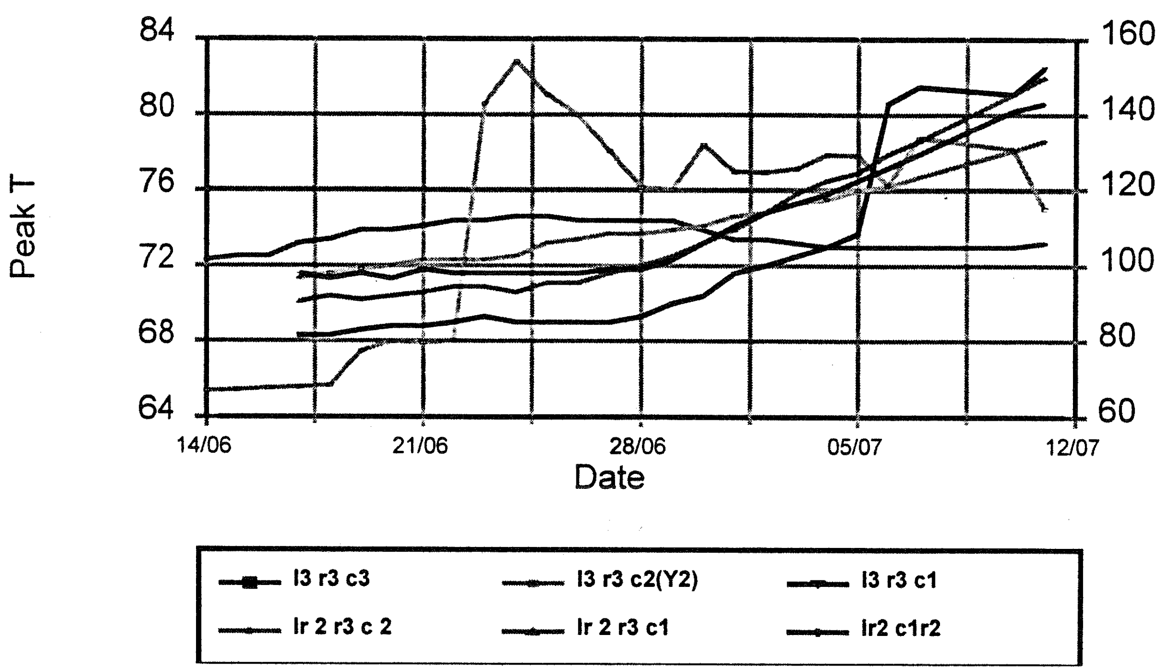

Figure 2 - Temperature measurements at various locations within the reactor

Key observations were:

- Gas extracted from the hot spot exhibited an odour consistent with the coal temperature in excess of 100 ° C.
- The temperature change of the coal as measured by the thermocouple did not display a monotonic increase rather a series of step changes
  - This is consistent with a small hot spot moving to the thermocouple rather than the initiation of a whole of pile heating.
  - from the above it is evident that the size of the hot spot therefore is less than 400 mm in diameter.
- The temperature at the hot spot did not exhibit exponential increase once it exceeded the "critical" temperature of 70 ° C, indeed a new equilibrium was established.
- Whilst in general temperatures changed slowly and monotonically the peak temperature detected demonstrated instability of up to 10 ° C in an hour. The temperature is depicted in Figure 3 below.

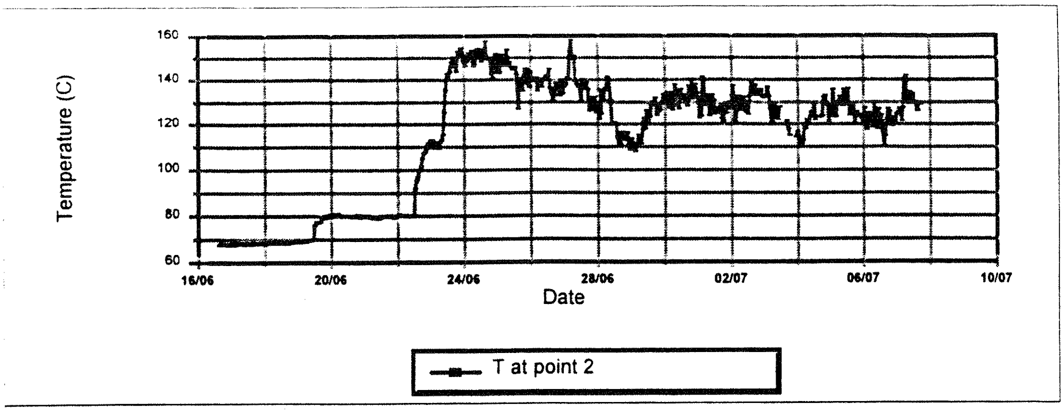

Figure 3. Variation in the temperature at the hottest point

The gas monitoring data obtained showed a number of interesting facets.

- The carbon monoxide produced at the hot spot was subsequently removed by a secondary conversion reaction to carbon dioxide or absorbed onto the surface of the coal.
- Typical gas ratios derived from the gas monitoring data are shown below in Table 1.

Table 1- Typical gas analysis

Gas	Port 2	Port 5	Port 8
Hydrogen	0.0105	0.0031	0.0007
Carbon Dioxide	1.51	3.46	3.61
Ethylene	Trace	trace	trace
Ethane	0.0004	0.0010	0.0011
Oxygen	14.90	8.76	8.70
Nitrogen	82.36	86.55	86.30
Methane	0.0009	0.0020	0.0022
Carbon Monoxide	0.145	0.23	0.14
Graham's ratio	2.09	1.61	0.99
CO/CO2 ratio	0.096	0.066	0.039

- Both of the ratios listed above indicate activity decreasing within the reactor as distance from the inlet air increases.
- Hydrogen also disappeared with distance indicating loss mechanisms - either conversion to water or absorption/adsorption in the coal.
- The methane, ethane and ethylene detected were also generated by oxidation of the coal.
- The temperatures at the gas sampling points corresponded to 147.3 ° C, 70.4 ° C and 64.4 ° C respectively for this data set.
- The degree of secondary reaction depended on the temperature of the coal pile with optimum secondary reaction occurring at about 50 ° C and declining as temperature increased or decreased.

CONCLUSIONS

Whilst run away spontaneous combustion has not as yet been achieved, the observations made potentially indicate that some of the conventional wisdom regarding spontaneous combustion needs to be questioned.

- Even under favourable conditions when coal is heated in excess of the "magic" temperature of 70 ° C run away heating does not necessarily occur.
- Heat loss can dominate the ability of the coal to self heat even at elevated temperatures indicating variation in loss and generation mechanisms as a function of temperature.
- The accuracy of ratios measured remote from the site of heatings is questionable due to subsequent reaction of the generated gases within the coal pile. Thus extreme care should be taken in applying the results obtained especially when the monitoring is remote to the heating. The resultant ratios can significantly underestimate the peak intensity as illustrated above.

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