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SPONTANEOUS COMBUSTION PROBLEMS ASSOCIATED WITH THE MINING AND STORAGE OF THERMAL COAL - A REVIEW

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SPONTANEOUS COMBUSTION PROBLEMS ASSOCIATED WITH THE MINING AND STORAGE OF THERMAL COALS - A REVIEW

by

R.N. Chakravorty*

ABSTRACT

Spontaneous combustion has always been recognized as one of the major hazards both from safety aspects and from economic considerations.

The paper reviews the factors responsible for the occurrences of spontaneous combustion during mining and storage of thermal coal and discusses measures likely to help in the prevention of fire caused by spontaneous heating.

An evaluation of methods for early detection of heating is also included.

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INTRODUCTION

Spontaneous combustion is a recognized hazard commonly associated with the mining and storage of low rank coals. A survey by Olaf (1) indicated that almost 80% of all mine fires result from spontaneous combustion.

In recent years the coal mining industry in Western Canada has begun a period of rapid and unprecedented growth and, as projected, the coal production may double by the year 1990 (2). Because of such increased activity, coal mining operators are showing renewed interest in problems associated with spontaneous heating.

The closure of a working face due to fire may involve huge losses, as capital investments are very high in most mechanized workings. There are instances where the whole mine had to be sealed off after the outbreak of fire. In high productivity mines, even interruption of production entails big financial loss.

Fire in coal stacks due to spontaneous combustion can be expensive and difficult to extinguish. Safe storage of coal has therefore been a matter of concern to coal producers.

In an earlier report Chakravorty (3) reviewed some of the occurrences of spontaneous combustion in the U.K., U.S.S.R., West Germany, Japan and India and it became obvious that millions of tons of coal were lost from fires caused by spontaneous combustion.

Table 1 summarizes the past incidences of spontaneous heating in British mines. The table is prepared from the proceedings of the symposium on the prevention of spontaneous combustion (4) held in 1970 in the U.K. It clearly illustrates that though no coal mines are free from the hazard of spontaneous combustion most cases occur while mining high volatile low rank

Table 1 - Summary of Incidences of Spontaneous Heating in British Mines

Location and name of coal seams/colliery	Method of working	Nature/rank of coal	Number of occurrences of spontaneous heating
Scottish South Area Lothian & Ayrshire	Room & pillar Longwall advancing	Low rank/high vol. coals	30 heatings in 22 years (1947-69)
Northumberland Lynemouth	Longwall advancing method & mechanized pillar & stall.	Low rank/high vol. coals	8 cases of heating in 3 years (1963-66)
North Durham	Longwall advancing	Medium-high rank	2 heatings recorded between 1965-67
South Durham	Bord & pillar and longwall advancing	Medium rank	8 heatings between 1924-54
North Staffordshire	Longwall advancing	Low rank coal	27 heatings in 10 years
Yorkshire Barnsley seam	Longwall advancing	Low rank/high vol. coals	Many cases of heating & fires, several major fires
North Nottinghamshire	Longwall advancing	Low rank/high vol. coals	About 10 heatings per year
South Nottinghamshire	Longwall advancing	Low rank coals	About 16 heatings in 4 years
South Wales Swansea, 5 ft seam	Longwall advancing	High rank/low vol. coals	5 heatings in 10 years

Table 2 - Past incidences of spontaneous combustion in Alberta (1953-70)

Name of province/ Name of Colliery	Year	Rank & Coal	No. of incidences of spon. comb.	Remarks
Sterling Coal Valley	1953	Low rank/high vol.	1	2 other fires of undetermined cause. May be due to spon. comb.
Drumheller Area	1954	Low rank/high vol.	1	Spon. comb. in underground goaf area
Brilliant Coal Co. Drumheller Area	1955	Low rank, sub-bituminous	1	Spon. comb. suspected
Murray Colliery, East Coulee	1956	Low rank, sub-bituminous	1	In the coal outcrop, because of dumping of waste coal
Amalgamated Coalfield, East Coulee	1959	Low rank, sub-bituminous	2	2 fires from spon. comb. in separate worked out areas underground
East Trochu Coal Co.	1960	Low rank, sub-bituminous	1	Fire of unknown origin
Star Key Mines Ltd. St. Albert	1963	Low rank, sub-bituminous	1	The mine was sealed off
Coleman Colliery	1965	Medium rank	1	Spon. comb. suspected
Amalgamated Coal Co.	1965	Low rank	1	An old gob fire became reactivated
Star Key Mines Ltd. St. Albert	1967	Low rank	1	Fire broke out as the spon. heating previously contained had rekindled
Alberta	1968-70		No incidences recorded	

coals. A summary of some of the incidences of spontaneous combustion during the same period in the coal mines of Alberta is shown in Table 2. The information was compiled from the annual reports of the Mines Division, Province of Alberta (5). Table 2 also indicates that in Alberta, most of the heatings occurred during mining of low rank sub-bituminous coals. In an earlier paper (6) Chakravorty and Feng discussed some of the heatings in a mountain coal mine in British Columbia producing metallurgical coals.

It is important to remember that under favourable heat accumulation conditions, spontaneous combustion is possible with almost all coals, and the assumption must never be made that spontaneous combustion risk does not exist.

In the late fifties, Coward (7) prepared an excellent review discussing the phenomenon of spontaneous combustion of coal. In some of the earlier papers, (6,8,9) CANMET work on spontaneous combustion was discussed with special reference to mountain coals. In the recent past a specialist team from the U.K. and the U.S.A. prepared an exhaustive report (10) on spontaneous combustion under contract with the United States Bureau of Mines. In the present review, an attempt is being made to outline briefly the factors responsible for the occurrence of spontaneous combustion during mining and storage of thermal coals and summarizes control measures which may prove helpful to deal with the problem.

FACTORS CONTRIBUTING TO SPONTANEOUS COMBUSTION

In spite of extensive research on spontaneous combustion during the last one hundred years the exact mechanism is still obscure and it is difficult to quantify the factors responsible for the onset of heating in a coal mine or in a coal stack. However an understanding of the process would indicate that there are three basic requirements for a heating to develop.

(i) Coal or other carbonaceous materials must be present in the mine or in the coal stack in a form which can readily oxidize at ordinary temperature.

(ii) Supply of air to support the process of oxidation.

(iii) Environment should be such as to favour heat accumulation. In other words the rate of heat produced due to oxidation should be more than the rate at which heat will be lost to the surroundings.

In an earlier Canmet publication (8) the occurrence of spontaneous combustion in coal mines was discussed in detail. It was observed that the nature of coal, the method of mining, and the geological features associated with the coal seams and adjoining strata determine whether spontaneous combustion is likely to occur in a particular mine. The occurrence of spontaneous combustion is very closely related to the ventilation system. A combination of sluggish ventilation and accumulation of fine coal appear to be ideal for initiation of heating in a mine.

Certain coals are more liable to spontaneous combustion than others under similar heat accumulation conditions. Lignite and sub-bituminous coals oxidize fairly rapidly whereas oxidation proceeds rather slowly with anthracite or low volatile bituminous coals. Presence of inferior coal or carbonaceous shale helps in the development of spontaneous heating in coal seams which are otherwise considered relatively safe. Petrographic composition also plays a significant role in the low temperature oxidation process. Chamberlain and Hall (11) showed that exinite has a much greater oxidation rate, particularly above 75°C, compared to vitrinite and inertinite from the same coal and they consider that maceral counts may prove useful in order to determine the relative susceptibility of a particular coal to spontaneous combustion. The rate of oxidation is directly related to the exposed surfaces. Thus friable coals which produce a large amount of fines during mining are usually more vulnerable.

Moisture plays a very complex role in spontaneous heating of coals. Absorption of water by coal will accelerate and desorption will retard the process (12). It appears that humid environmental conditions aid to some extent in the spontaneous heating of coal but it is the inherent moisture in coal which largely determines its susceptibility to spontaneous combustion. Berkowitz (13) observed that heating usually commences after rain following a period of dry and sunny weather. It was postulated that in practice heating can be triggered by heat release which accompany wetting of dry or partially dried coals.

In general, thicker coal seams are considered to be more liable to spontaneous combustion as opposed to thin and moderately thick seams. Often it is neither economical nor feasible to completely extract the whole thickness of a coal seam. Leaving roof coal is possible when the seam is thick, the intervening strata is weak or the top section contains poorer quality of coal. Roof coal in most cases fall into the gob where oxidation may start because of leakage through the gob.

When coal seams are worked in close proximity it is likely that air may leak to the gob area of any of the seams already worked through cracks developed in the intervening strata, resulting in spontaneous heating. If the parting between the seams is sufficient, the risk may not be serious. Presence of faults in the coal seam helps in initiating spontaneous combustion in a mine. Areas around the faults constitute lines of weakness thereby helping in the leakage of air.

In longwall workings the roadside packs containing fine coal pose the greatest danger since ventilation pressure is larger across these packs. The main roads in seams liable to spontaneous combustion in the past have caused problems due to leakage through fissured solid coal. The most vulnerable points are (14)

(i) Junctions

(ii) Air crossings

(iii) Doors and Regulators

(iv) Obstruction in roads.

The risk in each case increases with the increase in the thickness of coal. With most junctions some fractures may develop on the solid coal at corners resulting in the leakage of air. Air crossings are always a potential source of danger because of associated fissures in the solid coal in the area. Doors and regulators unless carefully installed will cause air leakage through breaks in the solid coal around them. The greater the pressure across such doors and air crossings, the greater is the leakage and the greater is the risk for onset of heating. In a main roadway air leakage is often caused because of constriction created by roof fall or floor heaving.

Most worked out areas often become inter-connected after caving and a fire developed in one area tends to spread to other adjacent areas as the movement of hot gases increases the temperature thereby increasing the rate of oxidation of coal. It has also been observed that a fire in an abandoned area often leads to many more heatings in adjacent areas which makes the entire district more vulnerable (6).

Table 3 summarizes the critical factors contributing to spontaneous combustion in a coal mine (8). The factors are divided under two main groups. Intrinsic factors are considered to be inherent with the system and the

Table 3 - Critical factors contributing to spontaneous combustion

Intrinsic factors which cannot be controlled		Extrinsic factors which can be controlled
Coal Properties	Geological Features	Mining Practice
a. High volatile matter	a. Thick seams	a. Accumulation of fine coal in worked out areas
b. High moisture	b. Presence of inferior coal, pyrite bands and carbonaceous shale	b. Leaving roof and floor coal during mining
c. High pyrite	c. Presence of faults	c. Poor maintenance of roadways and old districts
d. High exinite	d. Weak and disturbed strata conditions	d. Inadequate measures to prevent air leakage through air crossings, doors, seals, gateside packs
e. High Friability	e. High strata temperature	e. Caving to surface under shallow overburden
		f. Multi-seam working in close proximity
		g. Poor ventilation management

extrinsic factors may be attributed to the mining practice. In mines, where most of these factors exist, the risk should be considered high.

PREVENTION AND CONTROL OF SPONTANEOUS COMBUSTION IN MINES

Methods for the prevention and control of spontaneous combustion in coal mines have been discussed in a number of past publications (4,8,10,14). It is obvious that there is no simple method by which one can assess whether the underground mining of a coal seam will result in liability to spontaneous combustion. The geological conditions and the coal properties need to be evaluated carefully for each seam to be worked and a decision should then be made on the intended mining practice. The need for spontaneous combustion control in high risk thermal coal operations cannot be over-emphasized.

Mining layout is the most important consideration in the prevention of heating. Individual working places should be designed so that they can be quickly isolated or sealed off without affecting other operations. For each working section, sites for preparatory seals should be selected during planning.

With seams which are highly susceptible to spontaneous combustion a retreat method of working should be preferred. Retreat mining has the obvious advantage that the gob area is not subjected to ventilation pressure difference.

Coal pillars for support purposes are essential of any mining design. In planning against spontaneous combustion, the size of the pillars should be such that they are capable of resisting excessive crush.

There is a general agreement particularly with thick seam operations that the risk of spontaneous combustion can be considerably reduced if it is possible to backfill the worked out areas with inert material. Economics of such backfilling method should be carefully assessed.

The panel system of working is preferred while mining coals susceptible to spontaneous heating. The size of the panel is chosen on the basis of the incubation period and the rate of extraction.

Use of sealants are widely recommended to prevent air leakage through gateside packs, partially fractured pillars, in consolidating roof coal and in the solid coal around doors, air crossings etc. In short, sealants should be used in all areas where there is likelihood of air leakage.

Application of inhibitors for control of spontaneous combustion was investigated in detail at NCB Laboratories in U.K. Chamberlain and Hall (11) concluded that a borate solution or montan powder sprayed into the waste or infused into a low rank coal would reduce the possibility of spontaneous combustion.

Control of air leakage is the key to control of spontaneous combustion. As far as practicable, pressure absorption rates should be maintained even. Localized uncontrolled pressure difference should be avoided. Unnecessary stopping and starting of main ventilation fans should be discouraged. The ventilation pressure across the seals should be balanced wherever practicable. This is particularly important, as most worked out areas become inter-connected after caving and a fire developing in one area may spread to other adjacent areas. Ventilation efficiency of a particular area should be monitored regularly and investigation into the leakage occurring should be undertaken.

Most of the heatings occur when the production of a particular area or panel is about to be finished. Mine planning should incorporate the

Precautions Against Spontaneous Combustion

- **Mining Layout**
  - a. Capable of early sealing-off
  - b. Retreat mining
  - c. Dimensionally stable pillars to avoid excessive crush
- **Air Leakage** (minimize)
  - **Ventilation Pressure Difference (minimize)**
    - a. Proper siting of doors regulators etc.
    - b. Stabilize running of fans
    - c. Balance pressure
  - **Leakage Paths**
    - a. Sealant coating
    - b. Injection
    - c. Good gateside packs
- **Salvage**
  - Salvage and seal as quickly as possible (within incubation period)
- **Inhibitors**
  - a. Coal pillar corners
  - b. Coal packs
  - c. Face start line
- **Detection Systems**
  - a. Continuous carbon monoxide monitoring of mine air
  - b. Thermal scanning of vulnerable area

Fig. 1 - Precautionary measures recommended for the prevention and control of spontaneous combustion

salvaging of equipment and sealing of the district with minimum delay.

In short, a mining system based on rapid development followed by retreat mining with adequate measures to prevent air leakage, will prove helpful in reducing spontaneous combustion hazards. Table 4 summarizes the precautions against spontaneous combustion (15,16).

SPONTANEOUS HEATING IN COAL STACKS

Storage of thermal coal in large stacks has always been a matter of concern because of the outbreak of fire due to spontaneous combustion. In most cases the coal stacks show the sign of heating within a period of 8 to 10 weeks. There are instances where heating had taken place within 4 to 6 weeks under favourable circumstances.

The phenomenon of spontaneous combustion in coal stacks is very similar to that described earlier in the mining of coal. In other words, an environment for heat accumulation is essential for spontaneous combustion to develop. If the coal is spread out in thin layers no fire will occur. It has also been observed that the oxygen absorption capacity of freshly mined coal is greatest during the early weeks as this property gradually declines with time. Thus a stack of fresh coal is considered vulnerable to spontaneous combustion during the first few months. If no heating has taken place within 6 to 8 months the possibility of spontaneous combustion is much reduced unless fresh coal surfaces are exposed to the air due to the removal of coal or otherwise.

As indicated earlier, the degree of susceptibility to spontaneous combustion varies with the rank of coal. Coals belonging to higher rank, i.e.

the coals having low moisture and low volatile matter are less susceptible than the coals belonging to the lower rank, i.e. high moisture and high volatile matter coals. Fine coals are more susceptible to heating than lump coals in view of large surfaces available for oxidation.

Coward (7) reviewed the work done by earlier researchers and concluded that most favourable conditions for spontaneous combustion were a mixture of ungraded coals, large mass and a limited quantity of air. On the other hand, unfavourable conditions were lump coal, small mass and either thorough ventilation or complete exclusion of air. It was further observed that piles of coal up to 1.8 m in height did not fire on long standing whereas fire occurred in several places in a stack of coal 3 m high.

Chakravorty et al (17) carried out experiments to study the nature of self heating phenomenon in coal stacks made of high and low rank thermal coals. As expected, no heatings were observed with stacks made of middlings from low volatile bituminous coals. The stacks were 150 m in length, 30 m in width and 15 m in height and were consolidated very thoroughly, using mechanical means to exclude entry of air.

Further studies using three experimental stacks made from freshly mined low rank coals (moisture 9.4% and volatile matter 35.4%) indicated that they are vulnerable to self heating. The stacks were not consolidated. The 2.4 m high stack actually caught fire within a period of nine weeks. The temperature of the coal stack slowly increased to 90°C after a period of 48 days and then maintained a temperature of 90°C - 99°C for nearly 10 days. Smoke appeared on the 60th day. Within 24 hours there was an active fire from the toe to a height of 0.8 m along the slope. Figure 2 shows the variation in temperature in two different locations in the same coal stack which as indicated can be significantly different depending on local heat accumulation conditions.

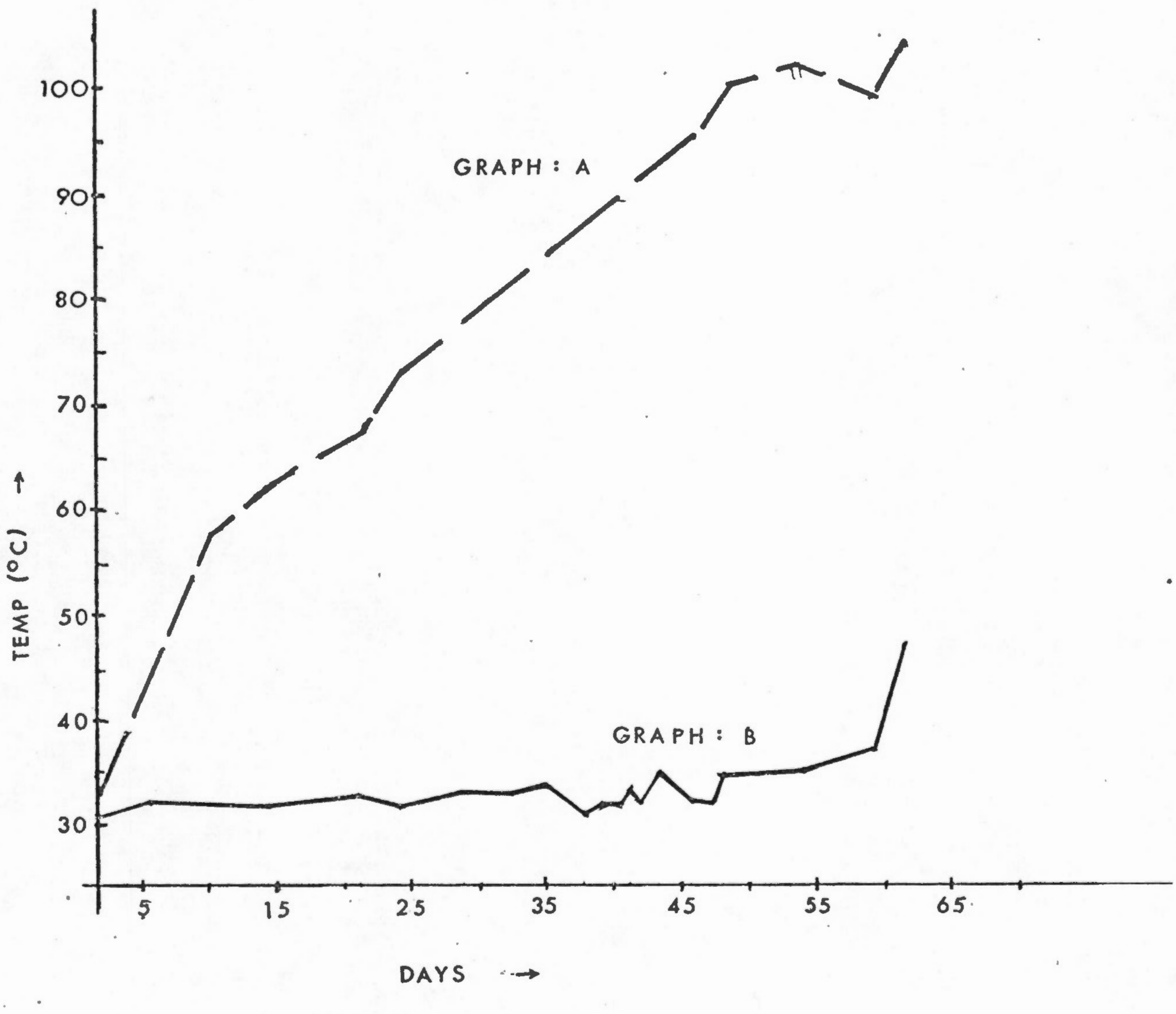

Fig. 2 - Graphs showing the variation in temperature with time in a coal stack

The fire however penetrated only to a depth of 15 cm from the surface. It is relevant to mention that there was a shower the day before the smoke appeared. It showed that the addition of moisture on a partially heated stack accelerates the process of self heating.

As expected, attempts to quench the fire with water proved futile and only by dismantling the stack completely could the fire be brought under control.

Berkowitz and Speight (18) concluded from their laboratory studies that by immersing the coal for a short period in a inert liquid before stock-piling the spontaneous heating in the coal stacks can be prevented. Commercial feasibility of this process needs to be evaluated. Hall (19) observed that by covering the coal heaps with road tar, the air leakage can be considerably reduced thereby decreasing the chances of spontaneous heating.

PROCEDURES FOR SAFE STORAGE OF COAL

A number of reports are available explaining the procedures for safe storage of coal. Some of the measures recommended (10,17,20) are summarized for quick reference.

For storage of small and fine coal the most practical approach will be to reduce air leakage from the coal heap. This is achieved by stacking coals in well compacted layers about 0.6 m in thickness. Each layer should be rolled before commencing the next. The sides of the stacks should also be thoroughly consolidated. The side slopes should be such that bull-dozing or rolling is possible when stacking is completed.

Coals belonging to different ranks should be stored separately. The coals which are more prone to spontaneous heating must not be stored with coals which are relatively safe. Occurrence of heating can be caused by putting fresh coal on top of old coal and these practices should be avoided as far as practicable.

The large and small coals should not be stacked together and separate stacks for the large and small coal should be made whenever possible. If the stacking of coal of different sizes becomes unavoidable the risk of heating can be reduced by alternating layers of fine coal and large coal.

The maximum height for a properly consolidated heap should not be critical as far as heating is concerned. However, a height of approximately 5 m is recommended as suitable (10). If it is necessary to have a coal stack without adequate compaction the height should be limited to 2 m or less.

Spraying of road tar is recommended for coal stacks which are likely to be left over for a long period. Such spraying provides an effective seal to air leakage. Road tar can also be used for treating coal heaps which have just started heating up, thereby eliminating air leakage to prevent further oxidation. Such spraying also prevents channeling caused due to rain. Organic binders used for dust proofing were found to be 80% as effective as road tar as a seal. This may be considered as an alternative depending on availability and cost (10).

In the mine site coal is often stored in vertical bunkers or silos. Such bunkers or silos reduce air leakage considerably. The risk of spontaneous heating could be further reduced by providing a blanket of nitrogen (10).

Measuring the change in temperature is strongly recommended for thermal coal stacks particularly during the first three to four months. Temperature readings should be taken at least once each week. If temperature abnormalities are observed more frequent measurements should be made. Steel pipes with closed lower ends should be driven into the coal stack at intervals of a few meters where thermister or thermocouple probes are inserted for measuring temperatures. Infra-red scanners (21) may also prove useful in locating hot spots in the coal stack. A temperature of 70°C is considered critical (11,20) for accelerated development of heating. If the temperature shows a steady rising trend it should be carefully monitored until it begins to fall again.

The most effective method for dealing with fire in a coal stack would be to dismantle the coal stack. All the coal in the stack must cool down to atmospheric temperature before a fresh stack is made from those coals.

LABORATORY METHODS FOR CLASSIFYING COALS

Numerous attempts were made in the past to develop tests for determining spontaneous combustion susceptibility of coals. It soon became obvious that with laboratory tests, it is virtually impossible to simulate all the conditions existing in a mine. Coward (7) concluded that though the laboratory tests are useful in categorizing coals with respect to their oxidation characteristics, mining conditions are of over-riding importance as to whether a potentially dangerous coal may become an active danger. Chamberlain and Hall (11) in recent years carried out an exhaustive survey of laboratory methods and came to similar conclusions. However everyone recognized that knowledge of oxidizability of coal is useful during mine planning and also for determining if one part of the seam is more vulnerable to spontaneous heating relative to another. Canmet studies (8) also indicated that none of the laboratory methods can be considered perfect for

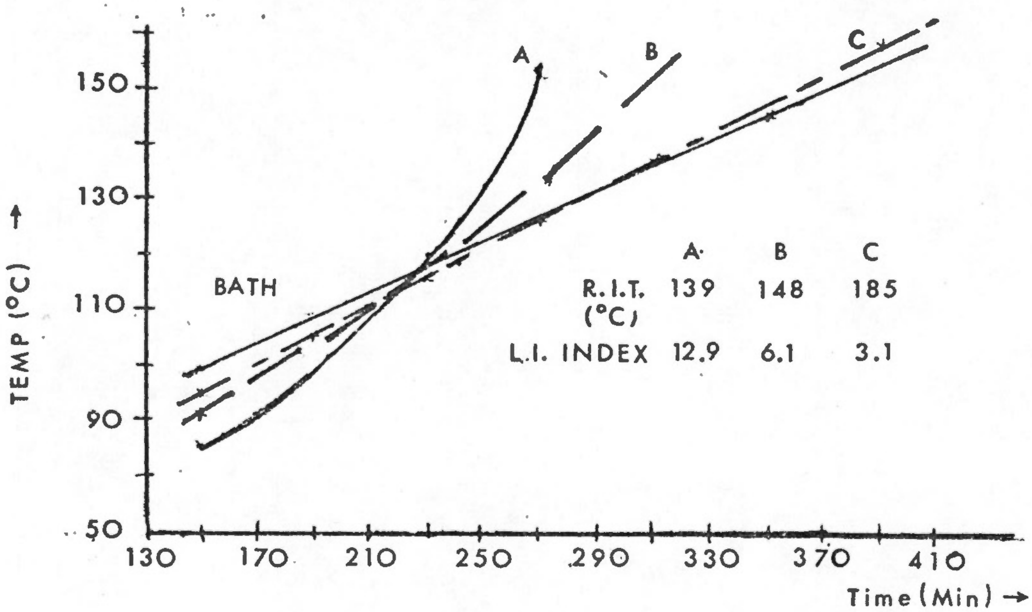

Fig. 3 - Graphs showing relative ignition temperature for three coals of different ranks. Coal A is high volatile, Coal B is medium volatile and Coal C is low volatile.

mining applications but they all appear to be useful in classifying coals with respect to their susceptibility to spontaneous combustion. Laboratory experiments carried out in the U.K. (11) in recent years showed that the tests based on oxygen absorption appear to be most reliable. Oxygen absorption tests using static isothermal method were first developed by Winmill (22). According to him, if, at a temperature of 30°C, the amount of oxygen absorbed after 96 hours exceeds 300 ml/100 gm, the coal should be considered highly susceptible to heating. On the other hand if the value is 200 ml or less the coal should not be considered prone to spontaneous combustion. Chamberlain (11) found this to be a good guide for determining spontaneous combustion liability. In Canmet laboratories (8,23) both oxygen absorption tests and relative ignition temperature tests were carried out and the results appeared to be suitable for categorizing coals with regard to spontaneous combustion susceptibility. Figure 3 shows typical graphs illustrating variations in the relative ignition temperature for different ranks of coal (24). A high heating rate and low ignition temperature will determine whether the coal is more liable to spontaneous heating. A liability index (8) was proposed based on the ratio of heating rate and ignition temperature which proved helpful in classification of coals. Coals showing a value of 10 or more are considered to have high liability whereas a value of 5 or less would indicate low liability to spontaneous combustion.

DETECTION OF SPONTANEOUS HEATING

The early detection of spontaneous combustion is considered essential since any fire which can be detected at an early stage may save the mine from considerable damage and subsequent loss of production. With underground mining of low rank coal, where the risk appears to be high, early detection system should be an integral part during mine planning.

In recent years considerable advances have been made in the design and development of methods for the early detection of spontaneous combustion (1,11). Some of the Canmet work on the detection of spontaneous combustion in underground coal mines was described in earlier publications(6,9).

It is well known that the development of heating is usually accompanied by progressive appearance of haze, sweating of the strata, gob-stink, fire stink and smoke. Fire stink or the petroleum smell is considered indicative of the development of spontaneous combustion and many heatings in the past were detected successfully using this technique. Obviously this method cannot be considered as quantitative and in a number of cases these signs were noticed after the heating had advanced to an uncontrollable stage.

Until the early seventies the most extensively used method for early detection of spontaneous combustion had been the carbon monoxide/oxygen deficiency ratio commonly known as Graham's ratio. For effective working of this method, it is essential that carbon monoxide concentration in the mine air be analyzed in parts per million and oxygen and nitrogen concentration be analyzed to an accuracy of $\pm$ 0.01% using sophisticated gas analysis methods. This ratio is independent of dilution by fresh air though contaminants from adjacent gobs will introduce errors if such air is deficient in oxygen or contains carbon monoxide. In the past attempts were also made to monitor saturated and unsaturated hydrocarbons such as ethane, ethylene, propylene, acetylene etc. produced during low temperature oxidation of coal with limited success. Pursal et al (25) indicated that the increase in the ethylene

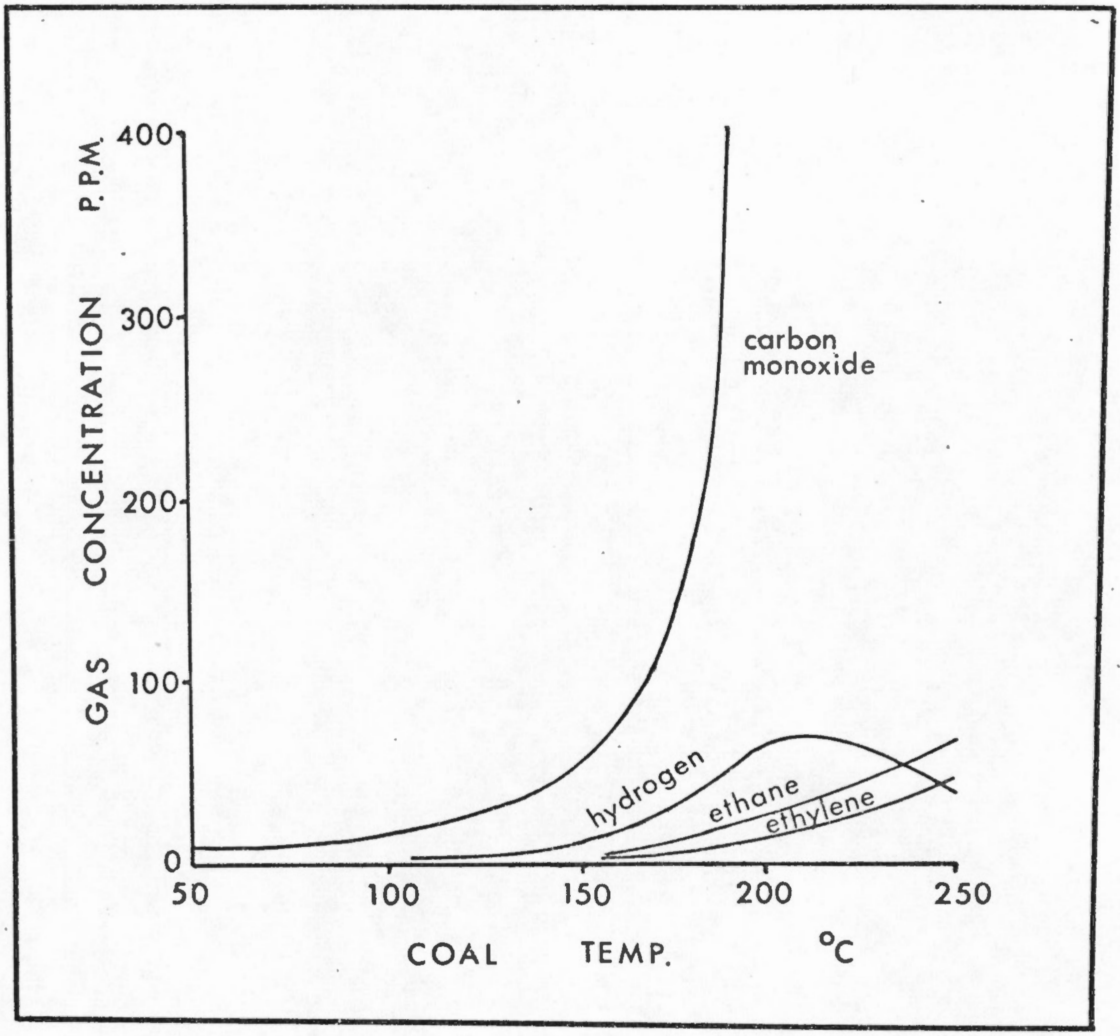

Fig. 4 - Graphs showing variations in gas concentration with the increase in temperature

concentration in the mine air gives a measure of progress of heating in the same manner as carbon monoxide/oxygen deficiency ratio.

In the last decade Chamberlain et al (11) carried out extensive studies on the nature of product gases during low temperature oxidation of British coals and the results indicated that although a large number hydrocarbons such as methane, ethane, ethylene, acetylene are produced during early oxidation, none of these gases appear to provide a better alternative to carbon monoxide as far as early detection is concerned. The study also demonstrated that the amount of carbon monoxide produced and the rate of rise of carbon monoxide with rise in temperature is far more significant compared to hydrocarbon gases mentioned earlier. Canmet work using Balmer coal also showed similar trends (6). Changes in the concentration of these gases with the rise in temperature are indicated in Fig. 4. Chamberlain (11) found that if the concentration of carbon monoxide is monitored on a continuous basis, the occasional peaks caused by shot firing or diesel exhaust can be easily distinguished and trends of carbon monoxide in mine air can be easily established. He concluded that carbon monoxide trends obtained from continuous monitoring should be as effective as any other methods attempted so far. Presently computers can be used to process the data for establishing the carbon monoxide trend. Similar systems have been used in West Germany (26), Japan (27) and many other coal producing countries and the success rate appears to be satisfactory. Figure 5 shows a typical graph indicating early stage of heating (27).

For continuous monitoring of mine air, two lines of approach may be adopted. In one system sensors are installed underground, and the data is telemetered to the surface, and in the other mine air is sampled continuously through a narrow bore polyethylene tubing and analyzed

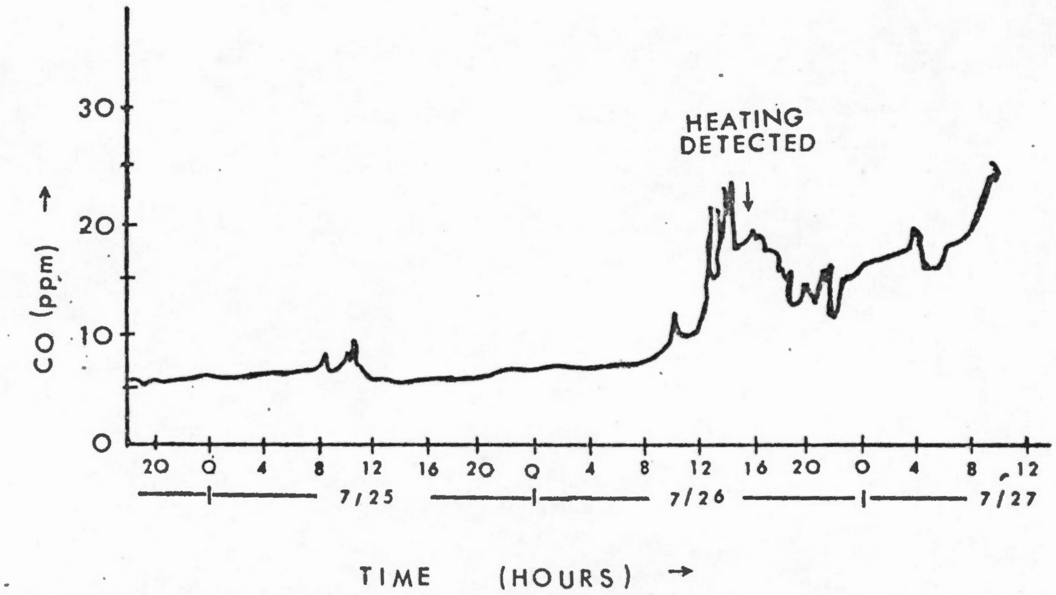

Fig. 5 - Changes in the concentration of carbon monoxide with time during early stages of heating

on the surface. Both the systems appear to be satisfactory but due to the lack of suitable carbon monoxide sensors the tube bundle system had wider application in underground mining.

For early detection of spontaneous heating most of the methods used are based on the detection of product gases evolved during the low temperature oxidation of coal. In the past, efforts were made to detect heatings based on thermal changes. It was observed that heat produced during oxidation is quickly dissipated by the main ventilating air and no appreciable change in temperature could be recorded unless the thermal sensors are located very close to the affected zone. Under actual mining conditions to work this system effectively, it would be necessary to install a large number of sensors all over the mine. Extensive instrumentation and associated maintenance problem did not make the system look attractive or feasible.

With the recent development of infra-red scanners and thermometers, fresh interest was developed to find out their suitability for early detection of heating in coal mines. Recent USBM (21) studies indicated that it is possible to locate hot spots in coal stacks using infra-red scanners and thermometers. Canmet studies (9) on the use of infra-red techniques for early detection of heating proved promising, provided the results are correctly interpreted.

Using the infra-red scanners and thermometers a number of heatings were identified without much difficulty. In most cases routine visual inspection did not indicate anything abnormal. Most of the hot spots were found to be several square feet in area. In some cases boundaries of the hot areas were marked by applying some coloured paint to study the spread. Infra-red scanners with photographic attachments were used for studying spread of fire near coal outcrops with a past history of heating. Figure 6

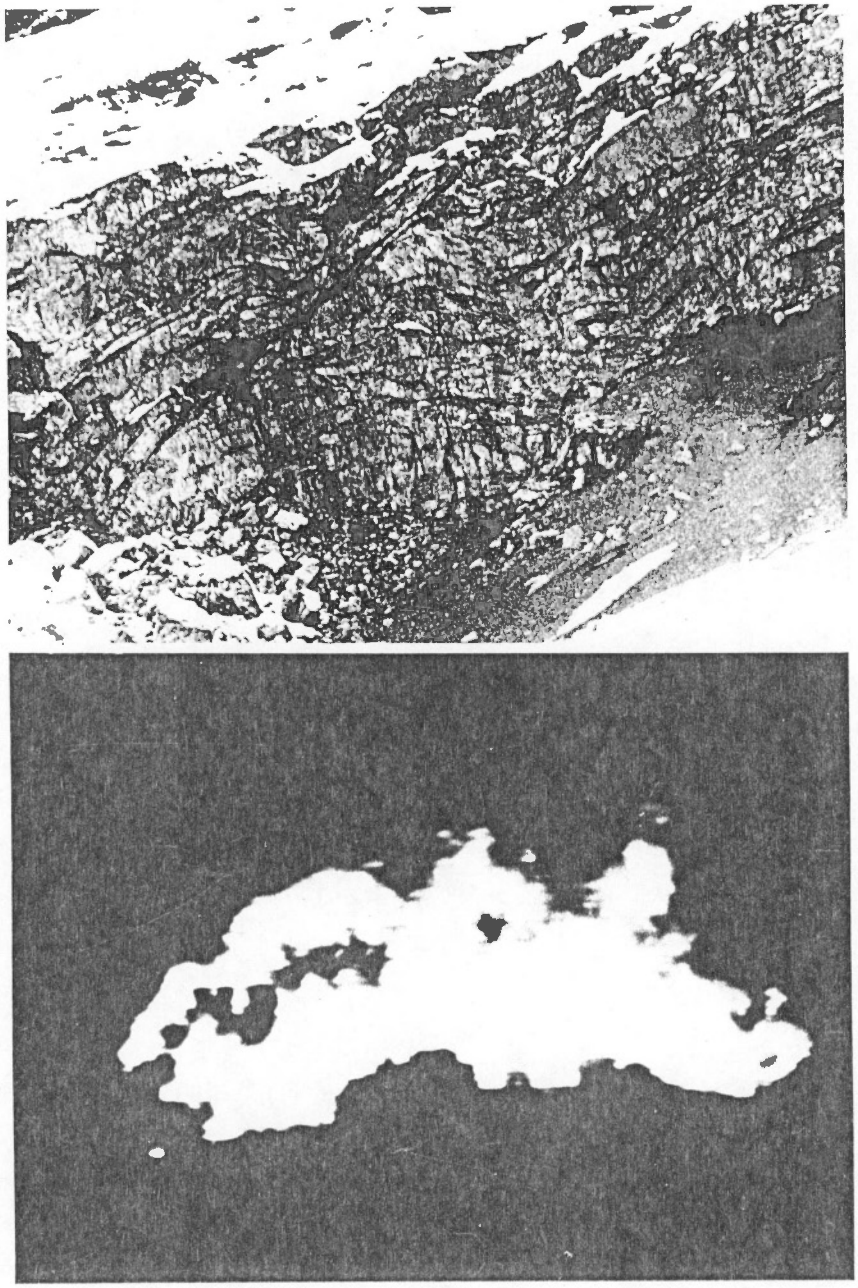

Fig. 6 - The top photograph shows a part of the outcrop as viewed through an ordinary camera. Bottom photograph shows the thermal image of the same area using infrared scanner with photographic attachments

shows a typical photograph obtained during this investigation.

The infra-red technique becomes ineffective when the instrument cannot be put in line with the hot spot and as such heatings developed deep inside the gob cannot be determined using this method.

CONCLUSIONS AND RECOMMENDATIONS

Spontaneous combustion is a potential hazard in all coal mines and the risk is high with thermal coal operations. In spite of extensive research, so far no simple method has been developed which can predict whether underground mining of a coal seam will result in liability to spontaneous combustion. This makes it imperative to evaluate the factors which contribute to such occurrences.

Laboratory tests are useful in categorizing coals with respect to their oxidation characteristics. However, the mining conditions are overriding in the question whether a potentially dangerous coal may become an active danger. The knowledge of oxidizability of coal will prove valuable during mine planning and for determining whether one part of the seam is more vulnerable relative to another.

Mining layout is the most important factor in the prevention of spontaneous combustion. Layouts should be such that these areas can be quickly isolated and sealed off.

Control of air leakage is the key to control of spontaneous combustion. Use of sealants are recommended to prevent air leakage through fractured coal and other vulnerable areas. Ventilation pressure balancing should be applied wherever practicable.

A mining system based on rapid development, followed by retreat mining with effective measures to prevent air leakage, will prove helpful in reducing spontaneous combustion hazards.

Fire in coal stacks caused by spontaneous heating can be expensive and difficult to extinguish. The most practical approach to control heatings in coal stacks will be to reduce air leakage. This can be achieved by stacking coals in well compacted layers.

Spraying of road tar is recommended for coal stacks which are likely to be left over for a long period. Such spraying provides an effective seal to air leakage.

Monitoring temperature changes in low rank coal stacks is strongly recommended during the first three to four months so that development of heating can be detected at an early stage and necessary control measures be adapted.

Early detection of spontaneous combustion is of utmost importance in underground coal mining to prevent major disruptions of production and to ensure safe working environment.

Continuous monitoring of carbon monoxide appears to be the most satisfactory method for early detection of heating in mines.

Infra-red techniques may be useful in the detection of heatings provided small variations of temperature can be correctly interpreted.

Early detection systems should be an integral part in mine planning particularly with underground mining of low rank coal. A combination of carbon monoxide monitoring and infra-red detection may prove suitable under most circumstances.

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