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Basil Beamish
B3 Mining Services Pty Ltd

Jan Theiler
CB3 MIning Services

Andrew Garvie
SRK Consulting Pty Ltd

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AGEING EFFECT ON THE SELF-HEATING INCUBATION BEHAVIOUR OF LIGNITE

Basil Beamish[1], Jan Theiler[2], Andrew Garvie[3]

ABSTRACT: A lignite seam present in overburden strata of an opencut mine poses an interesting question as to its spontaneous combustion hazard likelihood when placed into an overburden spoil pile. Lignite is often assumed to rapidly spontaneously combust when exposed to air due to its low rank. However, lignite also has a high moisture content as-mined, generally in the order of 40% or greater. Self-heating is a balancing act between the intrinsic reactivity of the coal and the moisture present, which can act as a moderating influence to the rate of self-heating. In addition, this balance can be altered by ageing since both the intrinsic reactivity of the lignite and the moisture content decrease over time. This feature of coal self-heating is frequently overlooked in almost all spontaneous combustion test methods. A new adiabatic oven incubation test method is now routinely used by the Australian coal industry to overcome this deficiency. It assesses the spontaneous combustion hazard for the environmental conditions that exist for each mining situation. Incubation testing of the fresh lignite demonstrates that in an as-mined moisture state of 45.2% the incubation period of the lignite is considerably extended by heat loss from moisture liberation and evaporation to the point of no thermal runaway being achieved in a practical timeframe. However, rehandling or exposure to the atmosphere of aged overburden spoil containing the lignite within a certain timeframe can alter the heat balance in favour of thermal runaway. This paper presents laboratory examples of how this mechanism can occur.

INTRODUCTION

Spontaneous combustion poses a significant environmental and safety hazard to overburden spoil piles, particularly if remnant coal is present from rider seams in the overburden sequence. It is therefore necessary to evaluate the likelihood of developing a spontaneous combustion event from these stratigraphic units under a range of site conditions. This is often done by laboratory investigation of the ability of the coal to self-heat to the point of thermal runaway, which subsequently could lead to spontaneous ignition. There are many spontaneous combustion index tests used for rating the propensity of coal for spontaneous combustion (Nelson and Chen, 2007). Many of these have deficiencies and several ignore the fact that the development of a spontaneous combustion event is primarily an incubation process at low ambient temperatures (Beamish and Theiler, 2017). To overcome these deficiencies a new test method has been adopted by the Australian coal industry referred to as the Incubation Test, which is applicable to coals around the world ranging from lignite through to anthracite as well as non-coal strata (Theiler and Beamish, 2018).

Low rank coals are well-known to have a high spontaneous combustion propensity. However, they are still successfully mined and managed for this hazard. There is a common misconception that lignite in particular is highly prone to spontaneous combustion, but there are certain key factors that interact to moderate the likelihood of developing a lignite spontaneous combustion event including an ageing effect. This paper presents examples of these factors for a lignite seam that is present in the overburden sequence of an operating opencut mine. The

[1] *Managing Director, B3 Mining Services Pty Ltd. Email: basil@b3miningservices.com Tel: +61 7 3375 4100*
[2] *Senior Mining Engineer, CB3 Mine Services. Email: j.theiler@cb3mineservices.com Tel: +61 7 3375 4100*
[3] *Principal Consultant (Geoenvironmental), SRK Consulting (Australasia) Pty Ltd. Email: agarvie@srk.com.au Tel: +61 2 8079 1208*

results obtained from adiabatic oven incubation testing clearly show the fine balance that exists between heat loss and heat gain in the low temperature region during self-heating incubation.

LIGNITE SAMPLE AND ADIABATIC TESTING

The coal quality details of the lignite sample are contained in Table 1. It has an ASTM rank classification of Lignite B and has a high ash content (>30%), but a low sulphur content (<1%). Both adiabatic R_{70} self-heating rate and incubation testing as described by (Beamish and Beamish, 2011; Beamish, Edwards and Theiler, 2018) was conducted on the lignite in its fresh state as well as after one week of exposure to air and again after four weeks of exposure to air. The air exposure took place under controlled laboratory conditions using replicate splits of the lignite in a broken state.

Table 1: Coal quality data for lignite sample

Sample	Moisture (%, as-received)	Ash (%, dry basis)	Sulphur (%, dry basis)	Volatile Matter (%, dry mineral matter free)	Calorific Value (MJ/kg, dry basis)
Lignite	45.2	37.6	0.83	54.1	16.76

ADIABATIC SELF-HEATING RESULTS AND DISCUSSION

R_{70} values of fresh and aged lignite

The R_{70} values obtained for the fresh and aged lignite samples are shown in Figure 1 compared against lignite coal samples from New Zealand and Indonesia as well as sub-bituminous coal from Callide. The intrinsic spontaneous combustion propensity rating of the fresh lignite is extremely high based on the classification scheme published by Beamish and Beamish (2011). The high ash content of the sample creates both a dilution and heat sink effect on the self-heating rate, which can be seen by comparing against the R_{70} value obtained for the low ash content lignite samples from New Zealand and Indonesia. This ash content trend for the lignite samples has a similar slope to the sub-bituminous Callide coal trend seen in Figure 1 and published by Beamish and Blazak (2005).

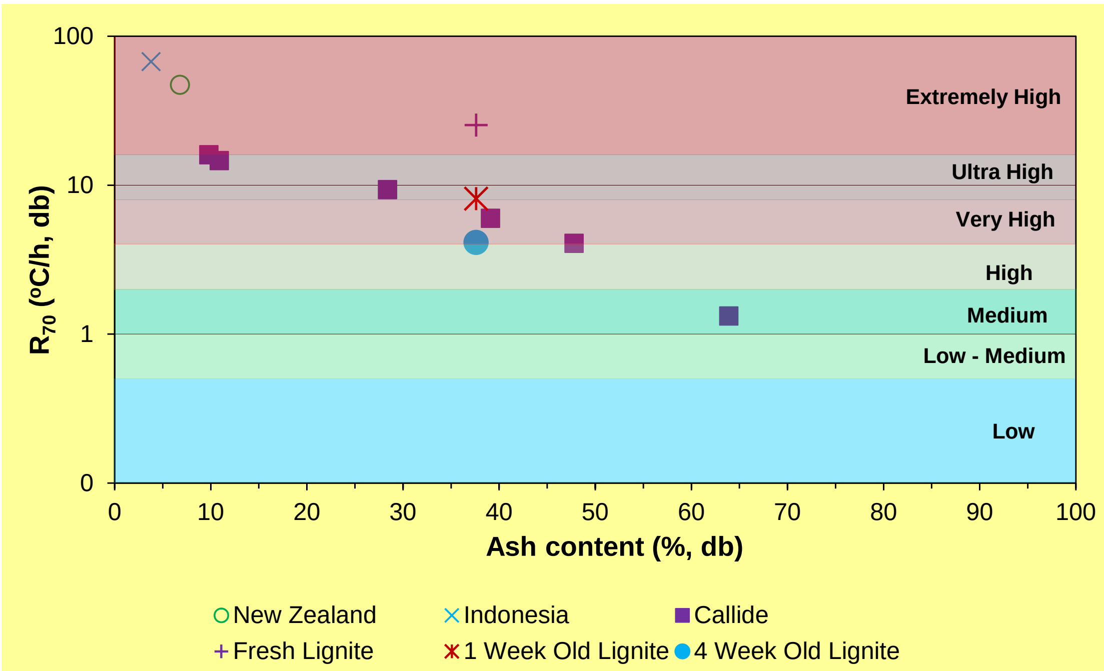

Figure 1: Relationship between R_{70} self-heating and ash content showing intrinsic spontaneous combustion propensity ratings

As the coal ages, the R_{70} value initially decreases quite dramatically due to the loss of reactive sites from oxidation. This is shown in Figure 2 and is due to the open macropore structure associated with lignites that enables ease of oxygen access to reactive sites. The R_{70} value decreases with exposure time, and would most likely approach a residual value. This is due to the greater degree of difficulty for oxygen to penetrate the finer micropore structure of the lignite after the majority of the macropore reactive sites have been deactivated. Beamish, Barakat and St George (2000) measured a similar non-linear decreasing trend in R_{70} value with ageing for a New Zealand sub-bituminous coal.

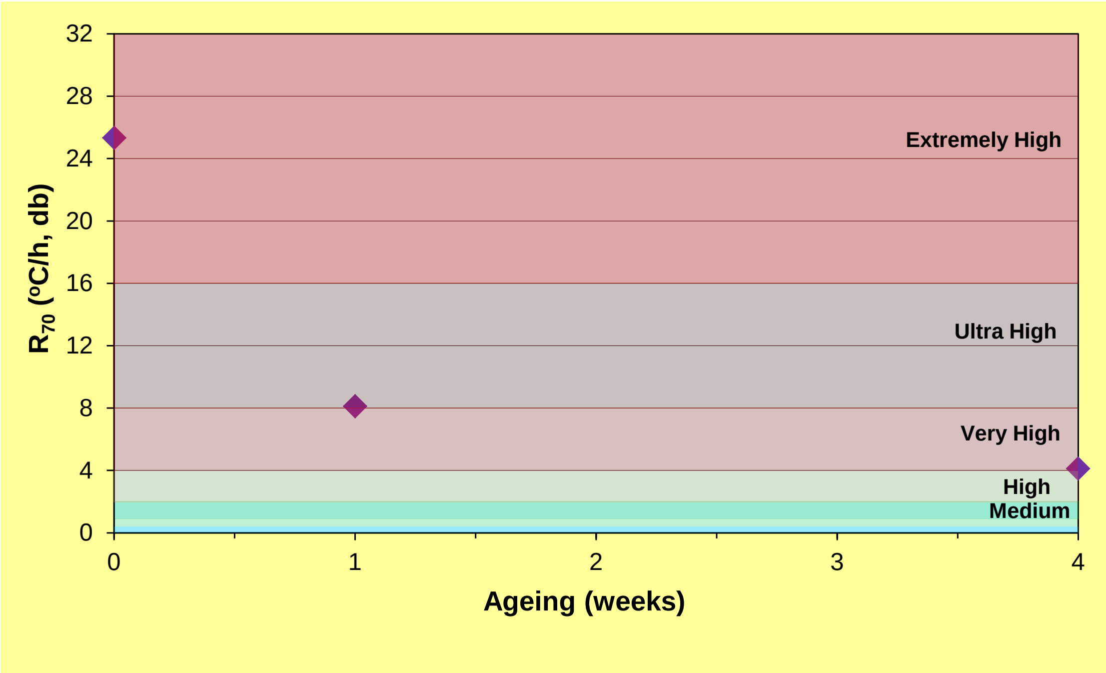

Figure 2: R_{70} self-heating rate decrease with exposure time to air

Incubation behaviour of fresh and aged lignite

Incubation testing of the fresh and aged lignite enables a greater understanding between the interaction of the intrinsic reactivity of the lignite and the moisture that is present for each situation. The fresh lignite gradually self-heats (Figure 3), consistent with the extremely high intrinsic reactivity as the oxygen gains access to the readily available reactive sites. During this process there is also heat loss as a result of moisture liberation from the coal and subsequent evaporation. After reaching a maximum temperature of approximately 90 °C, the heat loss by evaporation exceeds the heat gain from oxidation and the temperature decreases with no thermal runaway being recorded. This incubation feature of fresh lignite is not well-documented by previous research due to the limitations imposed by previous test methods.

After one week of ageing in air, the moisture content of the lignite reduces from 45.2% to 26.7%. The R_{70} value, which is a measure of intrinsic reactivity, decreases from 25.33 °C/h to 8.11 °C/h. This change in the lignite properties has a significant effect on the incubation self-heating behaviour. The low temperature self-heating rate is much faster than the fresh lignite (Figure 3), because the heat loss from the moisture liberation is substantially reduced. The sample temperature increases to approximately 96 °C with a subsequent balance of heat generated through oxidation and heat loss through evaporation. This produces a prolonged moisture evaporation temperature shoulder. Eventually, sufficient moisture is removed from the lignite to enable oxygen access to fresh reactive sites and self-heating continues at an increasing rate to thermal runaway.

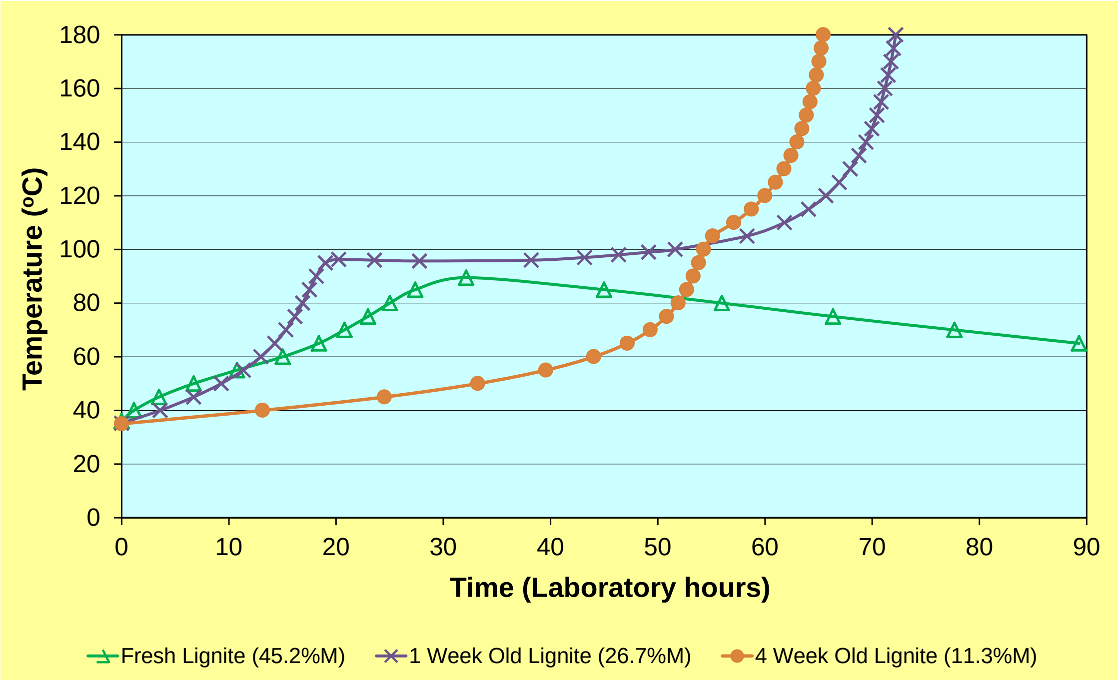

Figure 3: Adiabatic oven incubation self-heating curves for fresh and aged lignite

After four weeks of ageing in air, the moisture content of the lignite reduces to 11.3% and the corresponding R_{70} value is 4.12 °C/h. In this more aged state the incubation self-heating is much slower at low temperatures due to the loss of intrinsic reactivity from oxidation. However, as the coal temperature increases the heat loss from moisture evaporation is diminished compared with that of the fresh sample due to the lower starting moisture content and only a small decrease in self-heating rate is observed between 100-110 °C, before self-heating resumes to accelerate to thermal runaway. Consequently, in terms of overall incubation period the four week aged lignite has a shorter incubation period than the one week aged lignite.

Clearly as the lignite ages further, the intrinsic reactivity continues to decrease and a point is eventually reached where the incubation period begins to increase and no thermal runaway is possible. This is confirmed in recent work on aged coal characterisation at Leigh Creek Mine in South Australia (Garvie *et al*, in press).

CONCLUSIONS

Spontaneous combustion of freshly mined lignite is a complex process that is controlled by the interaction between heat release associated with the extremely high intrinsic reactivity of lignite and the heat loss due to liberation and evaporation of its initial moisture content. The process is one of self-heating incubation from low ambient temperature until either thermal runaway is achieved or the heat loss from the moisture liberation and evaporation dominates causing a decrease in temperature over time. If the lignite is left exposed to air and rehandled or if it is placed in a spoil pile that is later exposed to an air source, then self-heating to thermal runaway is possible due to a change in the heat balance controlled by the intrinsic reactivity of the lignite and its moisture content at the time of exposure. There is a range of material ages and moisture contents for which thermal runaway may occur that can be evaluated using incubation testing of the lignite.

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