Tests to determine the spontaneous combustion propensity of coal

Johan de Korte
Overview

- Reactivity
- Ignition temperature
- Crossing point Index
- Differential Thermal Analysis (DTA)
- Wits-EHAC Index
- Adiabatic tests
- Isothermal tests
- Large-scale test
Reactivity of coal

- Majority of tests measures ‘reactivity’ of coal to oxidation
- Term ‘reactivity’ of coal used in other contexts too - for example
- Propensity of coal to react with carbon dioxide to form carbon monoxide
- During use as a reductant in pyro metallurgical processes
In terms of spontaneous combustion testing the term ‘reactivity’ means the liability and/or propensity of coal towards rapid self heating.

Any coal can oxidize and continue to self heat until either the reaction rate decreases or ignition occurs.

This suggests that other factors may play a role in the chain of events.

The reactivity of the coal is therefore but one of the factors to be considered.
Spontaneous combustion tests

- Some coals are inherently more liable to oxidation than others

- Whether or not the coal will spontaneously combust depends on this property but also on other (external) factors

- Tests for the propensity of coal to self heat should therefore be seen as part of the overall risk assessment

- Due consideration should also be given to the specific circumstances in the practical situation
The so-called ignition temperature index is the temperature at which a coal starts to glow. The lower this temperature, the more reactive the coal. This method is highly subjective.
In this test, coal in a tube is slowly heated in a furnace or by passing hot air through the tube.

A point is reached where the temperature of the coal in the tube reaches the input temperature.

The coal temperature / input temperature curves ‘cross’ at this point.

After this point, ignition can take place.

Crossing point index
• Advantage of test is that the variables can be controlled

• The disadvantage is that the variables need to be carefully selected

• The rate of heating, initial temperature, mass of coal in sample, size consist of the coal etc. requires specification
Crossing point index

• Method suggested by Feng et al.
  
  Average heating rate 110° to 220°

• Index =  
  
  Crossing point temperature °C

• Distinct relationship between rank and ignition temperature
Differential thermal analysis (DTA)

- Test involves heating a small coal sample and an inert reference material at a constant rate – typically in an oil bath.
- The instantaneous temperature difference between the samples is measured.
- The chemical and physical changes that take place in the coal sample are recorded by plotting a graph of the temperature differences between the two samples.
- Graph is known as a thermogram.
Differential thermal analysis (DTA)

- Initially the evaporation of inherent moisture in the coal causes it to remain cooler than the reference sample.
- Thereafter, the coal’s temperature increases exothermally.
- The two temperatures equalize at the ‘crossing point’.
- The coal’s temperature can continue to rise until the onset of combustion.
Differential thermal analysis (DTA)

Thermogram

Differential temperature (degrees C) vs. Temperature of inert material

1. Initial baseline
2. Transition region
3. Exothermic peak
Wits – EHAC Index

- The Wits – EHAC (Explosion Hazards Advisory Committee) Index method is based on the DTA thermogram.

- Three different slopes are identifiable from the thermogram:
  - Slope 1 = cooling of coal due to moisture evaporation
  - Slope 2 = heating up of coal due to exothermic reaction
  - Slope 3 = rapid rise in temperature
Wits – EHAC Index

- Method proposed by Gouws combines thermogram and crossing-point temperature

\[
\text{Stage 2 slope} \times 500
\]

Wits-EHAC Index = \[
\frac{\text{Stage 2 slope} \times 500}{\text{Crossing-point temperature}}
\]

- WITS-EHAC index has been successfully correlated to practical sponcom results

- Influence of external factors still need to be taken into consideration
Paced adiabatic test

- Test method developed by National Coal Board in UK
- Method consists of passing oxygen through a bed of coal held in a tube placed in a reaction chamber
- Temperature steadily increased and exit gases monitored
- Temperature at which highest reactivity occurred established
- Temperature / reactivity related to rank
SABS Adiabatic test

• Test method based on work done by Dr. van Doornum (FRI)

• Approximately 300 g of fresh, pulverized, air-dried coal placed in reaction chamber in a water bath

• Water temperature increased to 40°C whilst circulating nitrogen through the coal sample in the reaction chamber

• Once coal is at 40°C, nitrogen closed off and oxygen circulated through coal sample (water surrounding coal maintained at 40°C)

• Temperature increase of the coal due to oxidation monitored
SABS Adiabatic test (continued)

- Time for the coal to reach 70°C is measured
- At 70°C, oxygen flow is stopped
- R70 index = Temperature increase / time

Example = \( (70°C - 40°C)/ 8.9 \text{ hours} \)

= 3.37°C per hour
SABS Adiabatic test – classification of results

- R70 index < 1.3 : low reactive coal
- 1.3 < R70 index < 1.5 : medium reactive coal
- R70 index > 1.5 : highly reactive coal
Isothermal test methods

- These tests establish the rate of oxygen absorption per unit mass of coal

- Early tests in Germany indicated that oxygen adsorption is rapid at first but slows down to almost zero after 96 hours at 30°C

- Effects of particle size, temperature etc. can be incorporated and exit gas can be monitored

- Results obtained could be correlated to the rank of coal but not necessarily to spontaneous combustion propensity
Limitation of laboratory-scale tests

- External factors not considered
- Stockpile construction methods
  - Particle size of coal
  - Ambient temperatures and humidity
  - Aeration conditions and wind patterns
  - Oxidation history of the coal
  - Moisture content of the coal and rainfall
  - Handling and re-handling of coal
Large-scale testing of coal

- Large scale tests conducted by FRI in Pretoria West
- Test conducted on 12 -> 15 tons of coal
- Coal sampled for size analysis and proximate analysis
- Coal loaded into thermally isolated bunker
- Air circulated through coal – temperature and humidity of the air controlled (temperature 25 °C, humidity 45 % and air flow rate 0.5 m3 per hour)
- Temperature rise of coal monitored and recorded
Temperature history curve – coal A

Graph 1: Temperature History Curve - coal A
Temperature history curve – coal B
Liability Index

• Factor ‘M’ determined from data

\[ M = \frac{AW_0 t_m}{(AV_m + \ln (W_0/E V_m))} \] ............... (1)

where

\[ M \] = the liability index
\[ A \] = a constant equal to 0.03 (°C⁻¹)
\[ W_0 \] = the initial rate of temperature rise (°C/day)
\[ t_m \] = the time required for the maximum coal temperature to be reached (days)
\[ V_m \] = the difference between the maximum and the initial coal temperatures (°C)
\[ E \] = a constant equal to 1/60 (day⁻¹)
\[ V_0 \] = the initial coal temperature (°C)
Typical reactivity data

<table>
<thead>
<tr>
<th>$W_o$</th>
<th>$V_m$</th>
<th>$t_m$</th>
<th>$V_o$</th>
<th>M</th>
</tr>
</thead>
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<td>°C/day</td>
<td>°C</td>
<td>days</td>
<td>°C</td>
<td></td>
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<td>46,4</td>
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<td>30,0</td>
<td>0,746</td>
</tr>
</tbody>
</table>
Interpretation of M Factor

- A liability index below 0.6 indicates conditions under which a coal is unlikely to ignite spontaneously.
- Above a liability index of 1.2 the occurrence of spontaneous combustion becomes increasingly more likely.
- Liability indices between 0.6 and 1.2 are indicative of coals which may be stored safely only when the necessary preventative measures are taken.
Large scale bunker test - issues

- Requires a large sample (12 -> 15 tons)
- Test duration typically > 30 days
- Simulates ‘worst’ stockpiling conditions
- More representative of conditions in practice
FUEL RESEARCH INSTITUTE OF SOUTH AFRICA

Information Circular No. 14

ASSESSING A COAL'S LIABILITY TOWARDS SPONTANEOUS COMBUSTION

by

Dr. G. A. W. van Doornum

Reprinted from Power & Plant in Southern Africa, October 1970

(Further information obtainable from F.R.I., P.O. Box 217, Pretoria)
Tests for spontaneous combustion

• No laboratory test facilities available in SA at present

• Large scale test bunkers demolished

• SANS standard based on SABS adiabatic test in process of preparation