SUSCEPTIBILITY TO SPONTANEOUS COMBUSTION OF SOME INDONESIAN COALS

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ABSTRACT

Eight Indonesian coal samples of different moisture contents obtained from the various coalfields were used to study spontaneous combustion characteristics by differential thermal analysis (DTA) and crossing point temperature (CPT). Results indicate that there is no direct correlation between the spontaneous combustion test data and the individual properties of the coal samples by both DTA and CPT test methods; in this study, a preliminary conclusion can be drawn on the coal moisture content effect on spontaneous combustion. Higher moisture content coals are more susceptible to spontaneous combustion than that of lower moisture content coals. It also can be stated that the susceptibility of coal to spontaneous combustion is basically a complex. Clearly more tests are required to investigate the effect of coal properties in more detail from other Indonesian coals that have various types and ranks.

Keywords: Spontaneous combustion, moisture content, differential thermal analysis, crossing point temperature

INTRODUCTION

The problem of spontaneous combustion is as old as that of coal mining itself and there has been a considerable effort to study and understand the mechanisms and factors responsible for spontaneous combustion. Almost all types of coal may ignite spontaneously in suitable environmental conditions (Kaymakçi and Didari, 2002). This leads to serious safety problems as well as economic losses for its coal mines and storage areas. Therefore, understanding spontaneous combustion to prevent such occurrences is very important.

It has been observed that the primary cause of spontaneous combustion is the exothermic oxidation of coal at low temperatures (ambient conditions). The reaction between coal and oxygen at low temperature is influenced by a number of factors such as temperature, particle size, surface area, coal pore structure, moisture content, coal rank and the composition of ambient air (Nugroho, et al., 2000) The process is an exothermic reaction in which the heat generated is dissipated by conduction to the surrounding environment, convection to the ventilation flow, radiation, and in some cases by evaporation of moisture from the coal. The nature of the interaction between coal and oxygen at very low temperatures is fully physical (adsorption) and change into a chemisorption form starting from an ambient temperature (Kaymakçi and Didari, 2002). The rate of oxygen consumption is extremely high during the first few days (particularly the first few hours) following the exposure of a fresh coal surface to the atmosphere. It then decreases very slowly without causing problems unless the generated heat is allowed to accumulate in the environment. Under certain conditions, the accumulation of heat cannot be prevented, and with sufficient oxygen (air supply), the process may reach higher stages.

The loose coal-oxygen-water complex formed during the initial stage (peroxy complexes) decomposes above 70-85ºC and yields CO, CO_2 and H_2O molecules. The rate of chemical reactions and exothermicity change with the rise of temperature and radical changes take place, starting at about 100ºC, mainly due to loss of moisture (Blazek, 2001 and Watanabe and Zhang, 2001). This process continues with the rise in temperature, yielding more stable coal-oxygen complexes until the critical temperature is reached, producing

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more heat. If the heat generated from the process is greater than that lost from it, spontaneous combustion is likely to occur.

The spontaneous combustion susceptibility differs from the nature of coal (Fei, et al., 2009) Vitrinite is always the maceral group most susceptible to spontaneous combustion. Lithotype of vitrain and bright coals plays a decisive part in the outbreaks of fire, whereas the other constituents absorb oxygen much less readily. In initial oxidation, the bright coal oxidises more rapidly than the dull coal. However, at a later stage, the oxidation of the bright coal is retarded (Santoso and Daulay, 2005) Most Indonesian coals, particularly from Sumatera and Kalimantan, are dominated by vitrinite maceral and bright coals (Santoso and Daulay, 2007). The lower rank coals that have high moisture content, such as lignite and subbituminous are usually more susceptible to spontaneous combustion than the higher ones such as bituminous (Mahidin et al., 2002). However, rank dependency of susceptibility is not definitive. While some coal properties such as pyrite and ash contents have been found to influence spontaneous characteristics of some coals; they do not affect those of some others (Beamish and Arisoy, 2008). However, most researchers have concluded that the moisture in both the coal and air is one of the important factors affecting the spontaneous combustion of coals. It has been found that coal reacts with oxygen more rapidly when wet than when dry at room temperature (Kadioğlu and Varamaz, 2003). Investigations into the influence of moisture on the spontaneous heating of coal have been carried out, both in the field and in the laboratory for many years (Blazek, 2001, Fei, et al., 2009, Kŭcŭk, et al., 2003 and Wang, et al., 2003).

Over the years, it has been observed that in most cases the mining and storage practices become the overriding factor (Kŭcŭk, et al., 2003). Under favourable heat accumulation conditions, spontaneous combustion can occur with any type of coal. There have been numerous instances of the spontaneous combustion occurring to coals of low moisture, low pyrite and volatile matter that are usually considered to be relatively safe. Mining and storage methods that significantly influence onset of spontaneous combustion have been discussed elsewhere (Nugroho, et al., 2000, Kaymakçi and Didari, 2002, Kŭcŭk, et al., 2003, Ejlali, et al., 2009 and Wang, et al., 2009). This paper presents the effects of coal properties such as moisture, volatile matter, carbon and oxygen contents of some Indonesian coal on the spontaneous combustion susceptibility.

METHODOLOGY

Coals

To study the susceptibility of coal to spontaneous combustion, eight Indonesian coal samples of different moisture contents collected from the various mines were examined by differential thermal analysis (DTA) and crossing point temperature (CPT). To maintain confidentially, the coal samples are identified as sample marks without indicating the company of the coal producers. Samples were prepared and pulverized individually as required for the tests, while the rest were kept in their sealed containers at room temperature. The proximate and ultimate analyses including calorific value of the coal samples are given in Table 1.

Spontaneous Combustion Tests

The determination of the liability of coal to spontaneous combustion is important to deal with the problem before, during and after mining. There is no simple method of estimating the liability for coal to spontaneously combust. More recent researches are based on either laboratory tests or more recently, theoretical mathematical modelling simulates physical and chemical reactions that may occur when coal particles are exposed to oxygen and moisture (Mahidin, et al., 2002 and Kŭcŭk, et al., 2003). Surprisingly, a number of studies that were performed in the 1990's indicated that factors involved with the spontaneous combustion of coal are still not well understood (Blazek, 2001). The main reason for the difficulties in understanding the mechanism of spontaneous combustion is the presence of many internal and external factors. In this study, the DTA and CPT methods have been applied to present conditions to evaluate the spontaneous combustion characteristics.

Differential thermal analysis (DTA)

Thermal analysis techniques have widely been used in the study of the coal combustion characteristics. Since only a small amount of sample is required in the test, this is most useful when it is impractical to test the large scale of coal in

Table 1. Analysis results of the coal samples

Coal sample mark	Moist. Wt % (adb)	Ash Wt % (db)	VM Wt % (db)	FC Wt % (db)	C Wt % (daf)	H Wt % (daf)	N Wt % (daf)	S Wt % (daf)	O Wt % (daf)	Calorfic value cal/g (adb)
BNG	0.30	5.60	47.00	47.40	74.34	5.59	1.67	0.43	17.96	6,279
KP	6.89	5.13	43.30	51.57	79.94	7.01	1.32	0.49	11.24	6,868
OMB	5.84	4.87	40.40	54.73	79.16	6.24	1.44	0.80	12.36	7,199
BRB	4.81	3.28	49.05	47.67	71.71	6.25	1.12	0.52	20.40	6,274
TB	15.35	5.22	48.06	46.72	72.46	5.48	0.97	0.18	20.92	5,431
BR	16.13	7.58	44.35	48.07	69.68	6.46	1.84	0.59	21.43	5,324
GT	17.41	4.82	52.22	42.96	60.09	3.27	0.77	0.41	35.46	4,697
BK	17.09	4.39	45.78	48.03	70.99	6.28	0.88	0.41	21.44	5,441

Note:
adb : air dried basis
db : dry basis
daf : dry ash free

existing installations or stockpile. This technique involves heating of a small specimen at a constant rate and continuously recording the temperature difference between it and an identically heated inert reference material as a function of temperature prevailing in the inert medium. DTA records continuously the rate of mass loss in air as a function of temperature by using a Shimadzu DTG-60 apparatus. As in past studies (Umar et al., 2005), the sample with weight of ca. 5 mg and particle size of less than 75 μm (passed through 200 mesh screens) was placed in a platinum cell at an airflow rate of 25 ml/min and heating rate of 10° C/min. The maximum experimental temperature was 350° C.

The resultant thermogram (temperature against heat released) depicts the physical and chemical changes of the material at a particular temperature and is a characteristic of the material used. There are three stages of transition in the DTA thermogram in sample heated up to 300º C. During the initial stage of heating at temperature of 60° C to 120° C, it is the endothermic reaction that predominates mainly from the release of moisture from coal. This is followed by exothermic reaction at temperature of 120° C to 200° C that takes into account a number of concurrent reactions and ultimately in the third phase leads to a reaction of high exothermicity at temperature of 200° C to 300° C. The rate of rise in heat evolution in phase two was observed to be much lower for coals with lower susceptibility to spontaneous heating, thereby delaying the initiation of phase three. Categorization based on DTA method is possible by taking into consideration only phase two of DTA thermogram.

Crossing point temperature (CPT)

This method envisages heating coal sample in an oxidizing atmosphere at a definitely programmed rate of temperature rise. Due to exothermicity of oxidation reaction, at some points the coal bed temperature exceeds the oven temperature that is commonly termed as CPT. Coals highly susceptible to spontaneous heating would have lower values, and coals with lower susceptibility will have comparatively higher values. The value of CPT for a coal sample depends to a certain extent on the design of the apparatus and also on the experimental parameters (Qi, et al., 2011). To alleviate the erroneous conclusions, the concept of liability index was introduced based on the ratio of the rate of heating of coal bed at crossing point and the CPT (Sensogut and Cinar, 2006). This index is considered to be more appropriate for classifying coals with respect to their susceptibility to spontaneous combustion.

The experimental system consists of a programmable furnace, two stainless steel containers (37 mm internal diameter and 65 mm long) furnished with three sets of thermocouples for monitoring the coal beds and oven temperatures, an air-nitrogen flow system and a multichannel chart recorder for continuous monitoring of the thermocouple output. The schematic diagram of the spontaneous combustion test can be seen in Figure 1.

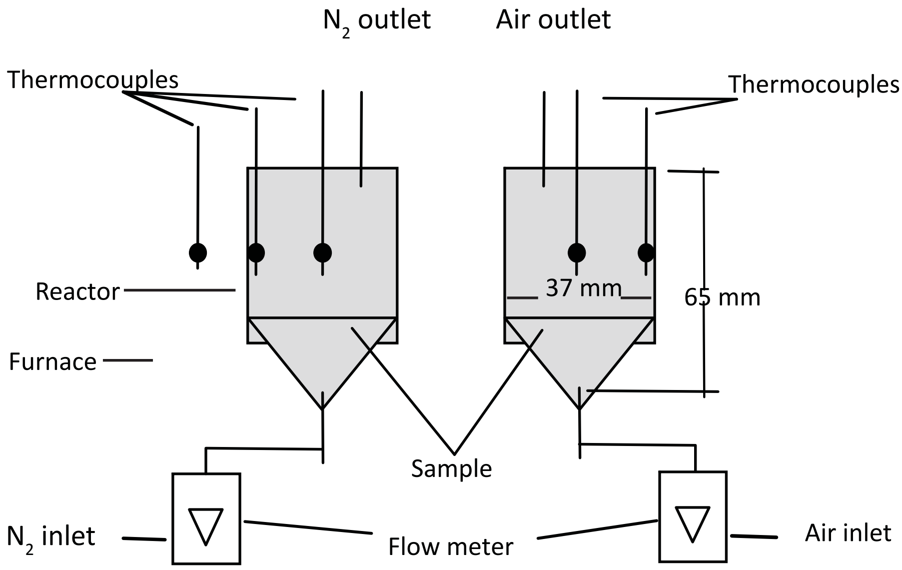


Figure 1. Schematic diagram of CPT

For each sample in each run, 40 g of the -60+200 mesh fraction of coal was weighed into the two reactors and placed in the programmable furnace. Air at a flow rate of 80 cm3/min was passed through a flow meter into one of the reactors, while nitrogen at the same flow rate was passed into the other reactor. The furnace was set at a heating rate of 0.5° C/min. The temperature rise in the furnace and the beds of coal in each reactor was continuously recorded. Nitrogen gas passed through a coal bed was used as control.

All of the data obtained were plotted on a thermogram. The temperature at which the air curve crossed the oven curve was referred to as the CPT. An index of liability to spontaneous combustion was computed from the CPT and the rate of coal temperature rise (Q) by:

$$Q = (T2-T1)/20$$

T1 was the coal bed temperature 10 minutes before the crossing point, and T2 was the coal temperature 10 minutes after the crossing point. The liability index (Li) is calculated by this equation:

$$Li = Q/CPT * 1000$$

This index was considered to be the most appropriate for classifying coals as to their susceptibility to spontaneous combustion. According to Kaymakci and Didari, 2006, Feng et al, 1973 proposed the classification to show the propensity of spontaneous combustion of coal according to the results obtained from the equation above as can be seen in Table 2.

Table 2. Classification of coal to the propensity of spontaneous combustion

Liability Index (Li)	Classification
0 – 5	Low
5 – 10	Medium
>10	High

RESULTS AND DISCUSSION

Many researchers are stated that the spontaneous combustion of coal is basically a complex and large scale phenomenon (Wang, et al., 2010). The spontaneous combustion is undoubtedly affected by the physical structure and chemical composition of coal. Although some of the components of coal such as moisture content were thought to be greatly responsible for the ignition and development of a heating, it is difficult to identify exactly what starts the oxidation process and why a particular coal is more susceptible to spontaneous combustion than another.

The results of spontaneous combustion tests of the eight Indonesian coals by DTA methods are shown in Figure 2 (2.1 and 2.2). Generally, the rate of temperature rise in the coal bed is the simplest and most common criterion to evaluate the susceptibility of coal to spontaneous combustion. The rate of heat generation in the coal is finely balanced with the rate of heat loss. The higher the rate of this temperature increases with air, the higher the rate of heat releases and the higher the susceptibility of the coal to spontaneous combustion occur. Figure 2 illustrates heat differentiation that was released during the test. There are two peaks in the DTA thermograms at three stages of temperature transition. The first peaks appear at around 60° C (endothermic) due to the vaporization of moisture at the first stage and second peaks at the third stage appear at around 330° C (exothermic) due to the combustion of volatile matter.

rate of coals during stage two can be evaluated. The moisture content of the coal samples were plotted against heating rate (Figure 3). The lower the heating rate, the lower the susceptibility of the coal to spontaneous combustion (Beamish and Arisoy, 2008). It seems that coal with high moisture content is more susceptible to spontaneous combustion than that of coal with low moisture content. However, in some cases, the heating rate shows anomaly as evident from Figure 3 that the heating rate of TB and BR coals is lower than that of KP and OMB coals which have higher moisture content than that of TB and BR coals.

Because of this apparent anomaly, the use of DTA method alone to determine the susceptibility of coal to spontaneous combustion does not provide accurate results. Accordingly, the CPT method

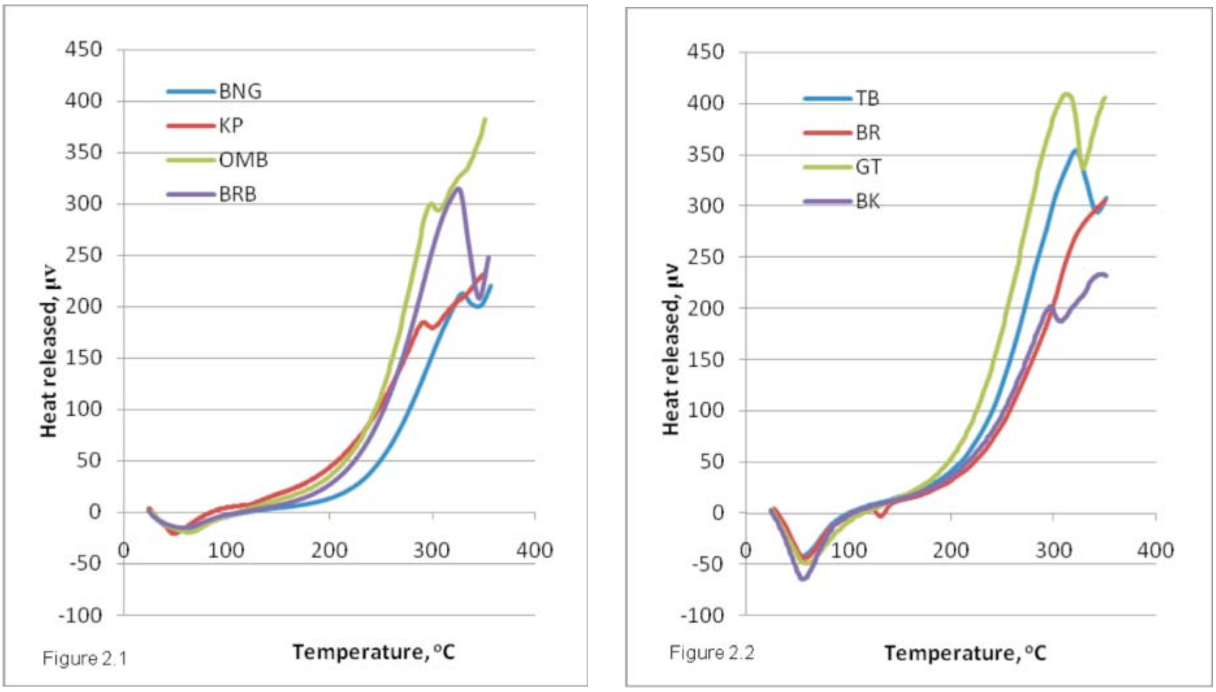


Figure 2. Differential thermal graphs for different Indonesian coals

This is clearly demonstrated in Figure 2 in which the first peak of BNG, KP, OMB and BRB coals with lower moisture contents of 0.3, 6.89, 5.84 and 4.81 wt % adb respectively (Figure 2.1) is lower than that of TB, BR, GT and BK coals with higher moisture contents of 15.35, 16.13, 17.41 and 17.09 wt % adb (Figure 2.2). The heat release drops due to the evaporation of moisture from the coal. From the thermograms, the heating

was conducted. Thermograms of the eight coal samples obtained from the tests are shown in Figure 4. Each thermogram shows the general pattern of the temperature time profiles of the oven and the coal bed when the air were passed through the coal bed. Three common observations can be made from these thermograms: a) the oven temperature increased linearly with time (as programmed); b) the temperature in the coal

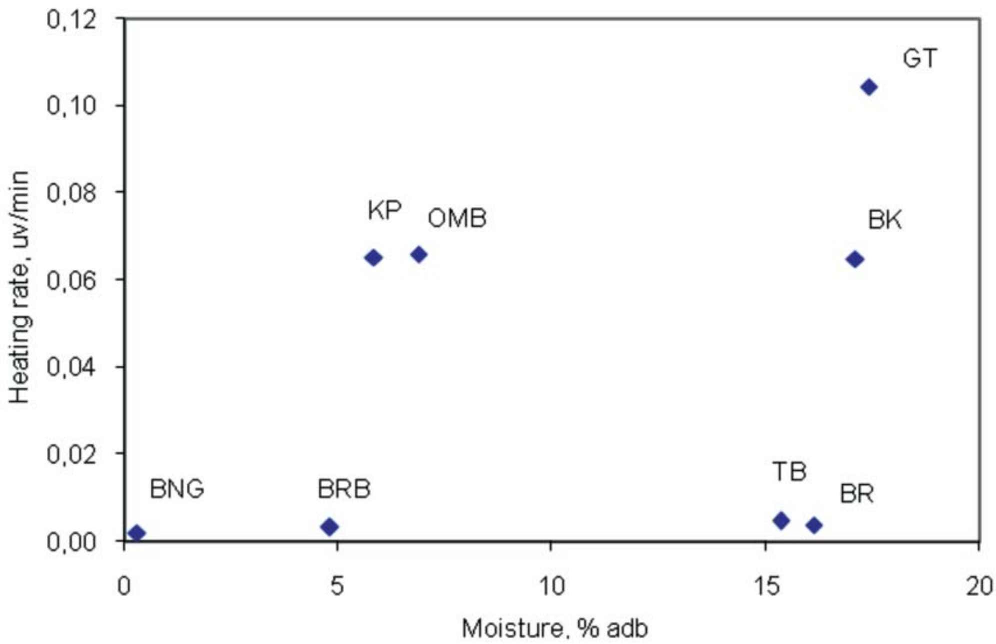


Figure 3. Heating rate (μv/min) as a function of moisture content

beds increased when the air was pass through, but not linearly with time a lower rate than that of the oven; and c) the air curve crosses the oven curve at a number of points generally referred to as the crossing point temperature (CPT). This point was an indicator of the susceptibility of the coal to spontaneous combustion.

From Figure 4 it can be seen that coals with high moisture content, the temperature increased rapidly at the beginning. This situation may be explained by moisture content conditions. As the moisture was trapped in the mesopores and micropores of the coal, it required much greater heat to release than moisture in mesopores and macropores. The moisture in coal evaporates and thus extracts heat from the coal. While the thermograms of the coals with lower moisture content, the temperature increased steadily with time to a maximum temperature at crossing point value. The reason for the coal bed temperatures exceeding the oven temperature above the crossing point is due to the exothermic oxidation reactions that heats the coal beyond the oven temperature. For the convenience of comparison, Table 3 lists the moisture content, CPT, Heating rate (Q) and liability index (Li) for each coals of the tests.

The CPT of coals with low susceptibility to spontaneous combustion will have lower value, and that of coals with higher susceptibility will have comparatively higher value (Kŭcŭk, et al., 2003). Coals with high moisture content exhibit an increase of CPT value with regard to an increase of the moisture (Kadioğlu and Varamaz, 2003). CPT data in Table 2 also give the same fact, where the coals with higher moisture content shows a higher CPT. Therefore, the concept of the liability index (Li) was used to overcome the limitation of the CPT. Coals with highly susceptible to spontaneous combustion are expected to have high liability index. The liability indices were reported to correlate better with intrinsic coal properties. However, an exceptional of BK coal with a relatively high moisture content (Table 2) that exhibits a lower liability than the TB and BR coals, which have lower moisture content. The reason for the unexpectedly higher susceptibility to spontaneous combustion is probably a result of the cooling effect due to evaporation of moisture in the coal.

Figure 5 shows the variation of CPT values for different coals tested. Generally, CPT increased with the increasing of moisture, volatile matter and oxygen contents and decreased with the increasing of carbon content and Figure 6 also shows the variation of heating rate and Figure 7 the variation of liability index (Li) as a function of moisture, volatile matter, carbon and oxygen contents respectively.

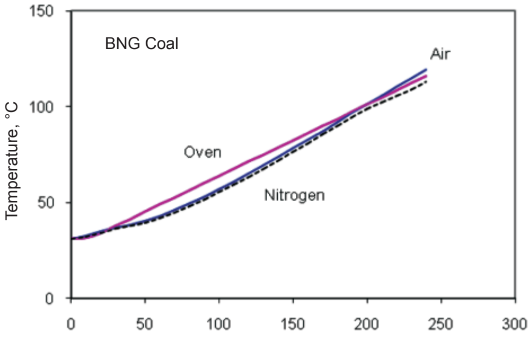


Figure 4.1

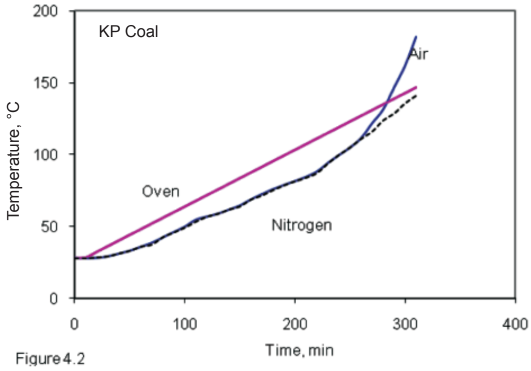


Figure 4.2

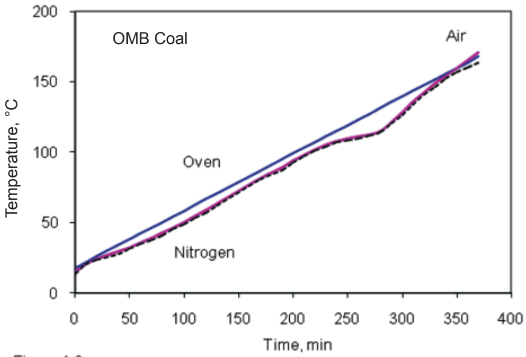


Figure 4.3

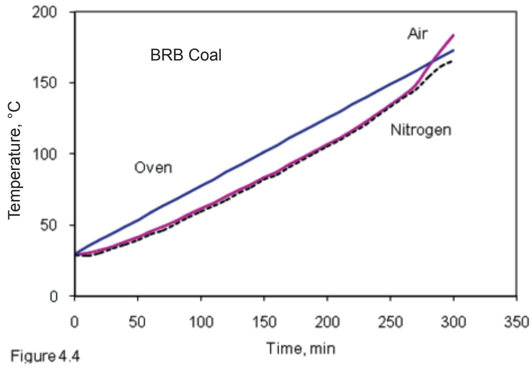


Figure 4.4

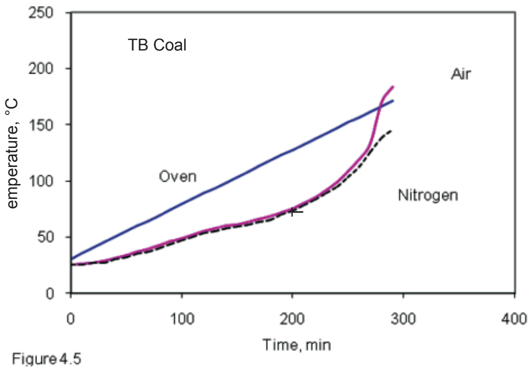
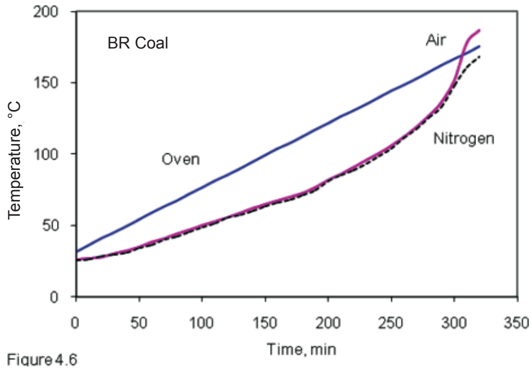


Figure 4.5



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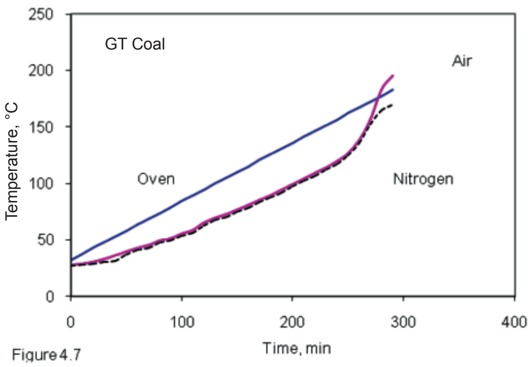

Figure 4.7

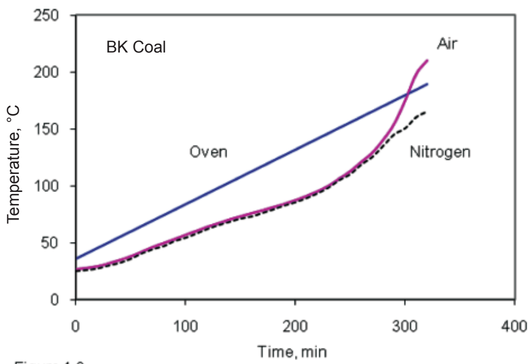

Figure 4.8

Figure 4. Crossing point temperature graphs for different Indonesian coals

Table 3. Crossing point temperature, heating rate and liability index for coal samples

Coal sample mark	Moist. Wt % (adb)	CPT, °C	Q, °C/min	Li	Risk Group
BNG	0.30	100.8	0.45	4.46	Medium
KP	6.89	132.0	1.19	9.09	Medium
OMB	5.84	159.6	0.56	3.51	Medium
BRB	4.81	165.4	1.12	6.65	Medium
TB	15.35	165.9	2.51	15.13	High
BR	16.13	169.7	1.71	10.08	High
GT	17.41	176.1	1.95	11.07	High
BK	17.09	181.2	1.76	9.71	Medium

Note:adb: air dried basis

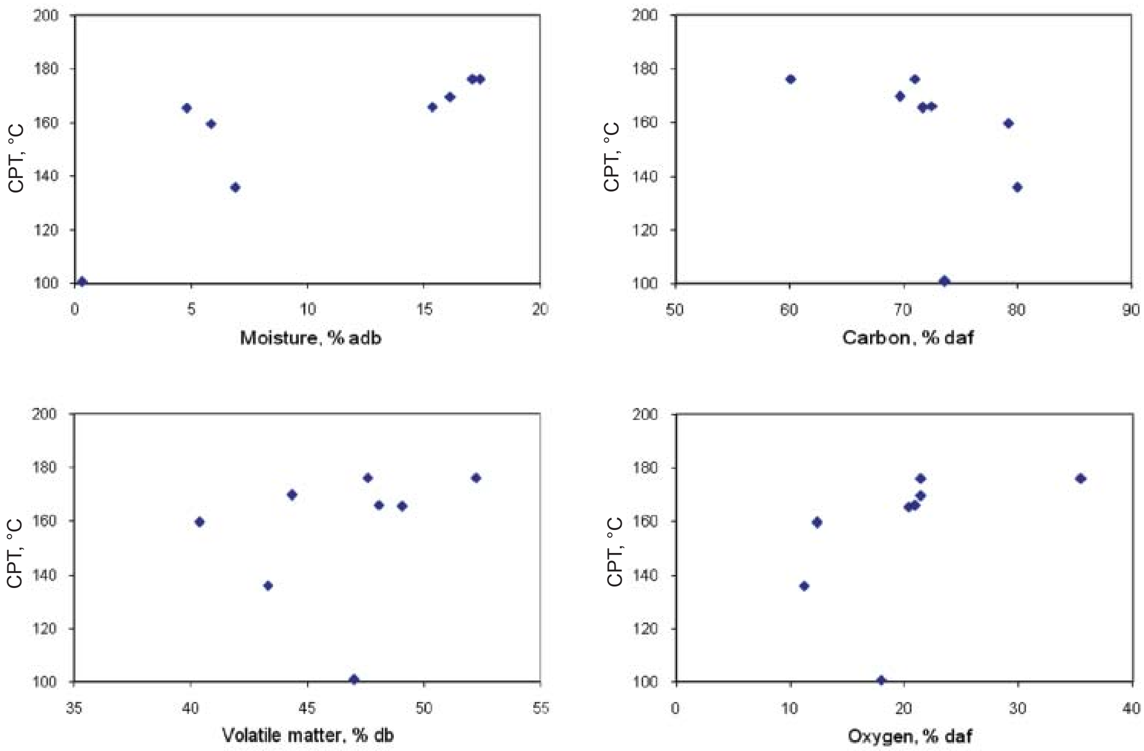

Figure 5. CPT as a function of moisture, volatile matter, carbon and oxygen

Some anomalies as the results of this research which are shown in Figure 5 to 7 can be understood, because the susceptibility to spontaneous combustion is not only depends on intrinsic factors such as chemical properties of the coal, but also depends on extrinsic condition such as climatic condition and storage practices. Therefore the correlation between CPT, heating rate and liability index of Li with coal properties as described does not show a straight line. Climatic factor that important in the spontaneous combustion of coal includes: air humidity, rainfall, temperature, exposure to the sun and exposure to the wind (Carpenter, 1999).

CONCLUSION

Results indicate that there is no direct correlation between the spontaneous combustion test data and the individual properties of the coal samples by both DTA and CPT test methods. However, in

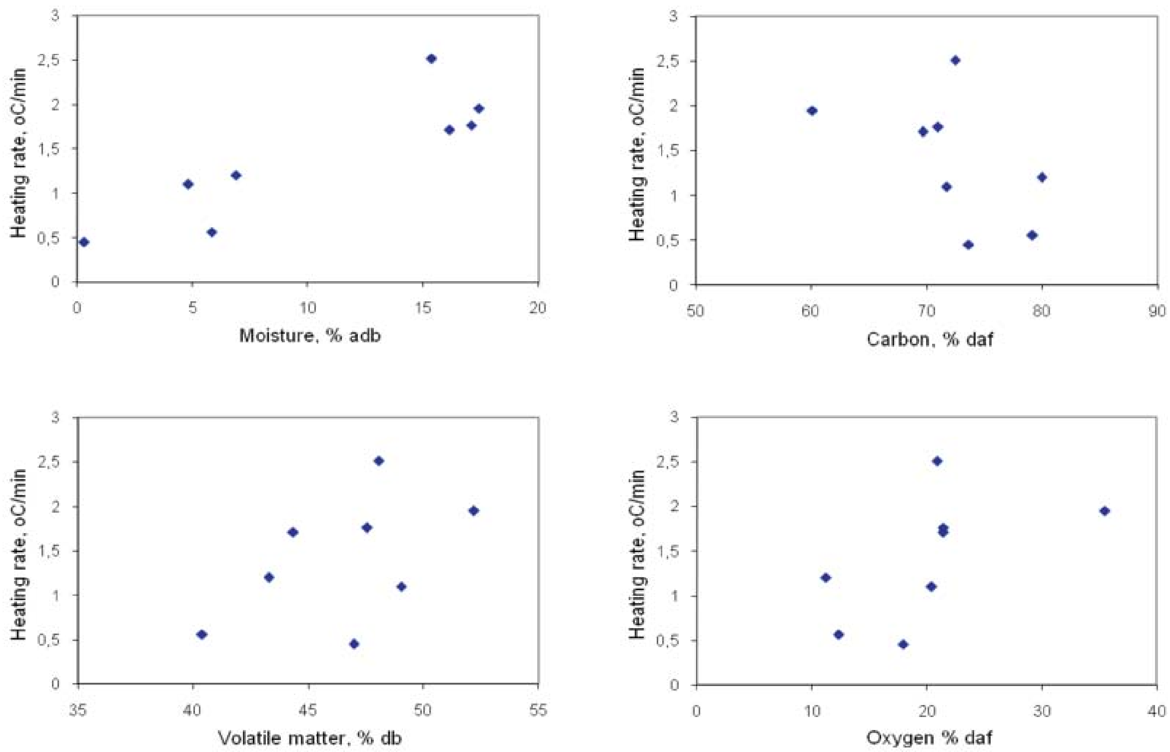

Figure 6. Heating rate as a function of moisture, volatile matter, carbon and oxygen

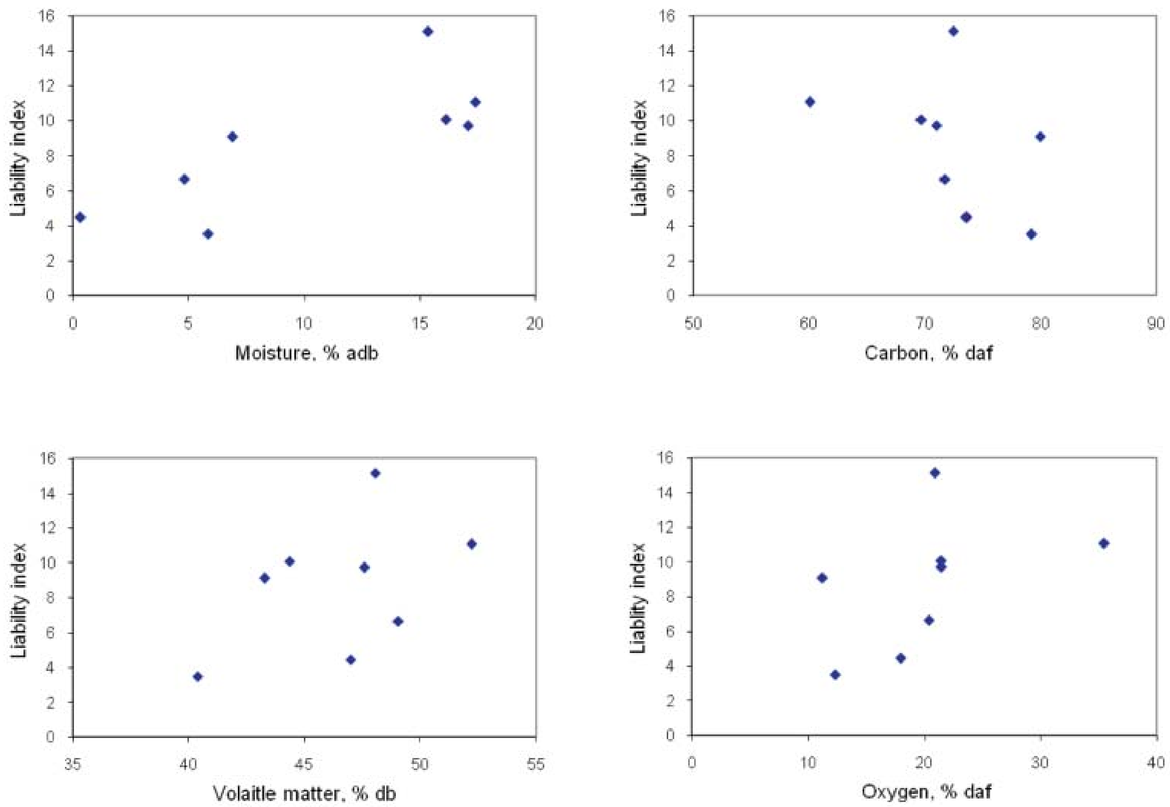

Figure 7. Liability index as a function of moisture, volatile matter, carbon and oxygen

this study, a preliminary conclusion can be drawn on the coal moisture content effect on spontaneous combustion. Generally, higher moisture content coals more susceptible to spontaneous combustion than that of lower moisture content coals. It can be stated that the susceptibility of coal to spontaneous combustion is basically a complex. Clearly more tests are needed to investigate the effect of coal properties both physically and chemically in more detail from other coals that have various type and rank.

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