Sensitivity of Adiabatic Self-heating Rates

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ABSTRACT

The repeatability of the adiabatic self-heating rate index, R_{70}, is less than ± 5% of the average value for repeated tests performed consecutively over 3-4 days. However, when repeat tests are performed on samples after a considerable time in storage, generally in excess of one month, there can be a significant decrease in the R_{70} value. The level of this decrease that occurs is strongly influenced by storage method, in particular storage temperature and particle size. Freezing samples at large particle size reduces the effect.

Introduction

Single index testing of coals to indicate their propensity to spontaneous combustion has routinely been used by the coal mining industry. The most common testing procedures are (Cliff *et al.*, 1996):

- Adiabatic heating
- Crossing point temperature
- Differential thermal analysis (DTA)
- Olpinski Index
- Oxygen absorption

Adiabatic heating is generally considered to simulate the in-situ condition whereby heat losses are not allowed to dissipate from the reaction vessel. Humphreys *et al.* (1981) reported results of this test procedure for Queensland coals. They defined a self-heating rate index R_{70}, which equated to the gradient of the linear portion of the adiabatic self-heating curve from 40 to 70 ºC. Although this index has been commonly used in Australia since 1981, few results have been published. This has been due to the method being adopted by Australian Coal Industry Research Laboratories (ACIRL) as a service to industry on a commercial fee-paying basis. As a result, R_{70} values for Australian low rank hard coals are non-existent in the literature, which is unfortunate as these coals are finding increasing application in power generation, particularly in Queensland.

At the end of 1998, the Department of Mining, Minerals and Materials Engineering at The University of Queensland (UQ) purchased an adiabatic oven that had previously been used by The University of Auckland (UA) for spontaneous combustion research (Vance, 1993; Vance *et al.*, 1996). This was a strategic initiative linked with the Minerals Industry Safety and Health Centre (MISHC) and is consistent with Faculty Operational Plan objectives for 2001-2005. After recommissioning the adiabatic oven, two projects were completed in 1999, one on Callide opencut coal mine in Queensland (Cooper, 1999) and the other on Dartbrook underground coal mine in New South Wales (Dudley, 1999).

This paper presents recent results of self-heating tests performed on highly reactive New Zealand and Australian coals using the adiabatic oven. In particular the sensitivity of the test is highlighted.

Experimental

New Zealand coal samples

A selection of coal samples was obtained from the Coal Research Limited (CRL) sample bank. These samples represented different coal ranks ranging from lignite to high volatile bituminous and were supplied as crushed (< 5 mm) run-of-mine coal. These coals also covered two different annual surveys of New Zealand mines, namely 1996 and 1998. The first batch of samples was delivered to The University of Auckland in May 1998 in airtight plastic bags containing approximately 250-300 g of coal. A second batch of samples containing Strongman and New Vale 1998 coal was received in July 1998. All samples were kept in the laboratory cold storage unit at a constant temperature of 5 ºC to reduce the effect of oxidation prior to testing.

A 2.5 kg lump of run of mine subbituminous coal was sampled from the working face of Huntly East Mine and sent directly to the university for testing. This sample was received on the 28th of May 1998. It was crushed to –5 mm the day after it was received. The crushed coal was split into 11 x 200 g samples and placed in airtight bags. One sample was sent to CRL for a proximate analysis, sulphur content and specific energy determination. The remaining samples were stored in the laboratory cold storage unit for later adiabatic testing.

Australian coal samples

Two strip samples (SC1 and SC2) were taken from the exposed highwall of Dunn Creek Mine. These samples were collected to obtain the first self-heating rate data for the mine using adiabatic testing procedures. Both strips were 2 m in height and only represented a small proportion of the overall working section in the mining highwall, which can be up to 20 m in height. A continuous sample interval of 50 cm was used, except for the first interval of SC1, which was divided into two portions due to the presence of a fusain-rich layer. The sample lumps were double bagged and sealed at the top to ensure they were airtight and to reduce pre-oxidation effects. Initially, 750 g was separated from the bulk strip sample of each interval. This was then reduced in size to < 1 mm. Approximately 450 grams was set aside and frozen as duplicate material.

Adiabatic oven and testing procedure

Full details of the adiabatic oven (Figs. 1 and 2) are presented in Beamish *et al.* (2000). The reaction vessel is mounted in the oven door (Fig. 2) and gas is supplied via a 16 m length of copper coil (Fig. 2) to enable the gas to reach oven temperature prior to coming into contact with the coal. All coal samples were crushed to -212 μm immediately prior to testing and dried under nitrogen. For the Auckland work a special drying tube was used (Barakat, 1998) and the drying temperature was 105 ºC. For the Australian work the coal was dried in the adiabatic oven using a conical flask (Dudley, 1999) in place of the reaction vessel at a drying temperature of 110 ºC. Drying time for both procedures was 15-16 hours.

At the completion of drying, the coal was allowed to equilibrate to a temperature of 40 °C in the adiabatic oven. Once this was achieved the coal sample was transferred into the reaction vessel and left to stabilise at 40 °C, with nitrogen passing though it. As soon as the sample temperature had stabilised, the oven was switched to remote monitoring mode (allowing the oven to track the coal temperature) and the gas selection switch turned to oxygen with a constant flow rate of 50 ml/min. The temperature change of the coal with time was recorded by a datalogging system for later analysis. The oven limit switch was set to cut-off the power to the oven and stops the oxygen flowing when the sample temperature reached 180 °C. After the oven cooled down, the sample was removed from the reaction vessel and it was cleaned in preparation for the next test.

Results and discussion

The analytical data for the New Zealand coals (Table 1) have been fed into the computer program “Coalap” (Sykes and Suggate, 1990) to define their rank. The Suggate rank number places the coals in strict rank order, while the ASTM classification is often influenced by coal type variations in the case of New Zealand coals. Both the 1996 and 1998 samples of New Vale and Strongman coal show that no rank variation has occurred over the two years of mining, with Suggate Rank numbers of 3.3 and 11.9 respectively being obtained for both years.

The self-heating rates obtained for the coals in these studies are much higher than the reported values of Humphreys *et al.* (1981). Tests go to completion in less than 15 hours for the Australian coals and less than 5 hours for the highly reactive New Zealand subbituminous coals (Fig. 3). Clearly, this is a reflection of the lower rank of the samples and their much higher propensity to spontaneous combustion. Sensitivity of the test is evident from the major impact storage conditions have on repeat testing for self-heating rates. Figs. 4 and 5 summarise the repeat testing of both New Zealand and Australian coal samples. The important points to note are:

- True repeatability of the test is obtained by testing over consecutive days only, as any appreciable time lag in testing results in a decrease in the self-heating rate index (Fig. 4). For example, samples HE3-HE5 (Table 2) have a mean R_{70} of 15.78 ± 0.72 (4.56%) °C/h, whereas samples HE6-HE9 (Table 2) tested the following week have a mean value of 14.14 ± 0.58 (4.10%) °C/h. A major part of the deviation is most likely the result of uneven particle size distribution from sample to sample.
- A reduction in particle size accelerates the rate of decrease in R_{70} for a repeat test on stored coal. HE1 and HE2 (Table 2, Fig. 4) were prepared to -212 μm at the same time. However, as HE1 was being tested adiabatically HE2 was stored at the reduced particle size instead of 5 mm, hence it tended to oxidise more readily prior to testing. These results show that at a stored particle size of -212 μm, R_{70} dropped by 4 °C/h in one day, whereas the same drop at the larger particle size of -5 mm takes 5-6 days.
- Storage conditions used at UA appear to be less effective than UQ (Fig. 5), even though the latter was stored at a smaller particle size. Presumably, the lower storage temperature used at UQ is the major control here.
- UQ and CRL storage conditions produce similar rates of decrease in R_{70} (Fig. 5), even though UQ samples are stored at a smaller particle size (< 1 mm versus < 5 mm).

Conclusions

Adiabatic testing for determining self-heating rates is a reasonably repeatable procedure, as long as consecutive tests are performed within 3-4 days of each other. The accuracy of the test is generally less than ± 5% of the average value for repeat tests. Testing of stored samples, however, is strongly influenced by the storage method. Primary influencing factors are storage temperature and sample particle size. Samples that have been frozen show the lowest reduction in self-heating rate with time. Samples that have been reduced in particle size show a high reduction in self-heating rate with time. Repeated testing of stored samples can be used to extrapolate a fresh coal value of self-heating rate. It is therefore important that sample history and storage method is documented when comparing self-heating rates of coal samples (either within a mine or between mines).

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Table 1
Analytical data for New Zealand and Australian coal samples (air-dried basis, except for 62/148 on an as-received basis)

Sample Ref	Mine	Moist (%)	Ash (%)	Volatile Matter (%)	Fixed carbon (%)	Calorific Value (MJ/kg)	Sulphur (%)	ASTM rank	Suggate rank
New Zealand samples									
58/106	New Vale 1996	25.0	3.1	39.5	32.4	19.42	0.40	LigA	3.3
61/856	New Vale 1998	14.9	3.7	44.5	36.9	22.11	0.49	LigA	3.3
61/814	Kopako 1998	19.2	7.2	35.6	38.0	22.08	0.21	SubC	7.9
62/148	Huntly East	19.6	2.5	34.9	43.0	23.65	0.18	SubB	8.5
61/810	BBL 1998	12.2	7.6	36.2	44.0	24.90	0.40	SubA	9.6
58/012	Strongman 1996	3.2	2.4	43.1	51.3	32.76	0.19	HvbB	11.9
61/074	Strongman 1998	4.6	2.3	40.6	52.5	31.88	0.24	HvbB	11.9
Australian samples									
SC1B	Dunn Creek	7.7	8.3	29.0	55.0	26.17		SubA	
SC2C	Dunn Creek	7.4	11.3	24.5	56.8	25.19		SubA	

Table 2
Self-heating rate repeat test results

CRL Ref	Storage Particle Top Size (mm)	Days Elapsed Since Exposed	R_{70} (°C/h)
New Zealand samples			
New Vale			
61/856	5	74	7.76
58/106		600	2.26
		609	1.89
Kopako			
61/814	5	20	17.23
		76	12.69
BBL			
61/810	5	21	14.91
		77	8.86
Strongman			
		74	2.23
		630	0.69
Huntly East			
HE1	5	2	19.53
HE2	0.212	3	15.20
HE3	5	6	16.55
HE4	5	7	15.12
HE5	5	8	15.67
HE6	5	12	13.88
HE7	5	13	13.47
HE8	5	14	14.39
HE9	5	16	14.80
HE10	5	33	13.47
Australian samples			
SC1B	1	29	5.79
		59	5.11
SC2C	1	180	4.83
		360	3.62

Fig. 1. Interior view of the adiabatic oven.

Fig. 2. Reaction vessel attachment to the oven door (note copper tubing wound in a coil).

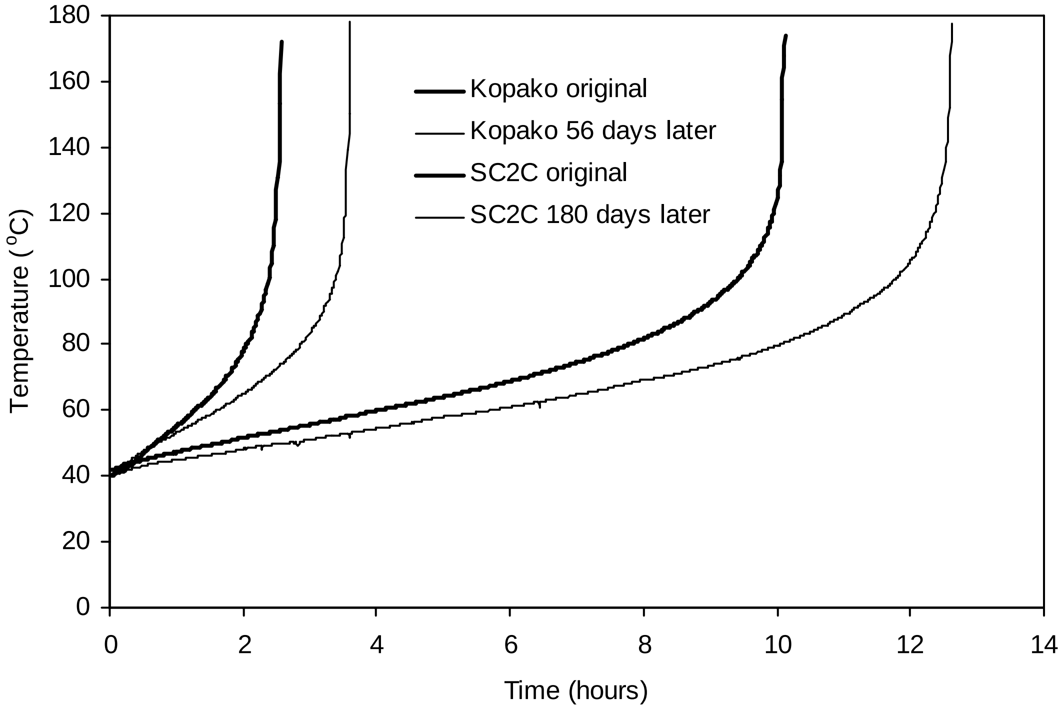

Fig. 3. Repeat self-heating rate profiles for Kopako (61/814) and Dunn Creek (SC2C). Note: the first two curves are the faster Kopako coal.

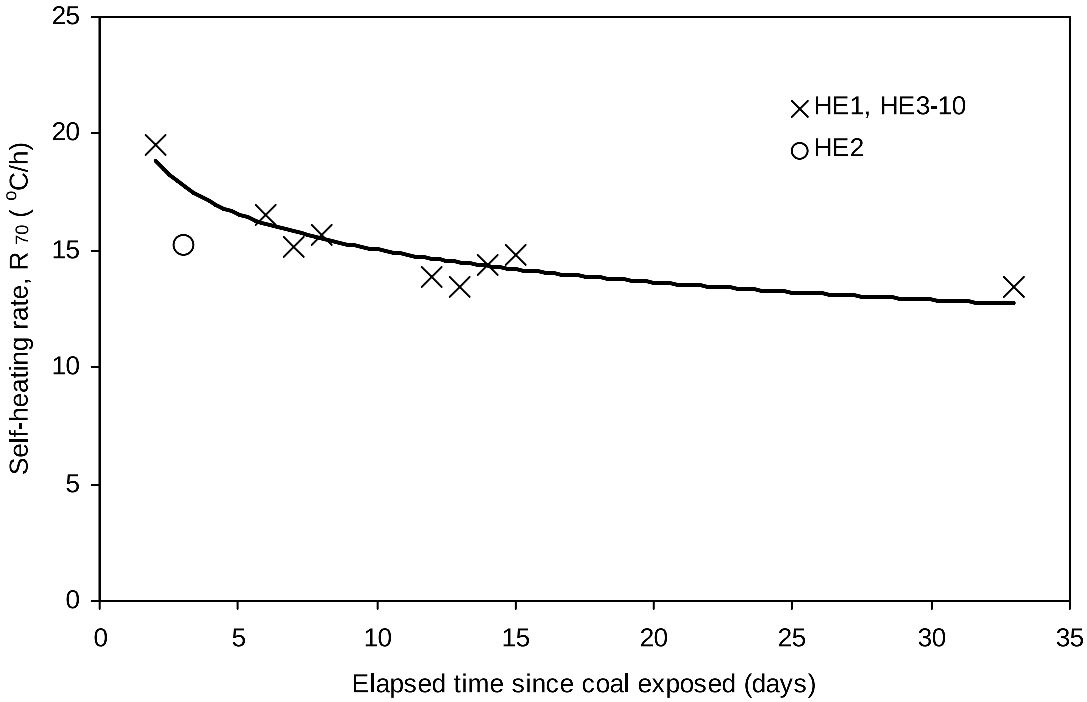

Fig. 4. Self-heating rates of repeat tests on Huntly East subbituminous coal.

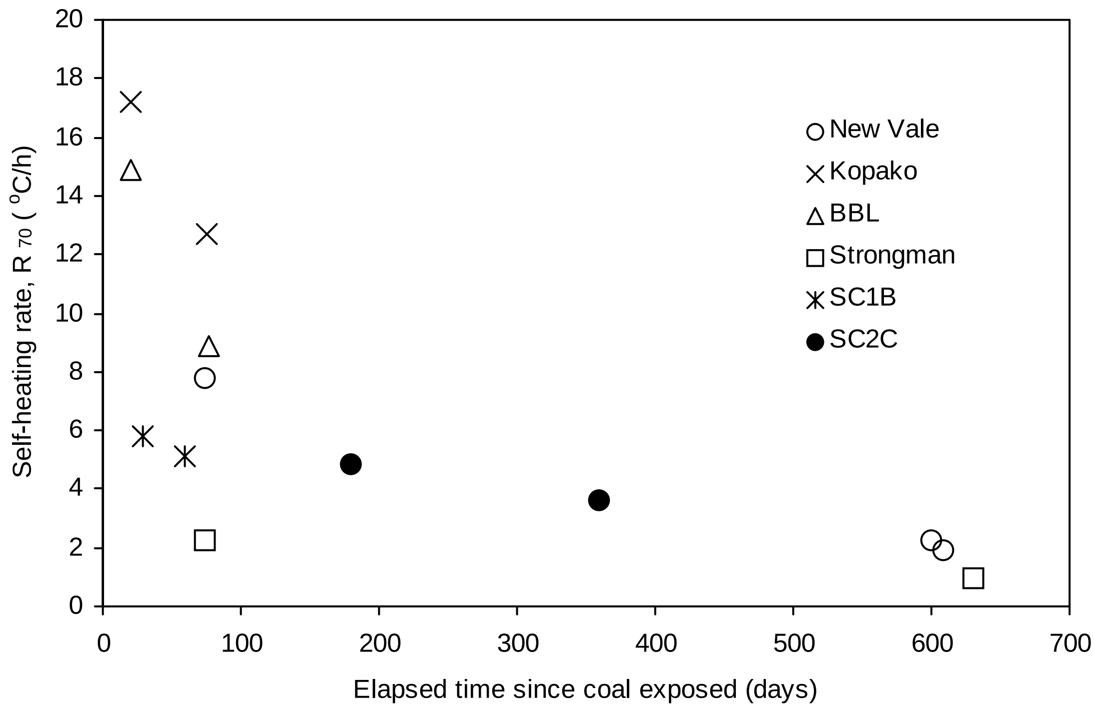

Fig. 5. Self-heating rates of repeat tests on stored New Zealand and Australian coals.