A visit to the research on Wits-Ehac index and its relationship to inherent coal properties for Witbank Coalfied

by S. Uludag*

Synopsis

Spontaneous combustion of coal has been studied by laboratory techniques using an apparatus in a small-scale laboratory testing. Coal's inherent characteristics can be measured using Differential Thermal Analysis (DTA) and Crossing Point Temperature (CPT) methods. The DTA curve obtained after testing is compared with actual inherent moisture and its effect on spontaneous combustion has been investigated. It has been found that the Wits-Ehac Index increases as the inherent moisture of the sample increases. Therefore it can be deduced that liability to spontaneous combustion increases with increased inherent moisture. In addition, volatiles have a catalytic affect on self heating immediately after the inherent moisture is reduced. This is identified as stage two in the thermogram. The inherent moisture has a cooling effect during the initial stages of testing and is visible in the DTA thermogram. In addition, while an increase in carbon content means an increase in Wits-Ehac Index value, an ash content decreases the likelihood of on spontaneous combustion.

Keywords: Spontaneous Combustion, Differential Thermal Analysis, Crossing Point Temperature, Moisture, Coal, Laboratory Testing.

Introduction

'Spontaneous combustion' of coal is interchangeably used with the terms 'self heating', 'autogenous ignition' and 'runaway heating' in the literature.

The atmospheric pollution associated with coal mining activities commonly results in combustion processes. Spontaneous combustion is one of the most prevalent and serious causes of coal fires. It is a process in which an oxidation reaction occurs without any externally applied heat from a spark. The temperature rise is attributable to the coal's heat release through chemical reaction (Querol, *et. al.*, 1998). This incomplete combustion of coal is known to generate poisonous gases which contain CO, CO_2 and SO_x.

It is characteristic of carbonaceous materials to become self-heated on exposure to air, which naturally liberates heat. The rate of heat generation may become faster than the heat loss rate. This is called endogenous heating. If coal does not end up burning, its quality changes rapidly. The coal is then considered to be weathered.

The mechanism of self-heating needs to be understood to motivate better implementation of techniques to prevent, control, detect and manage spontaneous combustion.

The prediction of the spontaneous combustion in underground coal mines has not met, largely because prediction depends on knowledge of the inherent liability of coal to self-heating, the geological conditions and mine design parameters. While the general circumstances leading to spontaneous combustion are well known and researched, the exact conditions leading to spontaneous combustion in underground coal mines depend on many factors. Spontaneous combustion may happen at the coal mine face, in old areas of a mine, in spoil dumps and in ships containing coal cargos. According to Stenzel (2002), there is evidence that previously-mined coal mines are more prone to spontaneous combustion during reworking than 'new' coal mines.

Once spontaneous combustion occurs, the control of fires can be difficult and expensive, depending on the size of the fire. If the right type of prediction system is put in place and this system is well controlled, the number of events of spontaneous combustion may be decreased considerably, if not prevented altogether. The prediction system should take into account coal's inherent properties, spatial position and the environment in which the coal occurs. Therefore, determination of the exact conditions leading to spontaneous combustion is necessary to prevent any occurrence of self-heating.

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Currently, indices are being used for the prediction of spontaneous combustion. One of these is the Wits-Ehac Index, first proposed by M J Gouws (1987). It was a product of joint research between the University of Witwatersrand (Wits) and the now defunct Environmental Hazard Advisory Committee (Ehac). It gives an indication of self-heating propensity calculated using Differential Thermal Analysis (DTA) and Crossing Point Temperature (CPT) through a classification system. If a value is between 2 and 3 it is considered low risk; if the value lies between 3 and 5 it is considered medium risk; and any value above 5 is considered high risk. The apparatus which is still in use, does not take into account mining and geology factors, so the Wits-Ehac Index cannot be used as a sole measure of the propensity. A full description of this apparatus, testing method and index calculation formula can be found in the research thesis written by M J Gouws (1987)

The self-heating of coal occurs in certain ambient conditions. Coal is known to react in an environment where oxygen exists, but because the process is very slow it cannot be detected easily. If heat loss is much quicker than the heat build-up due to oxidation, the coal starts deteriorating without creating a 'hot spot'. If the coal seam is buried deeply under a thick cover, the heat generated may be trapped, so that a self initiated hot spot develops.

Coal such as anthracite, which is hard, with little porosity and few impurities, will not self-heat as easily as low-quality coal. Many researchers such as Kuchta *et al.* (1980) and Jos J Pis *et al.* (1996) have found that brown and lower-grade bituminous coals tend to self-heat easily. Unfortunately, most of the South African coal-fields are bituminous and therefore prone to spontaneous combustion.

Self-heating temperatures between 180–270°C were observed for the coal samples studied by Pis *et al.* (1996). They noted that the lowest temperatures correspond with the lower-rank coals. Therefore low-rank coals are more liable to self heating.

Self-heating theory and earlier findings on relationships

Some general conclusions have been revealed by the researchers. These are listed as below.

1) A rise in temperature greatly accelerates the rate at which coal is able to absorb oxygen (Haldane and Meacham, 1898)
2) The relationship between the air and coal reaction can be given as $r = k^{-E}_{RT}$. The graph can be seen in figure which, in the variables are defined as:
   r: the rate of change of the measured index (the oxidation rate)
   k: a constant
   E: the activation energy of the reaction
   R: the gas constant
   T: the absolute temperature
3) The lower activation energies for lignites confirm the higher tendencies of low rank coals to spontaneously ignite (Humphreys, 1979)
4) During a period of falling barometric pressure, gases are removed from old workings, where as during a rise in barometric pressure, air is forced into the same workings (Graham and Morgan, 1926–1927)
5) When the humidity of the air falls relative to that of coal, the incidence of spontaneous combustion increases (Morris and Atkinson, 1986)
6) Heat of wetting is greater than heat of oxidation, and is the cause of ignition in some coals (Stott,1956)
7) Thomas *et al.* (1933) found that coal combustion may depend on seam thickness. Since thick seams are partially mined and coal left behind with little ventilation (and therefore less cooling effect), the back areas tends to burn spontaneously.
8) It is generally agreed that spontaneous combustion is a rank-related phenomenon. Davis and Bryne (1989) have demonstrated that as volatile matter and oxygen content increases (indicative of a decrease in rank), the rate of self-heating is also raised. Earlier, Schmidt and Elder(1940) obtained the results shown in Figure 1.
9. Oxygen functionalities in coal have been categorized as carbonyl, hydroxyl, carboxyl. High concentrations of these three groups in low-rank coals contribute to their hydrophilic nature, instability and susceptibility to oxidation and autogeneous heating (Berkowitz, 1989).
10. The ash content of some coals tested by Blazak *et al.* (2001) slows down the self-heating process and acts as heat sink.

The rank of coal is reported to be a direct contributor to self-heating of coal. Eder (Eder *et al.*, 1945 in Eroglu, 1999) has published self-heating rate results based on the American classification system of coal rank.

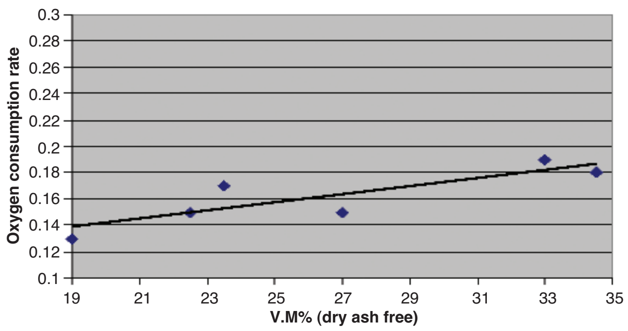

Figure 1—Rate of oxidation and rank of coal

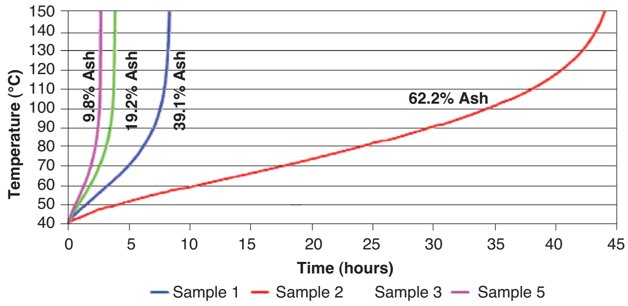

Figure 2—The effect of ash content on time to self-heating of coal (Blazak, 2001)

Spontaneous combustion in South Africa

It can be calculated that there are 15 billion tonnes of coal, sterilized in the form of pillars, that have been left behind by previous mining in South Africa. One-third of this is sufficiently close to the surface to be mined by opencast methods. It is therefore assumed that 5 billion tonnes of the coal locked in the form of pillars, which can replace coal currently produced from deeper and more methane-rich areas, can be recovered, (Anonymous, 2000).

In some of the older South African coalmines in the Witbank area, roof collapse occurred after the mines were closed, allowing air to enter the old workings and promoting spontaneous combustion in the residual coal. Some of the abandoned workings in the Witbank area have continued to burn for many years. This has resulted in unplanned surface collapse as well as ground and surface water contamination through acidification and salinization of local aquifers and streams (Ashton *et al.*, 2001, Wells *et al.*, 1996).

Middelburg Colliery which has been mined extensively over a long period has been experiencing spontaneous combustion for over 50 years. The first spontaneous combustion incident in this mine was reported as having occurred in 1947 during pillar-robbing operations (Bell *et al.*, 2001). During pillar-robbing, subsidence and therefore surface tension cracks were formed around the outer edges of collapsed areas, which started spontaneous combustion in the pillar. The mine was closed in 1947, and reopened during 1982–1983 to mine a smaller section. All areas were said to be sealed after mining operations stopped. The affected area is estimated to be 150 to 200ha and about two km away from the nearest town. Bell *et al.* (2001) explain in detail the circumstances that led to this example of spontaneous combustion, and give reasons why it cannot be stopped successfully.

Spontaneous combustion at Kleinkopje colliery, in old underground workings and on the spoil piles, has been an ongoing concern (Eroglu, 1999). Kleinkopje colliery is managing the problem by preventing the ingress of oxygen to areas of heating, and by cladding and capping cracks and openings with layers of soil. A similar situation exists at New Vaal Colliery (Stenzel, 2002), which exploits lowest-quality coal. This is an interesting mine in terms of its geology and coal properties.

Overall, experience shows that each spontaneous combustion problem is unique to each mine and that contributing factors can vary. At New Vaal the overburden is mostly sand, which is highly porous. During the period that the mine was closed, the old workings were flooded with water. After reopening, all the water in the old underground workings of the mine had to be pumped out so that the remaining coal could be extracted by means of surface mining methods. Since water prevents oxygen from reaching the coal pillars, it prevented self-heating of the pillar. However, as soon as the water had been pumped out, the pillars started to burn because oxygen had become available. The mine management has employed various mining techniques to alleviate the problem. These measures include:

➤ Pre-splitting has had to be abandoned to avoid oxygen ingress to old workings
➤ The location of old pillars has to be carefully done using advanced techniques
➤ Buffer blasting is employed and has been refined over a three-year period
➤ Cladding is used to cover cracks to prevent a chimney effect and to prevent oxygen entering old workings. Since sand is readily available at the mine, it is used for cladding (Eroglu *et al.*,1999).

New Vaal Colliery has coal with a very high Wits-Ehac liability index (6.18) for the middle seam. (Eroglu *et al.*, 1999)

Small scale laboratory testing methods measuring propensity to self-heating

Initial temperature determination

When subjected to a current of air/oxygen in a thermostat, coal shows signs of heating. This creates a curve which reaches a maximum and flattens out. The temperature of the medium used to heat coal should be kept constant for this experiment. Then the coal is tested again with a different temperature setting. In this way the coal is tested until the minimum temperature is reached at which the temperature of the coal does not rise.

Since the testing to find only one value per sample takes about a week, this method is no longer used.

Table I

Rates of oxidation and heating of coals (in Eroglu, 1999)

Rank of coal (American classification)	No. of samples	Carbon (AFD)	Relative oxidation rate at 100°C	Relative self heating rate at 100°C
Bituminous—low volatile	3	90 to 91	1.0	0.5
Bituminous—medium volatile	6	88 to 90	1.6	-
Bituminous—high volatile A	20	82 to 87	2.0	1.7
Bituminous—high volatile B	4	80 to 83	5.8	6.1
Bituminous—high volatile C	6	79 to 80	12	8.5
Sub-bituminous—A	2	77 to 79	20	14
Sub-bituminous—B	2	75	47	28
Sub-bituminous—C	2	70 to 74	68	12
Lignite	1	73	240	51

A visit to the research on Wits-Ehac index and its relationship to inherent coal properties

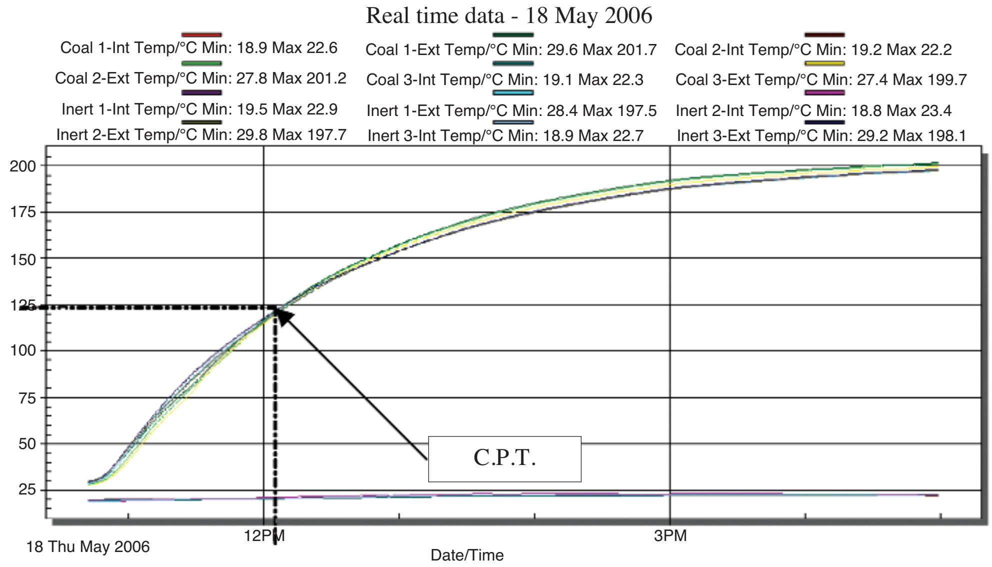

Figure 3—Temperature curves of coal and inert material showing crossing point temperature

Crossing point temperature

In this method coal is heated to a certain temperature, which is kept constant. The temperature increase of coal is compared with the temperature increase of an inert material. The point at which the coal temperature exceeds that of inert material is called Crossing Point Temperature (CPT). Naturally, the higher the CPT the less prone the coal is to self-heating. This method has become popular worldwide, and has also been used in South Africa.

Differential thermal analysis (DTA) has been used as a method to study the self-heating behaviour of fresh and oxidized coals. Pis *et al*. (1996) performed oxidation in air tests at 200°C for a period of up to 72 hours, using six types of coal from Spain, ranging from a High A bituminous coal to a semi-anthracite. They found out the following:

- ➤ As the rank of the coal increases, both the self-heating and the end of combustion temperatures increase
- ➤ The total heat loss (area under the DTA curve) increases with the rank of the coal
- ➤ An increase in the self-heating temperature, a decrease in the temperature of the end of combustion and a decrease in total heat flow were observed as a consequence of coal oxidation.

Differential thermal analysis

Going a step further than the methods described above, Banerjee, (2000) realized during testing of coal for CPT that not only the crossing point but the slope of curves obtained in a DTA is indicative of propensity to spontaneous combustion. During CPT testing two curves are obtained, one for inert and one for coal. A typical real-time chart drawn during testing of coal is shown in Figure 3, which shows the crossing-point temperature of the coal sample is 124°C, as determined from the dataset which is obtained in ASCII format. Typically, coals may have CPT values from around 100 to 150°C averaging at 130°C for most of the bituminous South African coals. If the temperature difference between the

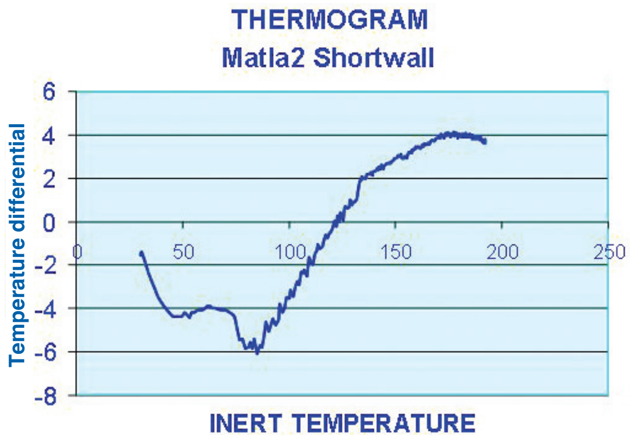

Figure 4—A typical D.T.A. thermogram obtained for a coal sample

coal and the inert temperature curves is plotted, a different type of curve is obtained. This has more characteristics than the raw curve obtained in Figure 3. The new curve is called a DTA thermogram (see Figure 4).

Banerjee reported that DTA is a good tool to measure qualitative and quantitative heat changes of any physico-chemical transitions, but, has limited use in indicating the repeatability of results (Banerjee, 2000).

Adiabatic calorimeter

Since spontaneous combustion is considered to be an adiabatic process (Banerjee, 2000), researchers have tried to simulate mining conditions using adiabatic calorimeters. Adiabatic testing is very difficult to achieve (Smith and Glasser, 2005a). The instruments used for this purpose are complex and very expensive. They are, however, more effective than these used for DTA analysis.

Other, less popular means of analysis than the ones described above include the Russian method of ignition temperature testing, the Olpinski Index (1975), the SHT index (Smith *et al*, 1987, USA), the Peroxy Complex Analysis

(Yohe et.al., 1941), rate of aerial oxidation studies (Banerjee *et al*, 1970), oxygen absorption methods such as Russian U Index (Karmakar *et al*, 1989) and Glasser Index. These methods measure inherent characteristics of coal and are similar to DTA analysis. No real benefit can be gained by applying these laboratory techniques to measurement of the propensity to spontaneous combustion. In the past an attempt was made by this author to compare the Glasser and Wits-Ehac Index tests (Uludag, 2007), but, as can be seen in Figure 5, the results of both tests are similar although on a different scale.

Recent research on Wits-EHAC Index testing

Each seam being mined in South Africa has different characteristics. In the past a map of the spontaneous combustion risk in South African coal mines was created using GIS (Geographic Information Systems) software with the data available at the time (Uludag, 2001). This database was formed as part of a Coaltech study. Several samples were tested for their Wits-Ehac Index. The results were used as part of the database for the risk map, combined with the findings of previous researchers. The results of these tests and the tests done by previous researchers are combined in one database to be used in risk mapping (Uludag, 2001).

The Wits-Ehac Index is now the commonly-used method of measuring propensity of self-heating in South African coal mines, because the number of qualified people capable of doing these kinds of laboratory test is limited. Over the years since the inception of the Index various tests have been performed by this author and other researchers at the Wits School of Mining Engineering. Most of the recent tests on coal samples have been carried out at the request of mines in Witbank Coalfield.

The testing procedure is as follows: For each coal sample a thermogram is obtained using the temperature records obtained during the testing. A typical thermogram from such testing has certain characteristics, which are shown in Figure 7.

- *Area A*—Starting with the onset of test from 30 °C degrees to the lowest point in the differential thermogram
- *Area B*—From the lowest point in the thermogram to the crossing point temperature, that is the temperature at which coal temperature exceeds that of the inert material
- *Stage I Curve*—This part of the curve shows a decrease in temperature of coal relative to the temperature of inert material. and defines the area A boundary

Figure 5—Wits Ehac and Glasser test comparison (Uludag, 2007)

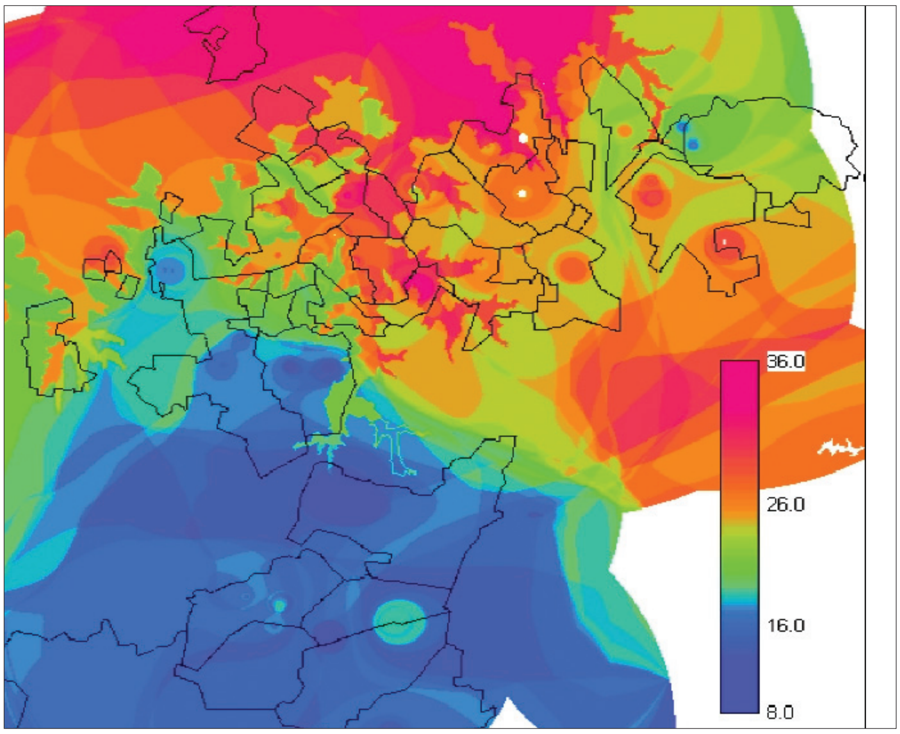

Figure 6—Risk map for Witbank Coalfield (Uludag, 2001)

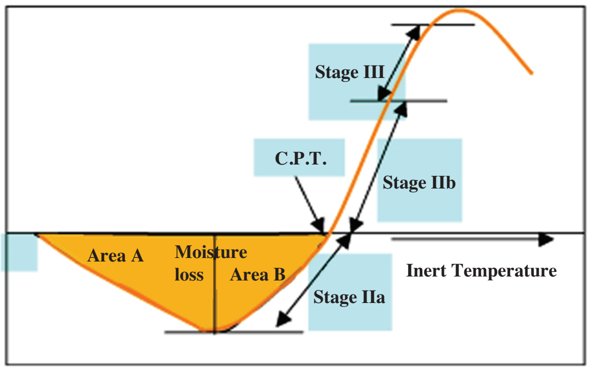

Figure 7—DTA thermogram showing important regions used in calculations

- *Stage IIa Curve*—The coal temperature increase accelerates and catches up with inert temperature. This part defines the Area B boundary and ends at zero differential line
- *Stage IIb Curve*—The coal temperature continues to increase until it reaches ignition point
- *Stage III Curve*—Coal starts burning until it reduces to sustain burning; therefore there is a decrease in slope angle towards the end of the curve.

The results of the tests and characteristics of the samples are given in Table II, which shows the properties and Wits-Ehac Index results of the coal samples tested over 2005–2006 by this author. These samples are taken from various localities and seams within Witbank Coalfield and are mostly bituminous.

The Wits-Ehac Index uses the slope of the Stage IIa, IIb and CPT of a thermogram, but it does not use the part where the coal sample loses its inherent moisture and probably volatiles as well (Area A). There should be a reasonable use for each part of the thermogram in an index calculation measuring the propensity to self-heat, therefore inherent moisture content should play an important part in measuring propensity.

M.A. Smith and D. Glasser (2005b) showed that the two factors with the greatest statistical significance in determining the propensity for self-heating were the volatile content and the inherent moisture. These suggest that the inherent moisture is related to the total surface area of the sample, and that the volatile matter component represents the reactive component. Measurement of these two parameters gives a reasonable prediction of the rate of reaction with oxygen at ambient temperature of a sub-bituminous coals, and identifies 'at risk' samples.

An attempt has been made to measure how inherent moisture content contributes to the risk of spontaneous combustion. If there is a possible link between the moisture content and Wits-Ehac Index values, it can be calculated using the thermograms obtained from the DTA test data. The hypothesis is that during the testing of coal, the inherent moisture of coal causes a decrease in temperature of the coal sample. Therefore it is important to determine whether the area below the zero line is really linked to the moisture content of coal. In order to prove this the area calculations and actual moisture content have to be compared. Table III shows the area calculations for each sample, using the real-time data obtained during testing.

Three different graphs are then constructed, using the Area A, Area B and total area under zero differential line against the inherent moisture content.

Table II

Wits-Ehac and coal analysis results for various collieries

Section	WITS-EHAC	CPT ASH	CV Vols	% Moisture	% DAF	%
Sample 1	4.5	129.2	26.29	17.5	31.34	2.4
Sample 2	3.75	137.8	20.7	30.6	33.09	2
Sample 3	4.4	131.4	23.51	25	30.71	2.3
Sample 4	4.5	129.2	21.65	32	33.08	2.1
Sample 5	4.7	129.4	24.32	21.9	31.89	1.9
Sample 6	4.5	132.9	26.01	17.7	30.71	2.2
Sample 7	4.7	125.8	27.58	15.7	37.47	2.1
Sample 8	4.2	136.3	23.64	25.7	40.11	2.5
Sample 9	4.2	125.6	21.73	30.9	31.39	2.2
Sample 10	4.1	131.6	24.34	19.6	32.27	3.6
Sample 11	4.5	124.2	20.47	28.6	34.83	4.8
Sample 12	4.5	127.4	19.41	36.2	31.59	2.7
Sample 13	3.9	131.8	11.92	54.6	35.5	2.3
Sample 14	4.4	128.7	16.78	41	33.51	2.9
Sample 15	5	123.9	32.28	23.2	40.99	3.52
Sample 16	4.8	123	20.87	28.84	37.11	3.66
Sample 17	4.7	130.8	23.14	22.43	33.62	4.17
Sample 18	5.8	115.6	26.44	15	35.65	3.1
Sample 19	5.2	119.7	26.67	15.3	38.49	2.6
Sample 20	5.1	124	23.52	22.3	29.64	2.8
Sample 21	4.95	118	13.91	19.37	21.74	1.77
Sample 22	5.1	124.4	23.28	21.15	31.89	3.65

Table III

Area under zero differential calculated for each sample

Sample Location	Total Area	Area A	Area B	% Moisture
Sample 1	314.7	172.5	142.2	2.4
Sample 2	279.4	103.2	176.2	2
Sample 3	372.8	197.3	175.4	2.3
Sample 4	321.4	216.6	104.8	2.1
Sample 5	374.2	188.3	185.9	1.9
Sample 6	383.2	207.8	175.3	2.2
Sample 7	302.2	157.6	144.6	2.1
Sample 8	373.2	233	140.2	2.5
Sample 9	100.2	93.3	6.9	2.2
Sample 10	304.2	151.5	152.7	3.6
Sample 11	329	221.8	107.2	4.8
Sample 12	389.2	212.4	176.2	2.7
Sample 13	206.3	128.5	77.9	2.3
Sample 14	394.6	262.1	132.5	2.9
Sample 15	478.4	268.4	210	3.52
Sample 16	462.9	323.5	139.3	3.66
Sample 17	495.5	254.4	241.1	4.17
Sample 18	491.9	217.9	274	3.1
Sample 19	280.5	135.9	144.7	2.6
Sample 20	346.3	161.9	184.4	2.8
Sample 21	283.27	144.4	138.9	1.77
Sample 22	585.9	332.5	253.4	3.65

The trend in Figure 8 shows a relationship between the Area A and the inherent moisture. It seems there is some degree of correlation within an upper and lower boundary. Therefore it is believed that this area represents the moisture loss during testing of the coal sample, which therefore contributes to temperature decrease in coal.

The next step would be to compare the Area B with inherent moisture content, which is shown in Figure 9. Although there seems to be some correlation for Area B, it is very slight. Therefore, total area versus moisture would be a mixture result of the Area A and B graphs, since some correlation is visible (Figure 10). It is possible that the available moisture is mostly consumed during the initial stages of testing, causing the coal to lose temperature initially. In Area B coal started oxidizing, causing an increase in temperature possibly due to the combined effect of CV and volatile (as can be seen in Figure 11). This would explain the possible relationship between the moisture content and Area B.

As the heat is added the coal starts heating and catches up with the temperature of the inert material until it reaches (CPT).

In order to understand how the inherent moisture content of coal affects the Wits-Ehac and CPT of coal samples two graphs are constructed that compare Wits-Ehac and CPT results with the measured inherent moisture content of coal samples (Figure 12 and Figure 13). The trend in Figure 12 suggests that as the moisture content increases the CPT decreases; whereas in Figure 13 the trend shows an increase in both the Wits-Ehac Index and the moisture content. This is to be expected, since lower CPT corresponds to higher Wits-Ehac Index values.

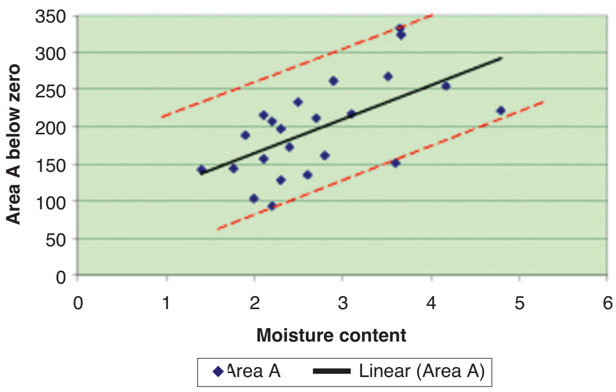

Figure 8—Area A versus moisture content

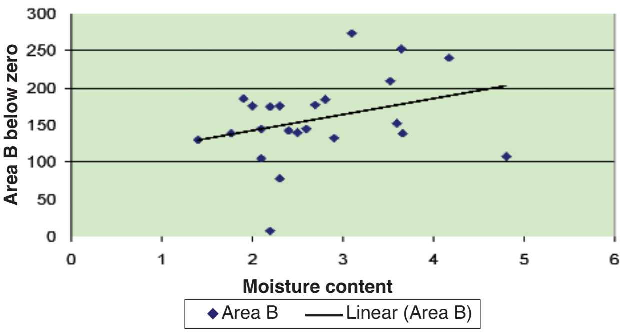

Figure 9—Area B versus moisture content

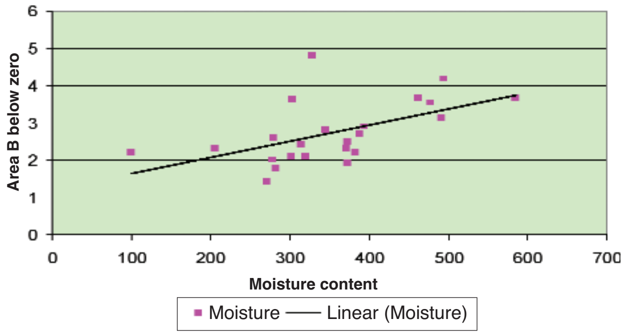

Figure 10—The total area under zero differential is compared with inherent moisture content

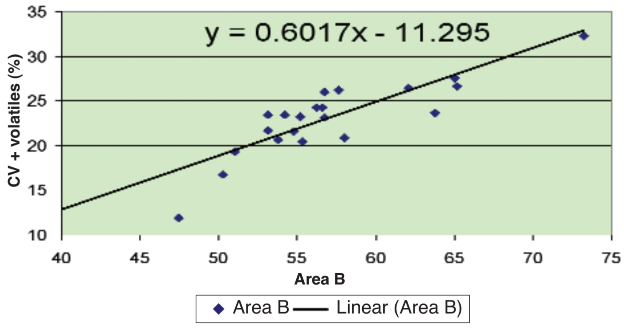

Figure 11—Combined effect of CV and Volatiles in area B calculations

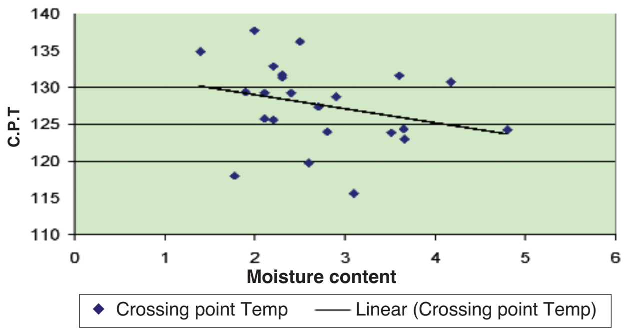

Figure 12—Inherent moisture content versus Crossing Point Temperature

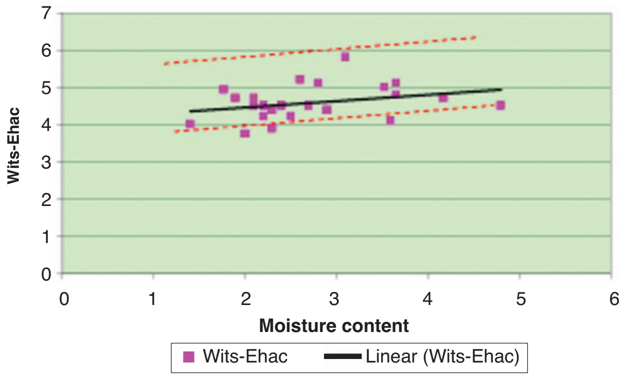

Figure 13—Inherent moisture content versus Wits-Ehac Index

The moisture within the coal has delayed the time at which the coal temperature crosses the inert temperature; the temperature at which coal crosses over is lower when the moisture content is higher. The evidence of this can be seen in Figure 12.

There is some correlation in Figure 13 to suggest that inherent moisture has some effect on the results of the Wits-Ehac index. Figure 13 shows that while moisture is increasing from a value of 1 to 5, the Wits-Ehac value increased from 4 to 5. It must be emphasized that Wits-Ehac uses curves IIa and IIb in its calculation. Curve I is the stage at which most of the moisture has been lost, which cause a decline in the slope of the curve. Therefore the relationship between Wits-Ehac and moisture in Figure 13 is a true reflection of the decreased percentage of moisture content in the second stage of the test. The implication for the interpretation of a single number such as Wits-Ehac could be considerable,since inherent moisture may have a delaying effect but does not necessarily help to prevent spontaneous combustion.

Calorific value has a direct relationship with the Wits-Ehac Index, as shown in Figure 14, where as the calorific Wits-Ehac values both increase. Initial research by Gouws (1987) classified the propensity to spontaneous combustion for Wits-Ehac in a range of values of 2 to 7 which covers a low to high propensity to spontaneous combustion. This research has to be revisited to establish risk values for different ranks of coal such as anthracite and lignite.

Since ash content is believed to have an inhibiting effect on spontaneous combustion (Blazak, 2001), it is also a factor in this study. Figure 15 shows a relationship in which Ash content is visibly decreasing in correspondence with the Wits-Ehac Index, which is to be expected since it should follow an opposite trend to Wits-Ehac vs calorific value.

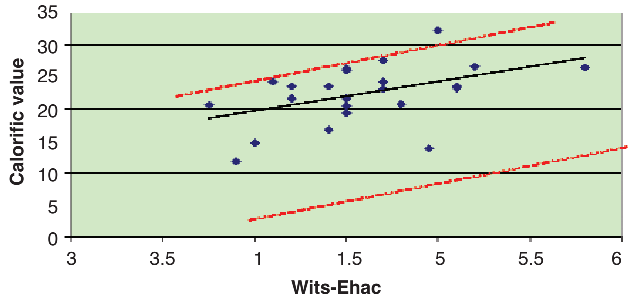

Figure 14—The effect of calorific value on the Wits-Ehac index

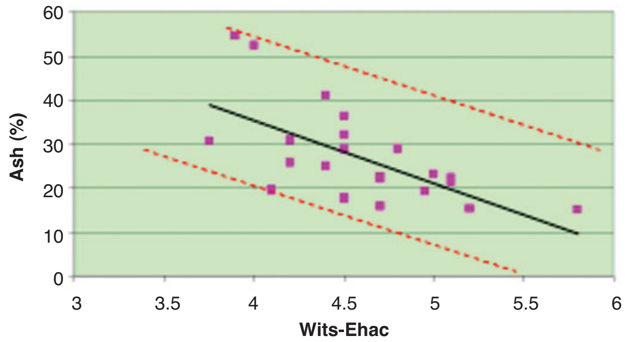

Figure 15—The effect of Ash % on the Wits-Ehac index

Conclusions

Each sample tested for the analysis has different characteristics in terms of calorific value, volatiles, moisture content, and porosity. It is impossible to isolate a single property of coal and analyze it individually. DTA analysis results are a combined effect of the inherent characteristics of coal.

During the heating process a certain sequence of events occurs which can be analyzed using various regions of DTA thermogram. The first stage of the heating process involves oxygen absorption and loss of inherent moisture. This is evident from the decline of temperature and the slope of the curve. The DTA curve rapidly accelerates during the second stage due to volatiles. Since most of the moisture is lost during the first stage, no temperature decrease is observed in the second stage. The volatiles and the constant increase in temperature of coal have a catalytic effect on the self-heating process, which occurs at temperatures around 70–90°C. This minimum point is believed to be one of the most important aspect of the DTA curve. Therefore a more detailed analysis of DTA should be used when describing the behaviour of coal in a standard testing environment. The Wits-Ehac index should be modified to include the minimum point of acceleration and inherent moisture content as factors in self-heating.

However, it is possible to draw some general conclusions based on the trends identified in the test results:

- The DTA curve represents the effect of moisture on the self-heating process
- The inherent moisture content of a sample should be integrated into the Index calculations
- The inherent moisture content has a cooling effect during the initial stages of heating
- The inherent moisture does not slow down the self-heating of coal but has a catalytic effect on it
- The inherent moisture of coal raises the Wits-Ehac Index, therefore we can conclude that inherent moisture partly increases the risk of spontaneous combustion
- The amount of volatiles and carbon in a given coal sample has a direct effect on the self-heating process during the second stage, after the coal loses its inherent moisture.

Based on the above, the following should be included in a future research study.

- More samples are needed for a comparative study which should include all ranks of coal
- The testing method used in Wits-Ehac Index calculation should be standardized and include modern equipment with a heating rate control
- A new index that should make use of all the important regions of the DTA curve as should be developed.

DTA results obtained during testing conform with the findings of other researchers in terms of calorific value, ash content and inherent moisture.

A big portion of a DTA curve is related to the inherent moisture content, which could increase the confidence level in Wits-Ehac Index testing by about 20%, since about one-fifth of testing time involves tracking the evaporation of moisture. This stage is believed to be the most significant in bringing about the self-heating of coal.

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